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Spatiotemporal Analysis of Environmental Changes Based On Integrated Remote Sensing Indexes in River Basin of Kelantan

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Abstract. Analysis of environmental changes is a key to knowing the state of vulnerability of the environment. However, in recent years, environmental changes are often evaluated based on one factor per research. In this study, several factors will be integrated to get an evaluation of the environment that consider the influences of many natural factors at the same time. In this study, spatiotemporal analysis of environmental changes based on integrated remote sensing indexes in river basin of Kelantan will be conducted to evaluate the environmental condition of the Kelantan river basin. It will also help in evaluating the environmental health of the Kelantan River. The Kelantan River basin is an important source of water to Kelantan's population, and up to 2014, Kelantan River basin is also housing about 68.5% of the Kelantan population lives within the Kelantan River Basin. This means that any negative changes of the environment of the Kelantan River basin could affect the community severely. Hence, the environmental quality evaluation throughout the time is needed in order for any protection and management enforcement if necessary. The process of environmental evaluation includes the usage of indexes, namely the normalized difference vegetation index (NDVI), wetness index (WI), albedo, salinization index (SI), and land surface temperature (LST) will be used to calculate the data obtained from Landsat TM and Landsat 8 from the year 2000, 2005, 2010, 2016, and 2020. Data processing, compilation, verification, calculation and analysis will be conducted using ArcGIS 10.3. The result of this study will give the condition status on the environmental that has happened since 2000 until 2020 in Kelantan River Basin. The information gained will be helpful assistant in creating rules and regulation, formulation, protection and management effort to conserve the environment of the river basin. This study will also show that by using remote sensing technology, environmental changes of certain area can be evaluated.

1. Introduction

Kelantan River Basin is a tropical climate basin in the northeastern part of Peninsular Malaysia with an area of only 5% undulating area, whereas the rest are steep mountainous areas [1]. [2] reported that the Kelantan River Basin is a combination of 64% of forests in the southern side of the basin, 26% of agricultural areas in the downstream site, and 10% are developing areas which are mostly in the downstream of the north. There is about 68.5% of the Kelantan population that lives within the Kelantan River Basin, and up to 2014, there are about 400 residential areas that are located along the Kelantan River [3].

Rubber plantation in Kelantan are known to be concentrated in the Gua Musang, Tanah Merah, Jeli, and Machang, meanwhile, palm oil plantation is concentrated in the Gua Musang only [4]. The expansion of logging, plantations of rubber, and palm oil mean that forests are being degraded. In 1990, Kelantan has 59% of the area that is classified as natural forest, 1% of mangrove, and 15% of secondary forest. Therefore, after 27 years in 2017, the percentage of natural forest in Kelantan has declined to 48%, and mangrove forest is no longer available, whereas secondary forest remains at 15% [5]. Forest clearing from logging activities and for plantation area expansion has shown an increase in erosion of sediment of soil into the river due to high rainfall level received by Kelantan throughout the monsoon season. This has caused sedimentation downstream of the Kelantan River, causing the stream to be shallow [6]. Moreover, the plantation of palm oils has caused excessive soil nutrients consumption. As the result of the usage of pesticides, herbicides, and fertilizers, the habitat is lost and the remains of the chemicals affect the water quality of the nearby river [7].

In assessing the quality of an environment, there are many factors that made up the environment that needs to be considered. To conclude that an environment is declining in quality- there needs to be a line drawn between the good and the bad, of each factor, and the factors combined as a whole. According to [8], the environment is modified by two types of changes, which are natural and non-natural. Further classified by [8], non-natural means man-made modifications and impacts on nature. Examples of non-natural impacts are the act of tree logging, agriculture activities, and urbanization. Natural changes or modifications are natural abiotic factors such as rain, fires, hurricanes, or earthquakes. As previously mentioned, remote sensing is a method of observing land and water surfaces without having to physically be present at the studied place. It is known that with such capability, remote sensing can be helpful when observing changes in the environment that occurs throughout time. Several indexes could be used to capture the changes that have occurred to an environment, be it from a natural occurrence or non-natural impacts. From the analyzed data of the indexes processed, the environmental quality will be able to be assessed. The indexes that will be used are Normalized Difference Vegetation Index (NDVI), Wetness Index (WI), Salinization index (SI), Land Surface Temperature (LST), and Albedo. The indexes are able to extract different results of environmental assessment. Spatial Principal Component Analysis (SPCA), Remote-sensing Spatial Distance Model (RSSDM), Environmental Interannual Change Index (EICI), and Environmental overall pattern index.

