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Assessing Environmental Quality Using the Risk Screening Environmental Indicators (RSEI) Method: A Multi-Year Remote Sensing Approach

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Abstract. Industrial areas in Indonesia are increasing every year with a total of 136 industrial estates in 2024, of which 61.76% are in Java, such as Kendal Industrial Estate (KIE) with an increase in built-up land of 289.52 hectares (2015-2017). The problem is that the development was carried out by converting vegetation cover. The purpose of the study was to analyze the impact of the increase in built-up land on the environmental quality index around Kendal Industrial Estate. Research method with supervised classification Random Forest method and spectral transformation Risk Screening Enviromental Indicators with indicators of greenness index, humidity Index, dryness Index and heat index with Principal Component Analysis technique. The results showed that built-up land around KIE increased by 894.17 hectares which resulted in a decrease in vegetation cover of 184.71 hectares (2015-2024), this phenomenon had an impact on increasing low-level RSEI by around 2,028.31 hectares (2015-2024). The regression results show that the increase in built-up land and the reduction of vegetation cover have an impact on the decline in environmental quality in the study area. The contribution of the research results can be used as a database for regulation of land use change restrictions.

Keywords: Environmental indicators, Landsat imagery, Spatiotemporal analysis

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1. Introduction

The industrial sector has an important contribution to national development so that it can encourage regional progress and improve people's welfare (1)(2). The development of industrial estates in an area will have a positive impact on development and economic growth (3)(4). Industrial development in

Indonesia is currently realized in the form of industrial estates to facilitate management and absorb more labor. At present in Indonesia there are 136 industrial estates that have an Industrial Estate Business License with an area of 71,418 hectares, of which 61.76% are on the island of Java (5). A growing industry will attract investors to provide supporting facilities, such as settlements, trade and service buildings and several other supporting facilities that have an impact on increasing land requirements. This will affect massive changes in land cover with an increase in built-up land, which if the phenomenon is not controlled can have an impact on reducing environmental quality (6)(7). So that to minimize these impacts, it is necessary to implement an Eco Industrial Park (EIP) in each industrial area so that the operation of the industry does not have an impact on reducing environmental quality. The implementation of EIP is one of the steps to protect the environment by creating a green design of infrastructure, planning, and implementing the concept of clean production, pollution prevention, waste management, emission control, and energy efficiency in industrial areas (8)(9).

The industrial estate that is currently developing on the North Coast of Central Java is Kendal Industrial Estate (KIE), where the establishment of KIE is in accordance with the Kendal Regency regional planning 2011 - 2031 which establishes the eastern coastal area as the center of KIE development. KIE was developed in Brangong Sub-district in 2016 by PT Jabeka and Semcorp Development Ltd in an area of 2,200 hectares, which is predicted to absorb 500,000 workers (10). The development of KIE has an impact on land use change, where during 2005 - 2017 there was an increase in settlements of 260.65 hectares and trade and service buildings of 28.87 hectares, while converted land use in the form of irrigated rice fields decreased by 235.54 hectares, moorlands decreased by 125.28 hectares, ponds decreased by 112.24 hectares and gardens decreased by 65.92 hectares (11). Land conversion that occurs has the potential for environmental degradation, especially when KIE is developed on the North Coast which has unstable soil with various environmental problems, such as abrasion, rob, intrusion, land subsidence (Zheng et al., 2022)(Nagara and Wibowo, 2024). So that a policy and strategy is needed in the management and development of KIE that is environmentally friendly and supports the establishment of an Eco Industrial Park in Central Java Province. Strategic planning can be done through monitoring environmental quality by utilizing remote sensing technology with the Risk Screening Enviromental Indicators method (RSEI) (14)(15). The results of the study can be used as one of the policy controls in the development of KIE, so that the increase in the economic sector does not have an impact on the decline in environmental quality and can support the establishment of the Eco Industrial Park in Central Java Province. The formulation of this research problem is how the increase in built-up land and changes in environmental quality index based on Risk Screening Enviromental Indicators. (RSEI) 2015, 2020, and 2024 around Kendal Industrial Estate.

The research problem solving approach is through monitoring land cover change and environmental quality index based on Risk Screening Enviromental Indicators (RSEI) around KIE, where land cover data extraction is obtained from the results of supervised multispectral classification, while for RSEI obtained by spectral transformation method from the parameters of Noormalized Difference Vegetation Index, Urban Index, Land Surface Temperature, Wetnes Index and Drought Index in 2015, 2020 and 2024 with Landsat 8 image data sources. So that a model of land use change and RSEI around KIE is obtained. The State of the Art of the research is that the model prepared can be used in solving current problems. As is known, the development of KIE will have positive and negative effects, where the negative impact will lead to a decrease in environmental quality due to land use changes around the area. So that an approach to developing an industrial area that is more oriented towards environmental balance is needed to create an eco industrial park which is one aspect of developing a green economy in Central Java Province. The purpose of the research is to analyze land cover changes and environmental quality indexes around KIE which can be used as indicators in realizing an eco industrial park in Central Java.

2. Research Methods

2.1. Study Area

Study area in Kendal District, Central Java Province of Indonesia to identify land cover change and environmental quality index based on Risk Screening Enviromental Indicators (RSEI) around Kendal Industrial Estate (KIE). The study focused on 5 sub-districts that are expected to be impacted by the development of KIE, including Brangsong sub-district, Kaliwungu sub-district, Kaliwungu Selatan sub-district, Kendal sub-district and Ngampel sub-district, as presented in Figures 1.

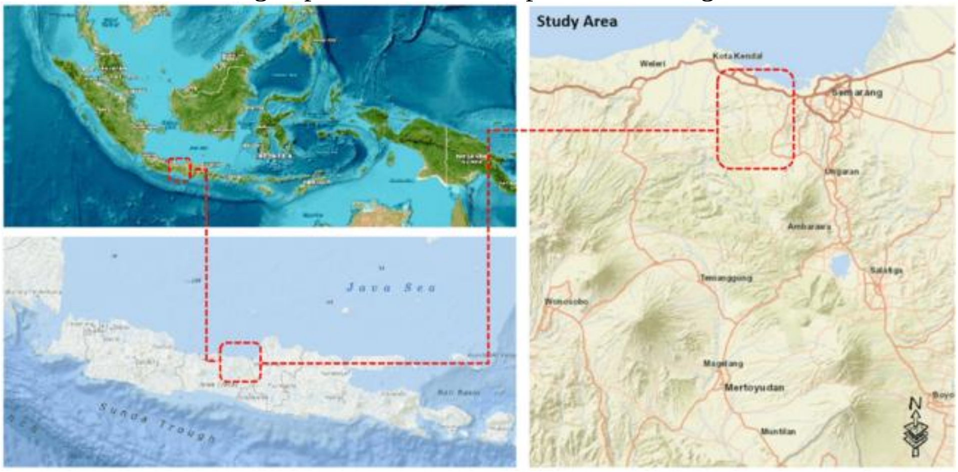

Figure 1. Research sites

2.2. *Research Data*

The primary data source in this research is Landsat 8 Level 2, Collection 2, Tier 1 images in 2015, 2020 and 2024 from the United Stated Geological Survey (USGS) through the Google Earth Engine (GEE) platform. The Landsat 8 time series has corrected surface reflectance and land surface temperature levels, time series data acquisition was taken in the dry season to avoid the effects of different seasons (5). The next process is pre-processing the QA band bit mask technique (pixel_qa) to clean the image from cloud and cloud shadow so that the objects in the image are clearly visible (16). The QA (pixel_qa) band bit mask technique is very helpful for image processing of tropical regions such as Indonesia which has a lot of cloud cover (17).

2.3. *Land Cover Change Analysis*

The time series land cover map is obtained from supervised classification processing based on GEE machine learning, which has the capacity to process high-dimensional data such as remote sensing images to produce complex thematic information in a region (18). Supervised classification method with GEE machine learning in preparing land cover maps utilizing RF (Random Forest) method with better accuracy than other machine learning such as SVM (19). Processing of time series land cover maps using band 1, band 2, band 3, band 4, band 5, band 6, band 7 of Landsat 8 imagery, where the band combination has the highest accuracy compared to other combinations (20). The land cover map of the study area from RF classification resulted in 5 classes, including water body, vegetation, agriculture land, open field, built-up (Table 1).

Table 1. Land cover classification in study area

Land Cover	Information
Water body	Land covers in the form of water, such as rivers, ponds and reservoirs.
Vegetation	Land covers in the form of forests, mixed gardens, and green open spaces.
Agriculture land	Land cover for cultivation of agricultural crops, such as paddy fields, moorlands and dry fields.
Open field	Land cover of unutilized open land, such as vacant lots, sand and stockpiles.
Built-up	Land covers in the form of settlements, industries, trade and service buildings and hardened land.

Source: ground check, 2024

2.4. Data Analysis

2.4.1 Risk Screening Enviromental Indicators Parameters

Monitoring environmental quality in the study area using Risk Screening Enviromental Indicators (RSEI) with 4 parameters used, including greenness level, humidity level, dryness level and heat level obtained from the spectral transformation of Landsat 8 images (21) (22). The following is an explanation of the calculation method of environmental quality parametet in the study area.

Greenness index

Greenness index can present the level of density that can indicate the quality of the environment in the study area. Greenness index processing uses the Normalized Difference Vegetation Index (NDVI) method which presents vegetation density with an interval value of -1 to 1 (23). NDVI spectral transformation uses band 4 (reflectance of infrared band) and band 5 (reflectance of near infrared band) with the following algorithm.

NDVI: $(\rho NIR-\rho R)/(\rho NIR+\rho R)$ [1]

Humidity Index

Humidity index can present the level of water wetness in the soil, where in this study the humidity index is obtained from the processing of wetness index and tasseled cap transformation (24). Soil wetness can be used as an indicator of environmental quality, such as drought and flooded vegetation (25) (26). Processing of wetness index and tassel cover using Landsat 8 time series image bands ρB, ρG, ρR, ρNIR, ρSWR1, and ρSWR2 which are reflectance of blue, green, red, near infrared, shortwave infrared 1, and shortwave infrared 2 bands with the following algorithm.

Wetness: $0.1511\rho B+0.1972\rho G+0.3283\rho R+0.3407\rho NIR-0.7117\rho SWIR1-0.4559\rho SWIR2$ [2]

Dryness Index

Land dryness can be affected by high building density and increased soil reflectance from the sun, which can lead to environmental degradation. Dryness index is obtained from the combination of Index-Based Built-Up (IBI) and Normalized Difference Soil Index (NDBSI) (27). The processing of these two indices uses many Landsat 8 image bands, including ρB, ρG, ρR, ρNIR, ρSWR1, and ρSWR2 are the reflectances of the blue, green, red, near-infrared, shortwave infrared 1, and shortwave infrared 2 bands that are able to discriminate impervious surfaces from other objects, and are sensitive to soil moisture dynamics (28)(29). The following algorithm was used in processing the dryness index in the study area.

NDBSI: $(IBI+SI)/2$ [3]

BI: $\{2\rho SWIR1/(\rho SWIR1+\rho NIR) -[\rho NIR/(\rho NIR+\rho R) +\rho G/(\rho SWIR1+\rho G)]\}\{2\rho SWIR1/(\rho SWIR1+\rho NIR)+[\rho NIR/(\rho NIR+\rho R)+\rho G/(\rho SWIR1+\rho G)]\}$ [4]

SI: $[(\rho SWIR1+\rho R) -(\rho NIR+\rho B)]/[(\rho SWIR1+\rho R) +(\rho NIR+\rho B)]$ [5]

Heat Index

Heat index can represent the level of land surface temperature in the study area, where the higher the temperature indicates that the location has a lower environmental quality because it has an impact on the low level of regional comfort. Heat index can also represent the microclimate in the study area, which in this study is represented in the Land Surface Temperature (LST) transformation. The calculation of LST is guided by the level of emissivity in centigrade units, where the emissivity is calculated by considering the level of vegetation density obtained from NDVI processing. The following algorithm is used to calculate LST in the study area.

L: $gain\times DN+bias$

Tb: $K2/\ln(K1/L6+1)$

Pv: $[(NDVI-NDVImin)/(NDVImax-NDVImin)]2$

ε: $0.004 \times pv + 0.986$
LST: $Tb/[1+((\lambda Tb)/\rho)\ \ln(\varepsilon)]-273.15$ [6]

2.4.2 Risk Screening Enviromental Indicators Parameters
Risk Screening Enviromental Indicators (RSEI) is calculated using the Principal Component Analysis (PCA) transformation method with data input of 4 indices namely NDVI, Wetness, NDBSI and LST. The following formula is used to calculate RSEI.
RSEI: $f\ (NDVI, Wet, LST, NDBSI)$ [7]

The use of PCA aims to rotate the coordinate system axis of the new orthogonal axis of all RSEI parameters by maximizing the variance of the data (30). In addition, the use of PCA also aims to synthesize parameters so as to reduce the anomaly of subjective factors in the weighting process (24), where before the PCA process, all RSEI parameter values are normalized in the interval of (0-1) (31) with the aim of equalizing the weight of each parameter that has a different value interval. The following is the formula for normalizing the RSEI parameter value interval.
Nli: $(Ii-Imin)/(Imax-Imin)$ [8]
The result of PCA processing is the first component, PC1, which combines several environmental indicators and contains information on some RSEI values so that it can represent environmental quality in the study area. The higher PC1 value indicates the better environmental quality, but sometimes there is an anomaly of inverse results so that the following calculation is needed (32).
RSEI0: $1-\{\text{RSEI}\}$ [9]

The final results of RSEI processing are then converted into a value interval of 0 -1 in order to facilitate the analysis process (31), where RSEI approaches a value of 1 indicating that the environmental conditions are getting better, while if it approaches a value of 0 then the environmental conditions are getting worse (21) (22). The formula for converting RSEI values so that they have a value interval of 0- 1.
RSEIf$=(RSEI0-RSEI0\_\text{min})/(RSEI0\_\text{max}-RSEI0\_\text{min})$ [10]