In this study, the factors that are going to be considered in the environmental quality evaluation of the Kelantan River Basin is the vegetation coverage of the land, soil degradation, soil moisture, desertification trend of bare soil areas, the temperature of the land surface, and also the acceleration of urbanization that take place in the Kelantan River Basin (KRB) as it impacts the surrounding water quality, microclimate of the urbanized region, and the biodiversity of the place [9].

2. Materials and Method

2.1. Study area

Kelantan River Basin is situated between the latitude of 6°12'60.00" North and longitude of 102° 13' 60.00" East, in the north-eastern part of Peninsular Malaysia as shown in Figure 1. It has an area of around 12,000 km^2 which got drain into the Kelantan River which has a length of about 248 km [3]. The river basin is made of mostly mountainous lands which majority are covered with natural forests, and the rest of the basin consists of palm oil and rubber tree plantations, urban areas, and tobacco plantations. The basin receives rainfall throughout the year; however, the precipitation amount increases at the end of the year due to the annual north-east monsoon season which occurs around November to January.

The data that will be used in this study are collected from Landsat Thematic Mapper (Landsat TM) and Landsat OLI/TIRS (Landsat 8) and are data from year 2000, 2005, 2010, 2016, and 2020. The processing of the images that includes data compilation, data correction, verification, index calculation, and analysis will be done using ArcGIS 10.3.

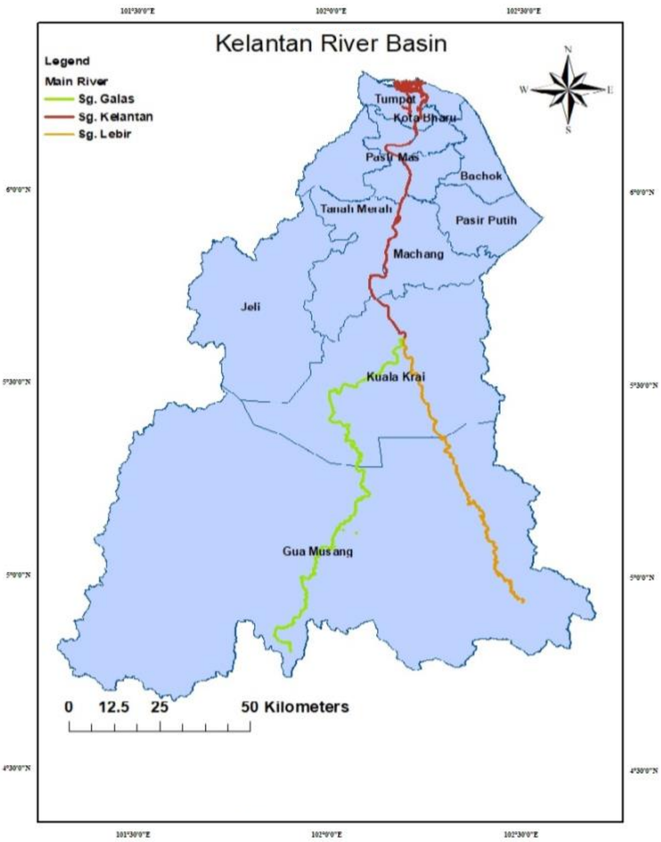


Figure 1. Map of the Kelantan River Basin.

2.2. *Data Acquisition and Pre-Processing*

Five different images from five different periods of time, precisely from the year 2000, and years of 2005, 2010, 2016, and 2020 were overlaid for the study to detect the changes in the environment that have occurred from 2000 until 2020. The images from 2000 to 2010 are taken from Landsat TM, and for 2016 to 2020, the data images were taken from Landsat 8. The images were chosen due to the fact that the time difference was suitable to be used in measuring the analysis of the environmental changes in the area.

The images were undergoing pre-processing step which includes atmospheric correction, image mosaic, radiometric calibration, cloud clearing, and geometric correction. Then, the Landsat TM images were undergoing the co-registration process to the Landsat 8 images for pixel-to-pixel alignment to be available between the data from Landsat TM and Landsat 8 [10]. It is also needed to ensure that the images are spatially aligned or to overlap as close as possible.

2.3. *Remote Sensing Indexes For Environmental Changes Evaluation*

Five remote sensing indexes were used to get multiple factors data of the Kelantan River basins. The indexes are Normalized Difference Vegetation Index (NDVI), Wetness Index (WI), Salinity index (SI), Land Surface Temperature (LST) and Albedo.