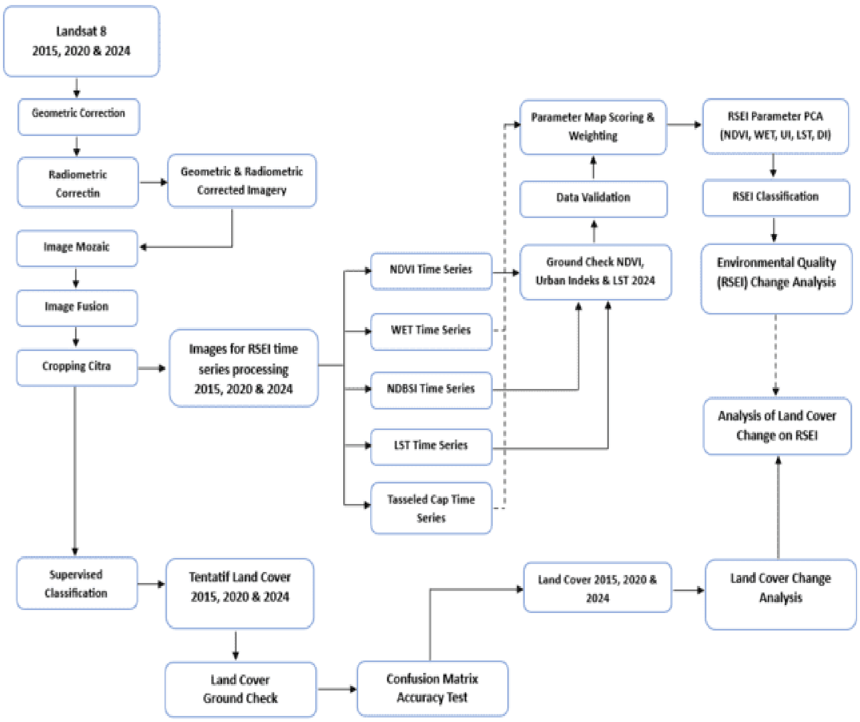

Figure 2. Research flow chart

3. Results and Discussion

The results and discussion in this study will explain the changes in land cover time series, the results of environmental quality index processing, changes in environmental quality index and the effect of increased built-up land and reduced vegetation on environmental quality index in the study area.

3.1. Land Cover Change Time Series

Land cover was obtained from supervised classification processing with Google Earth Enggine (GEE) machine learning of Landsat 8 time series images (2015, 2020 & 2024). Multispectral classification results show that there are 5 classes of land cover in the study area, including vegetation, built-up, agricultural land, open field and water body. Land cover with vegetation object has an area of 7,153.02 hectares (2024), where based on the spatial distribution vegetation is mostly located in South Kaliwungu Sub-district with clustered distribution. The high vegetation cover in Kaliwungu Selatan sub-district affects the improvement of microclimate quality in the area, thus making the environmental comfort better (33)(34). In addition, high vegetation cover also has the potential to act as a rainwater infiltration medium so as to improve the quality and quantity of groundwater in the area (35).

Furthermore, there is built-up land cover with an area of 2,956.96 hectares (2024) with spatial distribution extending along the road and clustering in areas with flat topography and good accessibility. Built-up in the study area consists of settlements, trade and service buildings, industries, public infrastructure facilities and others (Figure 4). Built-up in the study area is mostly concentrated in Kaliwungu Sub-district and Kendal Sub-district with clustered spatial distribution (Figure 3). Built-up is concentrated in these two areas because Kaliwungu Sub-district is the main area for the development of Kendal Industrial Estate which provides extensive employment opportunities that attract productive- age residents to access jobs. Meanwhile, Kendal Sub-district is the capital of Kendal Regency with the attraction of complete public facilities to support human life. Based on this phenomenon, it can be concluded that the factors of job availability and public facilities have an attraction for residents to live around the area (36). The following table shows the land cover types in the study area.

Table 2. Land cover time series in the study area

No	Land Cover	Area (hectares)				
		2015	2015-2020	2020	2020-2024	2024
1	Vegetation	7.337,73	-124,39	7.213,34	-60,32	7.153,02
2	Built-up	2.062,79	+757,48	2.820,27	+136,69	2.956,96
3	Agricultural land	5.542,39	-416,66	5.132,73	-109,90	5.022,83
4	Open field	4,39	+105,17	109,56	+164,69	274,25
5	Water body	3.718,49	-321,60	3.396,89	-131,16	3.265,73
	Total	18.672,29		18.672,29		18.672,29

Source: analysis result, 2024

Land cover in the study area is always changing due to various factors, one of which is the development of the Kendal industrial area developed in the area since 2016. Built-up in the study area is very dynamic, with an increase in the area of 757.48 hectares (20015-2020) and 136.69 hectares (2020-2024). The increase in built-up land is mostly in Kaliwungu Sub-district with an area of 321.60 hectares (2015-2025), which is the location of the development of the Kendal industrial area with a clustering pattern in the form of industrial buildings and settlements. The built-up land mostly converts agricultural land, which is reduced by 416.66 hectares (2015-2020) and 109.90 hectares (2020-2024), where some of the converted agricultural land is on the edge of the Pantura Road with an area of 226.89 hectares (2015-2020). The conversion of agricultural land into built-up land will certainly affect the decline in land productivity (37), Moreover, agricultural irrigation in the area is very good so that it has optimal yields every season. The following figure shows the land cover change in the study area.

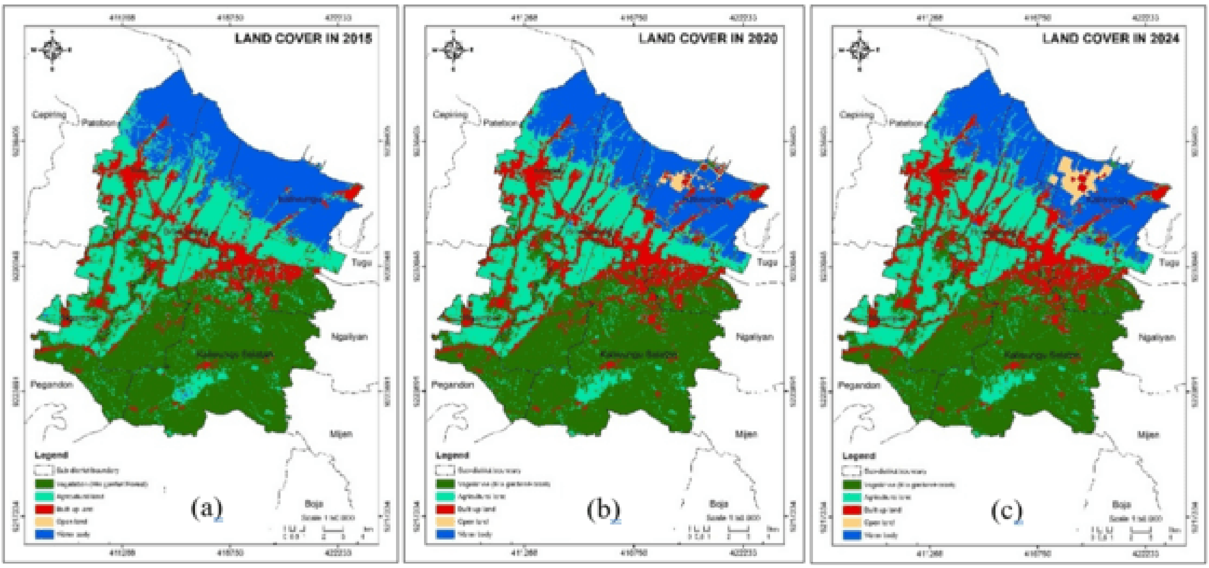

Figure 3. Land cover map time series in 2015 (a), 2020 (b) and 2024 (c)