2.3.1. *Normalized Difference Vegetation Index*

NDVI index is measured through the comparison of wavelengths in the visible and near-infrared sunlight that were reflected by the vegetations. Near-infrared lights reading will be high if the area is highly vegetated since healthy vegetation will reflect more near-infrared light giving result of high value of

NDVI, whereas area with less near-infrared light absorbed means low vegetation or unhealthy vegetation area [11]. This index is calculated as:

$$\text{NDVI} = (\rho NIR - \rho Red) / (\rho NIR + \rho Red) \quad (1)$$

where ρ is the planetary reflectance of every band in both Landsat TM and Landsat 8 sensors, respectively. R represents Red band and NIR represents near-infrared bands. The calculation shows that NDVI works by calculating the difference between the NIR and the Red band. The bigger the difference, the larger the chlorophyll or vegetation cover of the area.

2.3.2. *Wetness Index*

Wetness index were gained from the calculation of the data of the studied area. Basically, this index shows places that have healthy soil moisture content and water body, and vegetation cover since vegetation are known to keep water within its body and it requires sufficient amount of water to grow and moreover, the wetness index is tested by [12] to be able to distinguish between mature forest and secondary forest. WI's highest value shows the area with highest moisture level, and the lowest value is the area with least moisture level. This index is calculated as in the equations (2) and (3) shown below:

$$WI_{LandsatTM} = 0.0315\rho_{Blue} + 0.2021\rho_{Green} + 0.3102\rho_{Red} + 0.1594\rho_{NIR} - 0.6806\rho_{SWIR1} - 0.6109\rho_{SWIR2} \quad (2)$$

$$WI_{Landsat8} = 0.1511\rho_{Blue} + 0.1972\rho_{Green} + 0.3283\rho_{Red} + 0.3407\rho_{NIR} - 0.7117\rho_{SWIR1} - 0.4559\rho_{SWIR2} \quad (3)$$

2.3.3. *Salinity Index (SI)*

Soil salinization occurs due to many factors, one of them being the alteration of chemical composition of the soil from the usage of fertilizers in agricultural activities. Salinization of soil means the land is degrading due to unhealthy environment caused by human activities [13] and also by natural occurring process, such as the rising level of sea. The purpose of using this index is to study if there is any part of the environment that is undergoing soil salinization, as soil salinization changes impact the biochemical contents of the soil. This index is calculated as:

$$SI = \sqrt{\rho_{Red} - \rho_{Blue}} \quad (4)$$

where ρ is the planetary reflectance, R is the red band and Blue refers to the blue band.

2.3.4. *Land Surface Temperature*

Land surface temperature (LST) is regularly used in remote sensing to assist in understanding the ground thermal behaviour since it is capable of giving the reading of temperature radiated by the surface of the Earth. According to [14], the information extracted from band 6 of Landsat TM for data on the land surface temperature in 2000, 2005, and 2010, and for years 2015 and 2020, data from band 10 of Landsat 8 were retrieved. The data collected are then converted from DN values of its thermal bands, into at-satellite radiance value (T_λ) before it was calibrated for information on the at-satellite brightness temperature (T_b), then the process is then covered with correction of spectral emissivity, following the nature of the studied area.

2.4 *Remote Sensing Environmental Distance Index (RSEDI)*

The remote-sensing spatial distance model (RSSDM) is a method of calculation to solve wide-ranging indexes by following the Euclidean distance measuring method. It is used to measure the total distance between perspectives in multidimensional space as in Eq. (5):

$$dis(X,Y) = \sqrt{\sum_{i=1}^{n}(x_i - y_i)^2} \quad (5)$$

where X and Y are individuals with multidimensional characteristics, and $X = (x_1, x_2, x_3..., x_n)$ and $Y = (y_1, y_2, y_3..., y_n)$.

In the RSSDM method of calculating indexes, the indexes are to be assumed as having different dimensional space, so, when combined, it becomes a multidimensional space. Then, a point was chosen as the worst point, which is also the beginning point for all the indexes' results. After that, the Euclidean distance was calculated from each point to the worst point. If the result is larger, which means it is farther from the worst point, the better the environment quality is. By calculating the distance from other points in the five-dimensional space to the nearest point, the quality of an environment could be expressed.