Table 3. Land cover change at sub-district level

No	Land Cover	Area (hectares)				
		2015	**2015-2020**	**2020**	**2020-2024**	**2024**
Brangsong District						
1	Vegetation	1.169,98	-50,78	1.119,20	-9,40	1.109,80
2	Built-up	339,9	120,72	460,62	50,43	511,05
3	Agricultural land	1.323,08	-32,74	1.290,34	-27,53	1.262,81
4	Open field	0,26	-0,26	0	0,70	0,70
5	Water body	684,04	-36,94	647,10	-14,20	632,90
Kaliwungu District						
1	Vegetation	649,77	-35,72	614,05	-17,47	596,58
2	Built-up	605,36	321,60	926,96	8,2	935,16
3	Agricultural land	1051,87	-226,89	824,98	-42,44	782,54
4	Open field	2,07	106,42	108,49	164,94	273,43
5	Water body	1805,48	-165,41	1640,07	-113,23	1526,84
South Kaliwungu District						
1	Vegetation	4298,29	-91,31	4206,98	-12,64	4194,34
2	Built-up	289,19	137,6	426,79	35,30	462,09
3	Agricultural land	737,01	-38,26	698,75	-22,74	676,01
4	Open field	0,13	-0,13	0	0	0
5	Water body	22,3	-7,9	14,4	0,08	14,48
Kendal District						
1	Vegetation	158,12	-19,55	138,57	-20,19	118,38
2	Built-up	543,06	122,3	665,36	57,65	723,01
3	Agricultural land	1203,27	-5,58	1197,69	-29,55	1168,14
4	Open field	1,85	-1,85	0	0	0
5	Water body	1208,37	-95,32	1113,05	-7,91	1105,14

Ngampel District						
1	Vegetation	1091,22	-10,41	1080,81	-6,92	1073,89
2	Built-up	278,39	101,06	379,45	11,54	390,99
3	Agricultural land	1203,85	-85,16	1118,69	-4,72	1113,97
4	Open field	-	-	-	-	-
5	Water body	5,93	-5,49	0,44	0,10	0,54

Source: analysis result, 2024

3.2. Processing Result of Risk Screening Enviromental Indicators Parameters

Monitoring environmental quality index using the Risk Screening Environmental Indicators (RSEI) method with 4 parameters, namely greenness index, humidity index, dryness index and heat index with spectral transformation of Landsat 8 images in 2015, 2020 and 2024. The following are the results of parameter processing and RSEI time series levels in the study area.

3.2.1 Greenness Index Parameters

Greenness parameters were obtained from spectral transformations of Noormalized Difference Vegetation Index (NDVI) using near infrared (band 5) and red (band 4) bands of Landsat 8 images in 2015, 2020 and 202. NDVI can present the level of vegetation density with a classification of pixel values of -1 to 0 (non-vegetation) and 0 to 1 (vegetation), where pixel values close to 1 indicate a higher level of vegetation density (38). The results of NDVI processing in 2024 show that 5,671.30 hectares (30.37%) are areas with high density vegetation (Figure 6), where the area increased by 249.31 hectares from 2020 and increased by 7.83 hectares from 2015. The high-density vegetation is mostly community forests and protected forests located in South Kaliwungu Sub-district, which is quite far from the Kendal industrial area so that it is not so affected by industrial development in Kaliwungu Sub-district. However, the NDVI results show that medium-density vegetation has experienced a considerable decrease in area, where in the interval 2015-2020 the area decreased by 1,722.31 hectares and decreased again from 2020-2024 (847.18 hectares). Based on its spatial distribution, medium-density vegetation is located around the Pantura Road, which is close to the development of the Kendal industrial area in the form of mixed gardens, green open spaces and mangroves. Reduced levels of vegetation density, especially at medium density, will cause an increased microclimate in the area, which can indicate a decrease in environmental quality (39)(40). The following table shows the time series vegetation density in the study area.

Table 4. NDVI level classification time series

No	NDVI Value	Area (hectares)					Level
		2015	**2015-2020**	**2020**	**2020-2024**	**2024**	
1	-0,13 – 0,138	3.376,63	+875,46	4.252,09	+834,00	5.086,09	non vegetasi
2	0,139 – 0,235	3.461,12	-36,01	3.425,01	+639,00	4.064,01	low
3	0,236 – 0,316	6.420,38	-847,18	5.573,20	-1.722,31	3.850,89	moderate
4	0,317 – 0,496	5.414,16	+7,83	5.421,99	+249,31	5.671,30	high
	Total	**18.672,29**		**18.672,29**		**18.672,29**	

Source: analysis result, 2024

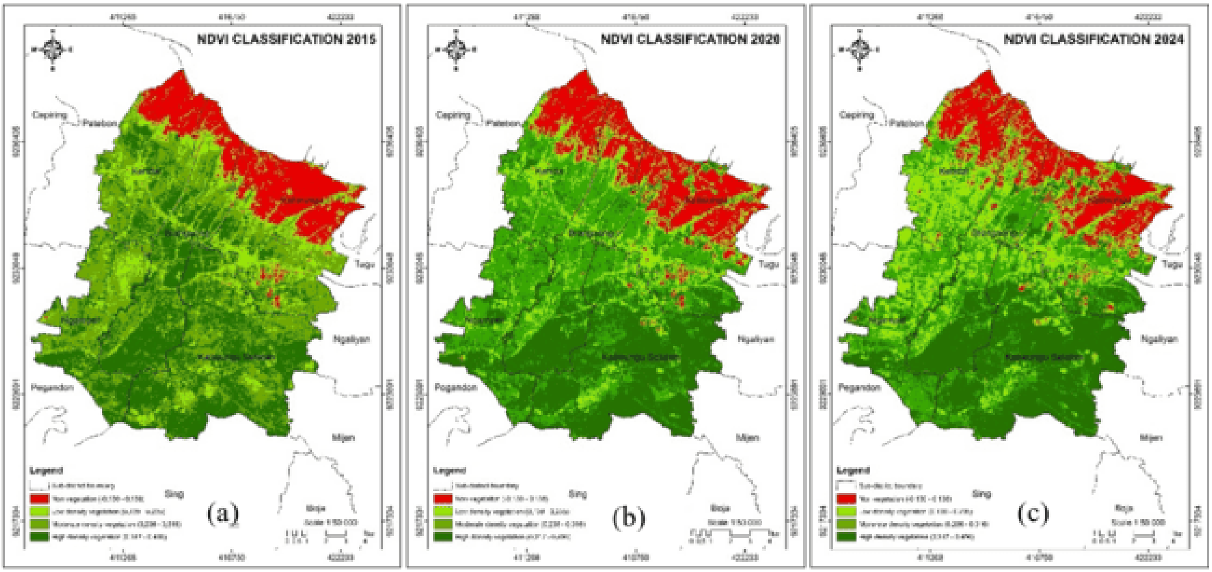

Figure 4. Vegetation index map time series in 2015 (a), 2020 (b) and 2024 (c)

3.2.2 Humidity Index Parameters

Humidity index is an RSEI parameter that shows the level of water content in soil and vegetation, which in its processing uses wetness index spectral transformation with blue, green, red, near-infrared, shortwave infrared 1, and shortwave infrared 2 bands of Landsat 8 time series images. The wetness index processing results show that the pixel value has a value of 2.12 - 13.67, where the higher the pixel value indicates the higher the wetness level in the study area, which indicates a better environmental quality index. The wetness level in the study area is mostly at the moderate level (3.79 - 4.27) with an area of 7,958.91 hectares (2024), then for the low level has an area of 5,714.08 hectares (2024), so that the processing results show that 73.22% of the study area has a moderate and low wetness level which indicates that it has low environmental quality when assessed from the water availability parameter. The low level of water content in the study area is more due to the type of land cover which is mostly in the form of built-up land, dry agricultural land and open land that have low water content. Meanwhile, the area with high water content is usually in the type of vegetation land cover which in the study area is only found in the South Kaliwungu Sub-district in the form of community forests and protected forests. Based on the time series data, there is a decrease in high-level wetness of 403.97 hectares (2020- 2024) and very high level of 282.56 hectares (2015-2020). Meanwhile, the area with a low level of wetness has increased by 667.03 hectares (2020-2024). So that the results of the wetness index processing show a decrease in environmental quality assessed from the availability of water in the study area. The following table shows the time series soil wetness level in the study area.

Table 5. Wetness index classification time series

No	Wetness Value	Area (hectares)					Level
		2015	2015-2020	2020	2020-2024	2024	
1	2,12 – 3,78	5.944,63	-897,58	5.047,05	+667,03	5714,08	low
2	3,79 – 4,27	8.302,22	-362,81	7.939,41	+19,50	7.958,91	moderate
3	4,28 – 5,91	4.402,01	+947,01	5.349,02	-403,97	4.945,05	high
4	5,92 – 13,67	23,43	+313,38	336,81	-282,56	54,25	very high
	Total	**18.672,29**		**18.672,29**		**18.672,29**	

Source: analysis result, 2024

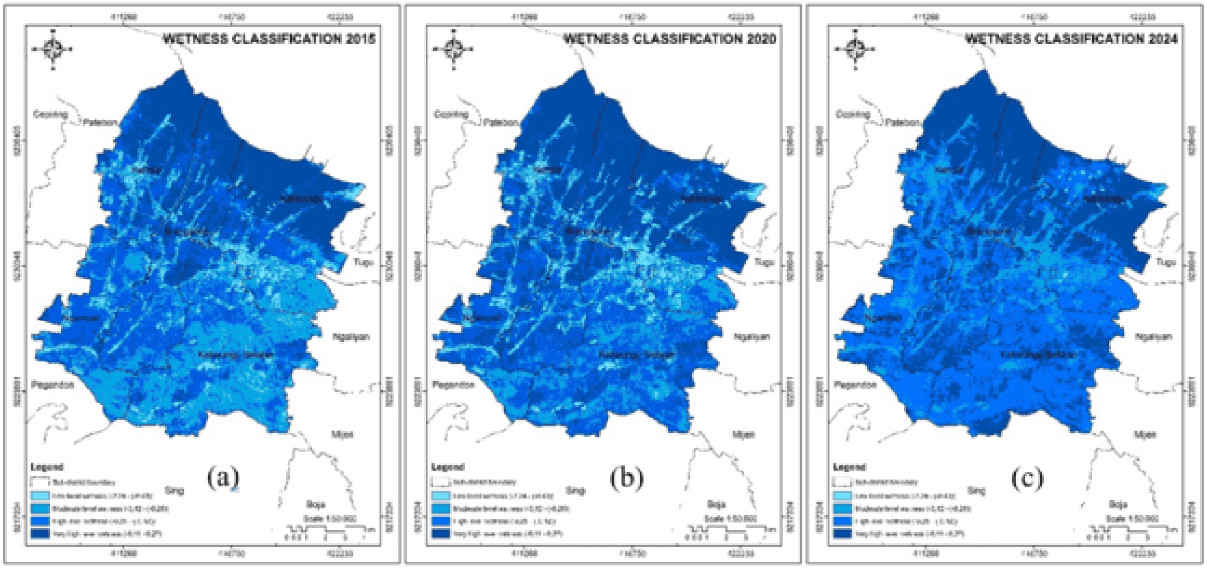

Figure 5. Wetness index map time series in 2015 (a), 2020 (b) and 2024 (c)

3.2.3 Dryness Index Parameters

Parameters dryness index can provide information related to the level of drought in a region so that it can describe the adequacy of water for living things which is one indicator of environmental quality (40). Dryness index in the study area was obtained by Normalized Difference Soil Index (NDBSI) method using blue, green, red, near-infrared, shortwave infrared 1, and shortwave infrared 2 bands of Landsat 8 time series images. The results of NDBSI processing show that the index value has a range of values -2.24 - 0.27, where the higher the NDBSI value indicates a higher level of drought which indicates lower environmental quality. Existing drought levels in the study area are mostly at very high (6,181.41 hectares) and high (8,319.38 hectares) levels or around 77.65% of the study area with spatial distribution evenly distributed throughout the region (Figure 8), where for areas with small drought levels identified in the north (ponds) and south (forest). Based on Landsat 8 time series data, there is an increase in the area of very high drought level of about 823.14 hectares (2015-2020) and high with an area of 1,452.11 hectares (2020-2024), where the phenomenon has an impact on reducing the area with moderate drought level of about 1,000.56 hectares (2015-2020) and 1,268.63 hectares (2020- 2024). So that based on the NDBSI time series data, there is a decrease in the environmental quality index of the drought indicator in the study area. The following table shows the time series soil drought level in the study area.