Based on this model, [14] has established the remote sensing environment distance index (RSEDI) suitable for such study, and its calculation formula is Eq. (6):

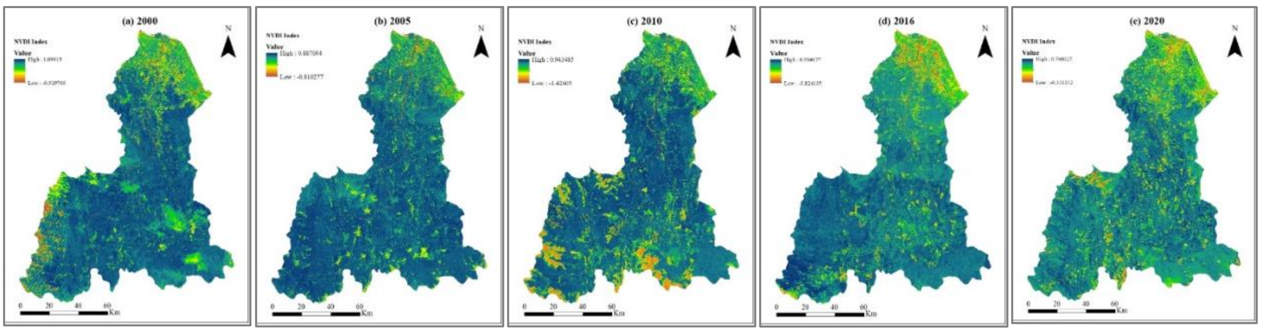
$$RSEDI = \sqrt[2]{\begin{matrix} (NDVI_i - NDVI_{min})^2 - (WI_i - WI_{min})^2 - (Albedo_{max} - Albedo_i)^2 \\ -(SI_{max} - SI_i)^2 \\ -(LST_{max} - LST_i)^2 \end{matrix}} \quad (6)$$

where $NDVI_i$, WI_i, $Albedo_i$, SI_i, and LST_i are values of each spatial position of NDVI, WI, Albedo, and SI, and LST, $NDVI_{min}$, *and* WI_{min} are minimum values of NDVI, WI, $Albedo_{max}$, SI_{max}, and LST_{max} are maximum values of Albedo, SI and LST.

3. Results and Discussion

3.1. Remote Sensing Indexes Analysis

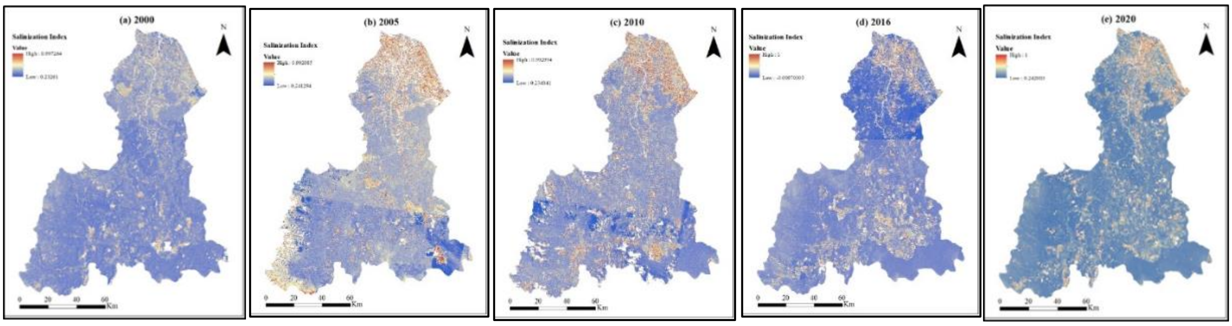
By comparing the yearly results of the NDVI values as in Figure 2, the dynamics of the vegetation health from 2000 to 2020 can be helpful to understand the pattern occurring at each area of the KRB. In the lower side of the KRB, the vegetation cover seems to show an increasing and decreasing pattern, and at the border areas of the KRB, which mostly are thick forest and mountainous area shows consistency in the high vegetation coverage value, meaning the areas are mostly untouched. On the other hand, the upper side of the KRB shows a continuous decline of vegetation cover from 2000 to 2020 which shows that the area is continuously developing, and the ecosystem in the area might be vulnerable.



(a) 2000 (b) 2005 (c) 2010 (d) 2016 (e) 2020

Figure 2. NDVI Index value of Kelantan River Basin.