Table 6. NDBSI index classification time series

No	Wetness Value	Area (hectar)					Level
		2015	**2015-2020**	**2020**	**2020-2024**	**2024**	
1	-2,24 – (-0,43)	1.527,51	+53,56	1.581,07	-142,81	1.438,26	low
2	-0,42 – (-0,26)	5.002,43	-1.000,56	4.001,87	-1.268,63	2.733,24	moderate
3	-0,25 – (-0,12)	6.743,41	+123,86	6.867,27	+1.452,11	8.319,38	high
4	-0,11 – 0,27	5.398,84	+823,14	6.222,08	-40,67	6.181,41	very high
	Total	**18.672,29**		**18.672,29**		**18.672,29**	

Source: analysis result, 2024

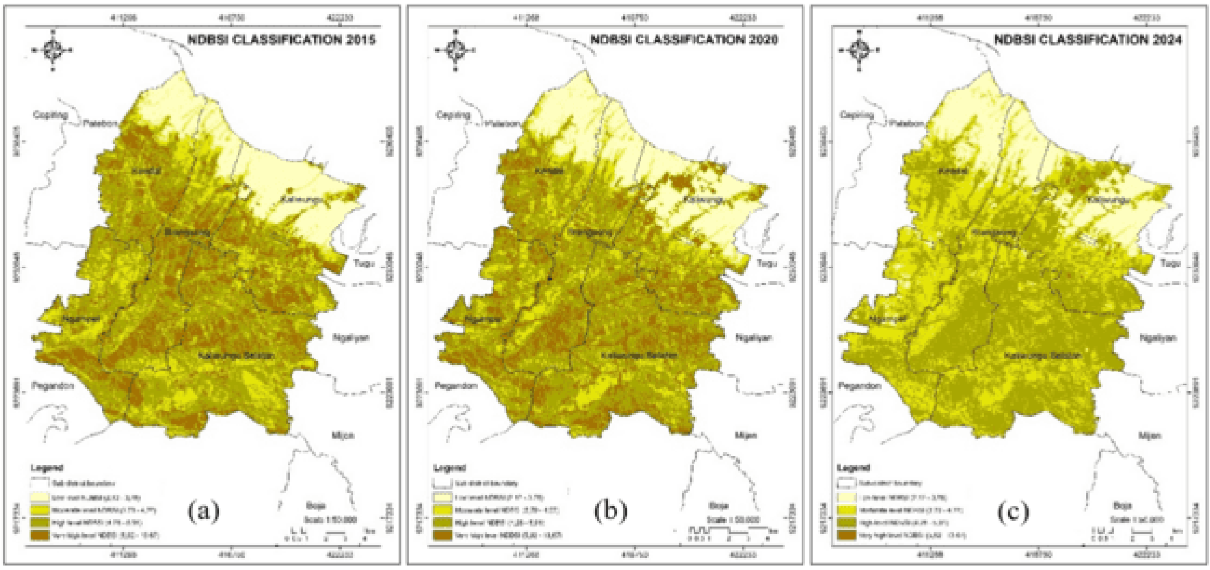

Figure 6. Dryness index map time sereis in 2015 (a), 2020 (b) and 2024 (c)

3.2.4 Heat Index Parameters

Heat index parameters are obtained from Land Surface Temperature (LST) spectral transformation processing with thermal band 11 and 12 data sources of Landsat 8 time series images. The result of LST processing shows the land surface temperature in Landsat pixel units with a spatial resolution of 100 meters, where this temperature has a correlation with environmental quality in the study area. LST can describe the microclimate conditions in the study area which is one of the indicators of the comfort level of the area, where microclimate conditions are strongly influenced by the availability and density of vegetation in the area which can be visualized through NDVI values (41). The results of ESG processing show that the land surface temperature in the study area has an interval value of 29.45 - 33.39 °C with the distribution of high and very high temperatures around Brangsong Sub-district, Ngampel Sub-district and Kendal Sub-district with low vegetation cover (Figure 9). LST in the study area is mostly at low level (29.45 - 30.46°C) with an area of 6,043.07 hectares and moderate level (30.47 - 30.98°C) with an area of 5,646.42 hectares with spatial distribution in the area of South Kaliwungu Sub-district and Kaliwungu Sub-district (Figure 9) with high level of vegetation density. Based on the results of the LST time series processing, it shows that there is an increase in the area for the high level of around 4,622.45 hectares (2020-2024) and the very high level with an area of 2,360.35 hectares (2020-2024), where the increase in LST in the region is influenced by the decreasing level of vegetation density for high and very high-density levels. The increasing phenomenon of high and very high levels of LST indicates a decrease in environmental quality and comfort in the study area. The following table shows the LST level time series in the study area.

Table 7. LST classification time series

No	LST Value (°C)	Area (hectares)					Level
		2015	2015-2020	2020	2020-2024	2024	
1	29,45 - 30,46	7.568,50	+2.554,47	10.122,97	-4.079,90	6.043,07	low
2	30,47 - 30,98	5.485,10	-847,57	4.637,53	+1.008,89	5.646,42	moderate
3	30,99 - 31,25	4.056,21	-1.136,52	2.919,69	+1.702,76	4.622,45	high
4	31,26 - 33,39	1.562,48	-570,38	992,10	+1.368,25	2.360,35	very high
	Total	**18.672,29**		**18.672,29**		**18.672,29**	

Source: analysis result, 2024

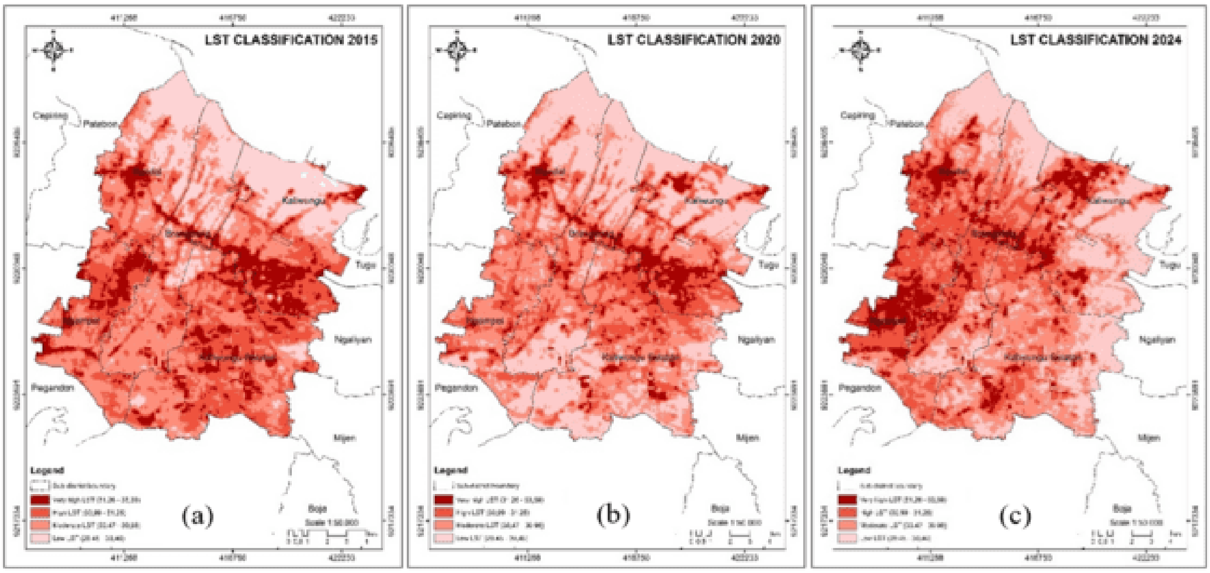

Figure 7. LST map time sereis in 2015 (a), 2020 (b) and 2024 (c)