Based on the soil salinization analysis, it has shown to have high visible light reflectance whereas the near-infrared bands are reflected less by areas with high salinization levels. Relating this to NDVI, and WI, it means that areas that show a low level of NDVI and WI value will show a high level of salinization index. This means that salinization of the soil can be used to predict or produce a model of the soil property of an area. The high value of the salinization index means the area is not in a good condition, but the lower value indicated a healthier of that area. Figure 3 (a) shows that in 2000, soil salinization value ranged from 0.997264 to 0.23261, and a majority of the KRB have low SI value, indicating that KRB is still healthy. However, it is observed, that urban areas of the KRB show medium to high value of the salinization index. The lower area of KRB that was cleared and developed also shows the same result. 2005 SI value ranged from 0.992085 to 0.241294. The range does not show any sudden increase in value, however, Figure 3 (b) shows that the urban area of KRB had an increased area of salinization. 2010 SI value ranged from 0.99294 to 0.234341. This means that over the gap of 5 years, the highest value of SI did not increase drastically, but the area of high valued SI increased, and in the urban area of the KRB, which is at the top of the map shows that the majority of the urbanized areas have a high reading of SI, which shows that the place is developing, and the land is not a healthy environment for vegetation to grow on. In 2016 the SI value ranged from 1 to -0.00070305. More forest clearance was visible and recorded, hence the area with fair to poor salinization level increase in the lower area of KRB. Overall, the soil salinization level of KRB is still within the normal range.



(a) 2000 (b) 2005 (c) 2010 (d) 2016 (e) 2020

Figure 3. Salinization Index value of Kelantan River Basin.

3.2. Environmental Evaluation Analysis

3.2.1. Remote Sensing Environmental Distance Index (RSEDI)

The result of the RSEDI are shown in form of area (km^2) and index value as in Figure 4 and Figure 5, respectively. The changes within the river basin are evaluated and normalized to (0, 1) with a 99% confidence interval evaluated and finally, classified into five-level classes of the environmental quality grades which are poor, fair, average, good and excellent. For Figure 5, the higher value indicates a better environmental quality level of the area.

The year 2000 recorded RSEDI value ranged from 0.977564 to 0.00192319, overall has the best environmental evaluation result as not only it has the least poor areas (310.795 km^2), it also a high level of excellent environment area (6827.9 km^2). The year 2005 recorded RSEDI value ranged from 1 to 0.0011121. Year 2005 recorded the highest level of RSEDI value, and also the biggest excellent area (7229.69 km^2). This means that the environmental health has increased from the year 2000 to 2005 in certain areas, but the poor classified area increased from 310.795 km^2 to 424.601 km^2. The year 2010 recorded RSEDI value of 0.938197 to 0.000518482. The year 2010 also has the highest level of RSEDI value, and also the biggest excellent area (7689.69 km^2). Year 2020 recorded RSEDI value ranging from 0.57352 which is lower by half compared to the year 2005 and the low RSEDI value of 4.90599e^{-11} with a majority of the area classified as Fair (5672.44 km^2), and also Good (4142.35 km^2). It can be observed that overall, 2020 has decreased in environmental quality compared to the previous years where the environmental quality has deteriorated in most places, especially in the urban area of the KRB.