3.3 Risk Screening Enviromental Indicators Processing Result

The study area environmental quality index is obtained from Principal Component Analysis (PCA) spectral transformation with 4 parameters, including greenness index, humidity index, dryness index and heat index from Landsat 8 image processing in 2015, 2020 and 2024. Before processing with PCA, normalization is carried out first on the value interval of each parameter with a value interval of 0-1 with the aim of equalizing the value interval of each RSEI parameter. So that the RSEI value of PCA processing results will bring up pixel values with an interval of 0-1, where pixels with values close to 0 indicate that they have lower environmental quality, while if they are close to the value of 1, they indicate higher environmental quality. RSEI processing results show pixel values have an interval of 0 - 0.708, which are then classified into 4 classes, where RSEI with a very high level has the largest area in the study area with an area of 5,531.81 hectares or around 29.62% of the study area (2024), but for RSEI with a low level also has a large area of around 5,035.85 hectares (26.96%). So that the distribution of RSEI values shows that the level of environmental quality in the study area is quite varied with a not too large difference in area.

RSEI with high and very high levels are mostly distributed in the southern part of the study area in South Kaliwungu Subdistrict and Ngampel Subdistrict which have high vegetation cover (Figure 10), then for RSEI with low and very low levels are mostly in the southern part of Kendal Sub-district and Kaliwungu Sub-district, while for Brangsong Sub-district is dominated by moderate level RSEI (Figure 10). Based on the spatial distribution of RSEI levels, it can be concluded that areas with high RSEI levels are located in areas with high vegetation cover with low land surface temperatures, while areas with low RSEI levels are located in areas with low vegetation cover (42). So based on this phenomenon indicates that vegetation cover is very influential on the environmental quality index in an area, this is because the level of vegetation cover affects the level of dryness, wetness and land surface temperature which are indicators in the assessment of the environmental quality index. The following table shows the RSEI level in the study area in time series.

Table 8. Risk Screening Enviromental Indicators (RSEI) lassification time series

No	RSEI Value	Area (hectar)					Level
		2015	2015-2020	2020	2020-2024	2024	
1	0 – 0,441	3.007,54	+818,09	3.825,63	+1.210,22	5.035,85	low
2	0,442 – 0,625	2.844,83	+786,12	3.630,95	+623,16	4.254,11	moderate
3	0,626 – 0,707	6.989,67	-1.200,35	5.789,32	-1.938,30	3.851,02	high

4	0,708 - 1	5.830,73	-403,86	5.426,89	+104	5.531,81	very high
	Total	**18.672,29**		**18.672,29**		**18.672,29**	

Source: analysis result, 2024

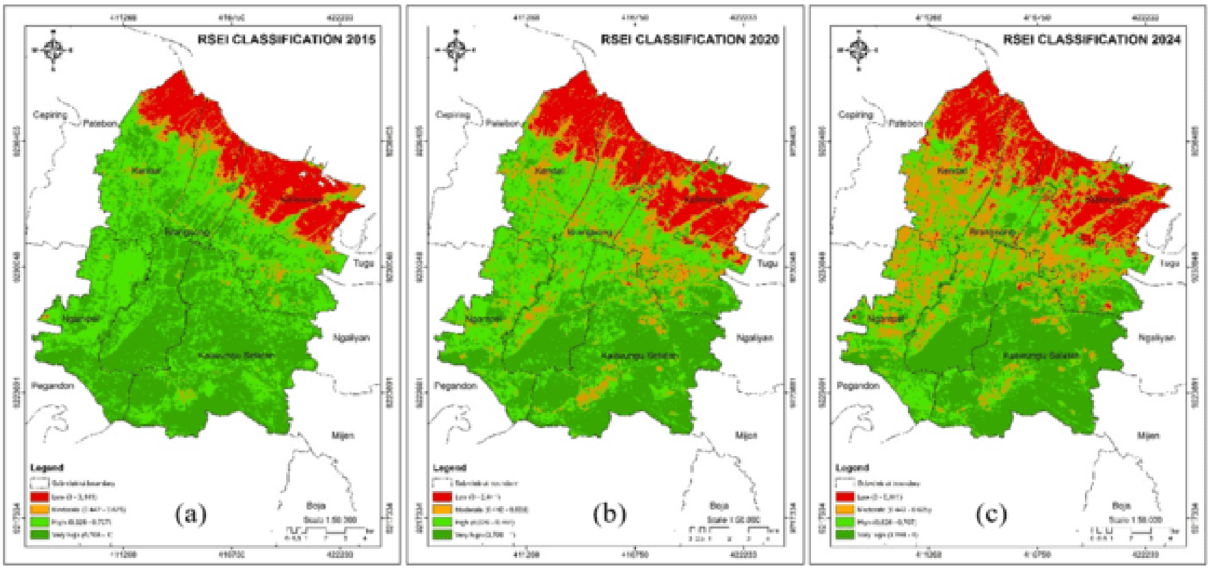

Figure 8. RSEI map time series in 2015 (a), 2020 (b) and 2024 (c)

Based on the results of Landsat 8 time series image processing, the RSEI value in the study area is very dynamic in the last 10 years, especially in areas with high built-up land growth. The area with a high level of RSEI experienced a very large decrease in area from 2015-2020 which decreased by 1,200.35 hectares and decreased again by 1,938.20 hectares (2020-2024), while there was an increase in the area with low RSEI of around 818.09 hectares (2015-2020) and 1,210.22 hectares (2020-2024). Furthermore, the change in the high RSEI level at the sub-district level shows that Brangsong Sub- district experienced a decrease in area of around 474.77 hectares (2020-2024) and South Kaliwungu Sub-district with a decrease in area of 355.94 hectares (2020-2024). Meanwhile, the increase in the area of high-level RSEI occurred in South Kaliwungu Sub-district with an increase in area of 254.70 hectares (2020-2024) and Brangsong Sub-district which increased by 108.68 hectares (2020-2024). Based on the analysis of the RSEI time series level, it can be concluded that sub-districts with a relatively long distance from the Kendal industrial area have a more stable environmental quality because the area does not occur land conversion from vegetation and agricultural land to built-up land, where the increase in built-up land in an area greatly affects environmental quality. The following table shows the RSEI time series for each sub-district in the study area.

Table 9. Risk Screening Enviromental Indicators (RSEI) time series each sub-district

No	RSEI Value	Area (hectares)					Level
		2015	2015-2020	2020	2020-2024	2024	
Brangsong District							
1	0 – 0,441	506,07	+159,80	665,87	+213,75	879,62	low
2	0,442 – 0,625	496,44	+270,05	766,49	+152,34	918,83	moderate
3	0,626 – 0,707	1.217,11	-60,82	1.156,29	-474,77	681,52	high
4	0,708 - 1	1.297,64	-369,03	928,61	+108,68	1.037,29	very high
Kaliwungu District							
1	0 – 0,441	1.712,07	+215,46	1.927,53	+178,16	2.105,69	low

2	0,442 – 0,625	863,01	+46,47	909,48	-126,95	782,53	moderate
3	0,626 – 0,707	1.128,54	-238,38	890,16	-104,58	785,58	high
4	0,708 - 1	410,93	-23,55	387,38	+53,37	440,75	very high
South Kaliwungu District							
1	0 – 0,441	19,43	+29,70	49,13	+122,61	171,74	low
2	0,442 – 0,625	438,61	+166,83	605,44	-23,71	581,73	moderate
3	0,626 – 0,707	2.005,00	-536,77	1.468,23	-355,94	1.112,29	high
4	0,708 - 1	2.883,88	+340,24	3.224,12	+257,04	3.481,16	very high
Kendal District							
1	0 – 0,441	765,05	+386,24	1.151,29	+494,19	1.645,48	low
2	0,442 – 0,625	681,33	+97,19	778,52	+256,23	1.034,75	moderate
3	0,626 – 0,707	1.251,17	-235,19	1.015,98	-655,09	360,89	high
4	0,708 - 1	417,12	-248,24	168,88	-95,33	73,55	very high
Ngampel District							
1	0 – 0,441	8,26	+3,34	11,60	+200,45	212,05	low
2	0,442 – 0,625	367,10	+207,49	574,59	+370,16	944,75	moderate
3	0,626 – 0,707	1.385,13	-116,62	1.268,51	-345,96	922,55	high
4	0,708 - 1	818,90	-94,21	724,69	-224,65	500,04	very high

Source: analysis result, 2024

3.4 Land Cover Change to RSEI Value Analysis

Based on the results of land cover processing and RSEI time series study area shows the phenomenon of increasing built-up land and decreasing the area of vegetation cover, especially in locations close to the Kendal industrial area. The increase in built-up land occurred from 2015-2020 with an area of 757.48 hectares, where the increase was mostly distributed in Kaliwungu Sub-district and Brangsong Sub-district, which is the location of the development of the Kendal industrial area with land use types in the form of industrial buildings and settlements. Built-up land also increased from 2020-2024 with an area of 136.69 hectares, which was partly distributed in Kaliwungu Sub-district and dominated by residential land use. Furthermore, vegetation land cover also experienced a decrease in area of 124.39 hectares (2015-2020) and 60.32 hectares (2020-2024), where the vegetation is mostly in the form of mixed gardens converted into built-up land around the Kendal industrial area.

The increase in the area of built-up land and the reduction of vegetation area correlates with the area of environmental quality index in the study area, where in the 2015-2020 period there was a decrease in the area of high level RSEI with an area of 1,200.35 hectares and reduced again around 1,938.30 hectares (2020-2024) which was mostly located in Kaliwungu Sub-district, the location of the development of the Kendal industrial area. In addition, there was also an increase in low-level RSEI with an area of 818.09 hectares (2015-2020) and 1,210.22 hectares in 2020-2024, mostly in Kaliwungu and Brangsong Sub-district. Based on this phenomenon, it indicates that an increase in the area of built- up land and a reduction in vegetation area can affect the decline in environmental quality in an area, this is because vegetation has a function as a balancer of environmental conditions, while an uncontrolled increase in built-up land can have an impact on increasing microclimate and reducing water infiltration media which can affect environmental quality in an area (43) (44). The following table shows the relationship between land cover change (built-up and vegetation) and environmental quality index in the study area.

Table 10. RSEI, Built-up and Vegetation Change in Study Area 2015 - 2024

No	Information	Area (hectares)	
		2015-2020	2020-2024
1	Low level RSEI area Increase	818,09	1.210,22
2	High level RSEI area decline	1.200,35	1.938,3
3	Built-up area Increase	757,48	136,69
4	Vegetation area decline	124,39	60,32

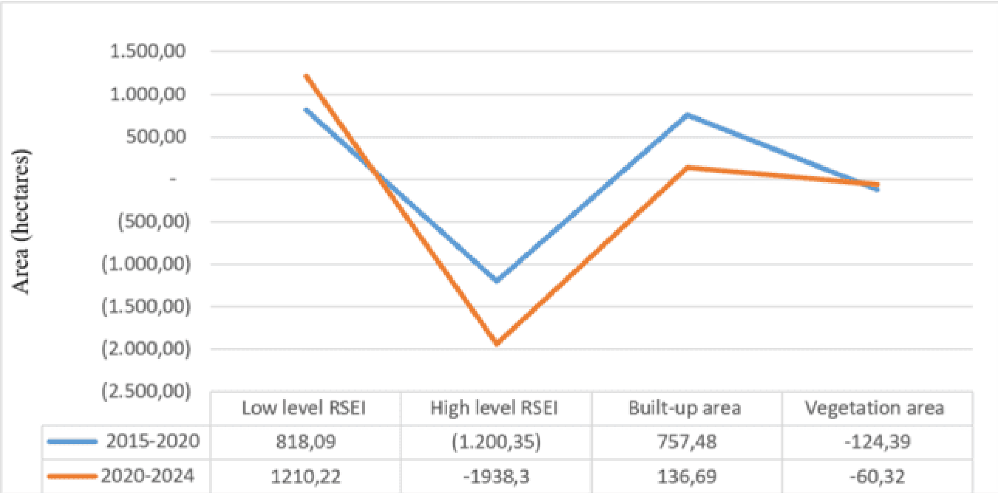

Figure 9. Relationship between land cover change (Built-up and vegetation) to RSEI level

4. Conclusion

Based on the results of the research, it can be concluded related to land cover change and environmental quality in the study area, including:

- Existing land cover is dominated by vegetation with an area of 7,153.02 hectares, agricultural land with an area of 5,022.83 hectares and built-up with an area of 2,956.96 hectares. Built-up land has increased by 757.48 hectares (20015-2020) and 136.69 hectares (2020-2024) which has an impact on reducing agricultural land by around 416.66 hectares (2015-2020) and 109.90 hectares (2020-2024).
- RSEI processing results show pixel values have an interval of 0 - 0.708, where RSEI with a very high level has the largest area in the study area with an area of 5,531.81 hectares or around 29.62%. The results of the RSEI time series show that high level RSEI has decreased in area by 1,200.35 hectares (2015-2020) and decreased again by 1,938.20 hectares (2020-2024), while there is an increase in the area of low RSEI around 818.09 hectares (2015-2020) and 1,210.22 hectares (2020-2024).
- An increase in the area of built-up land and a reduction in the area of vegetation can affect the decline in environmental quality in a study area, where this is because vegetation has a function as a balancer of environmental conditions, while an uncontrolled increase in built-up land can have an impact on increasing microclimate and reducing water absorption media which can affect environmental quality.

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