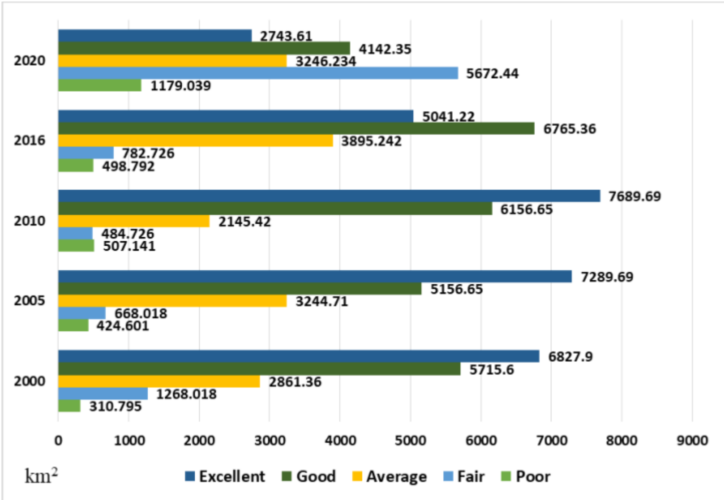
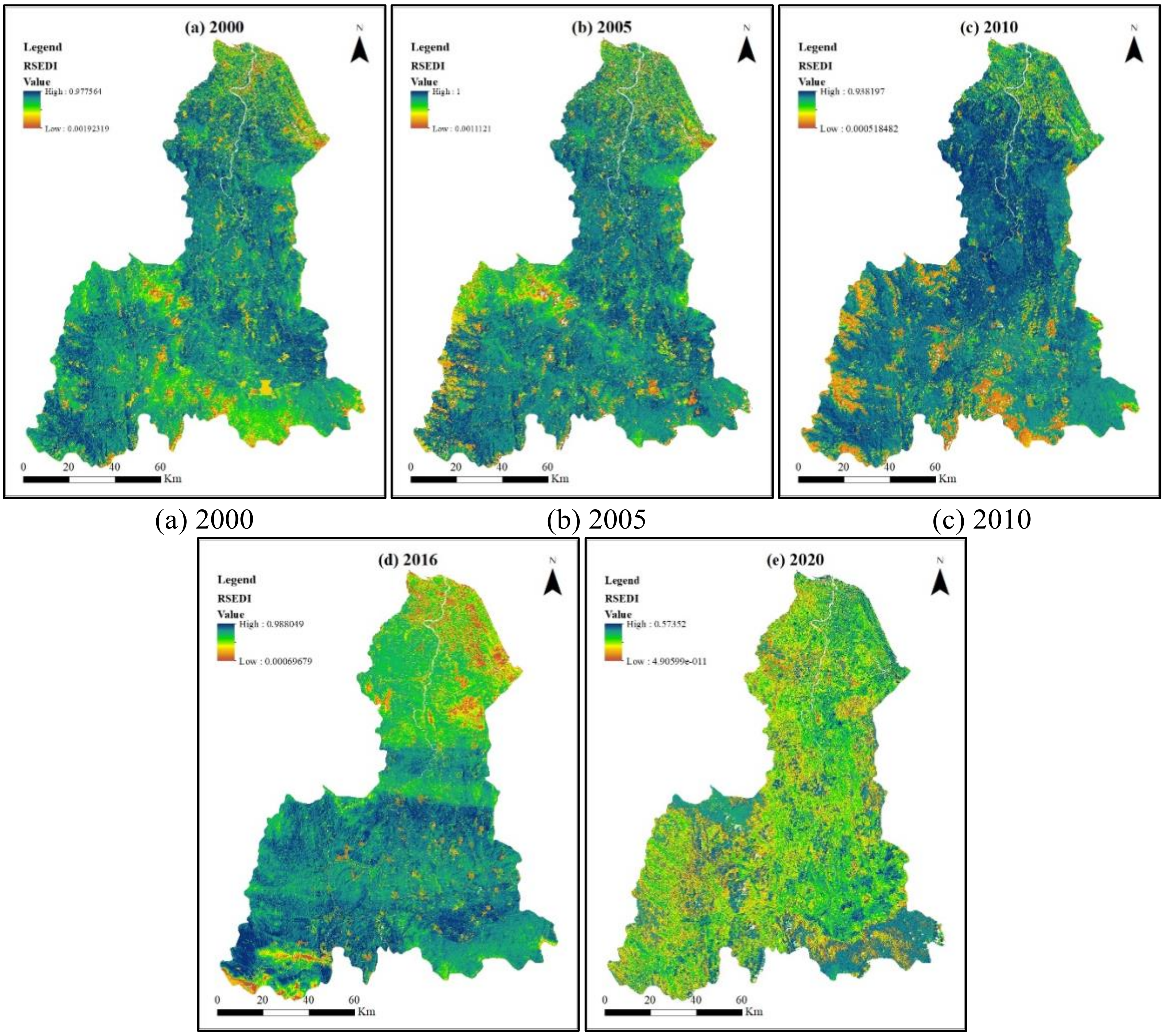


Figure 4. Area of each RSEDI level in Kelantan River Basin.



(a) 2000 (b) 2005 (c) 2010

(d) 2016 (e) 2020

Figure 5. RSEDI value of Kelantan River Basin.

4. Conclusion

This study has used five remote sensing indexes, which are NDVI, WI, SI, LST, Albedo, and also environmental evaluation method, which is RSEDI. The RSEDI has been used to evaluate the environmental quality of the study area and any spatiotemporal changes that occurred starting from 2000 to 2020. The analysis of the results shows how the environment of the Kelantan River Basin has changed over the years. The studies show that the environment was recovering in most of the places in KRB from 2000 to 2010, however, starting from 2010 to 2020, the environmental quality has deteriorated in most places, especially in the urban area of the KRB. It can be observed that the urban areas of the Kelantan River Basin are constantly deteriorating due to continuous development. Nevertheless, the majority of the KRB area is still under acceptable environmental quality level, except for the urban area on the north side of KRB. The government and authorities need to create policies and take actions to control human activities that might lead to creating an unhealthy environment.

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