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Independence and Interdependence of
Sustainable Spaces

PATCH ISOLATION ANALYSIS OF PERI-URBAN NATURAL ECOSYSTEM; THE CASE OF BAHIRAWAKANDA TERRAIN, KANDY, SRI LANKA

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Abstract: Development impact on Natural ecosystems is especially a major problem in the developing world. This is mainly due to the rapid urban developments and inadequate concern of managing natural ecosystems. Urban and peri- urban natural terrain ecosystems are the most vulnerable ecosystems, facing this predicament. This research investigates, using the remote sensing field, the ecological deterioration due to the neglect of natural terrain in the rapid urbanization process. In Sri Lanka, the field of remote sensing is not widely applied in analyzing urban issues. The study focuses on understanding and calculating the ecological impact with reference to Kandy Bahirawakanda natural peri-urban terrain ecosystem based on remote sensing field. There are four ecological impact indexes that can be used to measure the impact using remote sensing technology. This paper uses the patch isolation index as the measuring device to measure the increase of isolation of ecological patches.This approach provides a clear insight in to how a singular ecological patch fragments in to the separate patches and the increase of gaps between those patches. This provides a very good physical and visual indication of one important aspect of the destruction of natural ecosystems.

Keywords: *patch isolation, peri-urban, natural ecosystems, remote sensing*

1. Introduction

Continuous urban expansion in the past two decades has caused a massive decline and loss in the connectivity of urban terrain landscapes leading to significant fragmentation in the urban landscape leading to challenges (Kowe et al., 2021) in maintaining good Urban natural ecosystems. These ecosystems serve the urban population in a verity of ways, both physically and psychologically. For example, these systems may mitigate the heat island effect via evapotranspiration and shading and provide soothing vistas for the inhabitants.

However, in some of the urban areas, these ecological clusters are becoming more and more isolated, less dense and declining in size due effects from transit network developments and legal and illegal encroachments due to property developments(Ranaweera et al., 2021). These threats are global and will lead to problems in urban terrain ecosystem Biodiversity, environmental condition and urban microclimate(Wijayawardana et al., 2020).Of these urban areas, peri-urban areas are the most vulnerable as they still retain significant ecosystems which face development pressure.

Therefore, it is important to analyze this impact. There are four ecological impact indices (increased patch isolation, edge effects, impact of fragmentation and habitat buffer) that can be used to measure the deterioration of peri-urban natural ecosystems using remote sensing technology (Spiesman et al., 2018). This paper analyses the

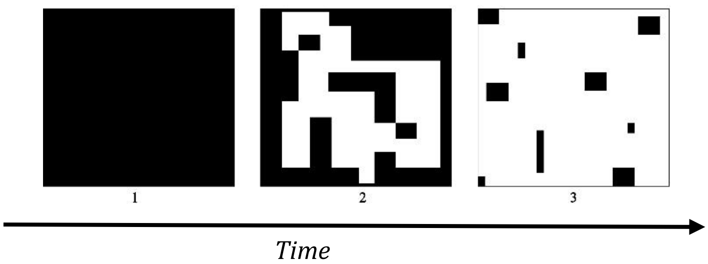

Figure 1- An expansive single natural ecological patch transforms into a number of smaller patches with a smaller overall area and isolated from one another. (Wilcove_et_al_1986.Pdf, n.d.). Black areas represent natural ecological patches.

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impact of fragmentation using the patch isolation index as the measuring device to measure the increase of isolation of ecological patches. This approach provides a clear insight in to how a singular ecological patch fragments into the separate patches and the increase of gaps between those patches.

While a combination of all the four indexes provides a more detailed view of the deferent aspect of fragmentation, increased patch isolation provides a clear and simple view of the separation and increase of isolation of a natural ecological cluster (Figure 1).

2. Literature Review

2.1. PERI-URBAN NATURAL ECOSYSTEMS

While there is no universally accepted definition, peri-urban areas are often defined as transitional zones between rural and urban areas, where the characteristics of both commonly overlap. These areas, for example, feature a wide range of land-use patterns, from agricultural and forestry to residential and industrial applications. Natural Ecosystems in these regions are called peri-urban natural ecosystems (figure 2). (CDKN-PB-Peri-Urban-Ecosystems-India_Web.Pdf, n.d.)

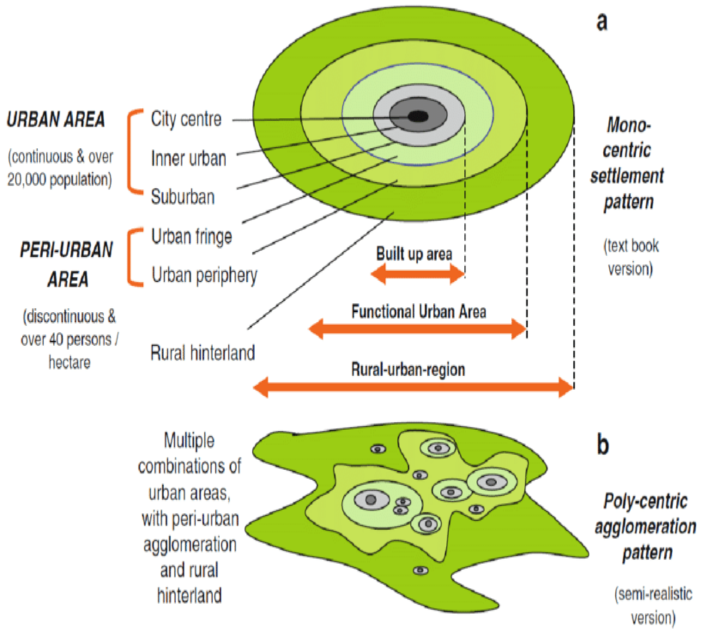


Figure 2- Concept of peri-urban areas and the rural–urban-region (Source: Idczak & Mrozik, 2018)

Peri-urban environments, which can feature valuable protected biotopes, preserved woods, prime agricultural fields, and significant wetlands often provide crucial ecosystem services for city dwellers (Douglas, 2006). From an economic, environmental, and social perspective, peri-urban areas represent very complex territorial spaces. However, despite their complexity, both urban and peri-urban inhabitants rely on the various peri-urban ecosystem services that these places provide (Lee, 2015).

2.2. IMPACT ON PERI-URBAN NATURAL ECOSYSTEMS DUE TO RAPID URBANIZATION

Natural resource consumption in peri-urban areas are increasing due to fast urbanization and increased human activity, putting peri-urban ecosystems at risk of deterioration and loss. (Degradation-and-Loss-of-Peri-Urban-Systems.Pdf, n.d.) The influence of urban growth on peri-urban ecosystems varies depending on whether growth is characterized by expanding sprawl or increasing population density in these areas (Degradation-and-Loss-of-Peri-Urban-Systems.Pdf, n.d.).Urban areas do not function in isolation, but rather as part of a "sphere of dependency" on their surroundings and ecosystems. As a result of the degradation of these ecosystems, ecosystem services that support urban and peri-urban populations are lost.

2.3. INCREASED PATCH ISOLATION

Human land-use activities are transforming the earth's ecosystems, resulting in increased patch isolation (Spiesman et al., 2018). Four ecological impact indexes as mentioned above (Figure 3), can be used to ascertain various aspect of the impact. Of these Indexes, index for patch Isolation is ideal for understanding the increase in isolation of ecological patches (Figure 3).

There are four isolation metrics (nearest-neighbor distance, Voronoi polygons, proximity index, and habitat buffers) that were representative of the various families of metrics commonly used to measure patch isolation in the literature. (Bender et al., 2003a) (Figure 4)

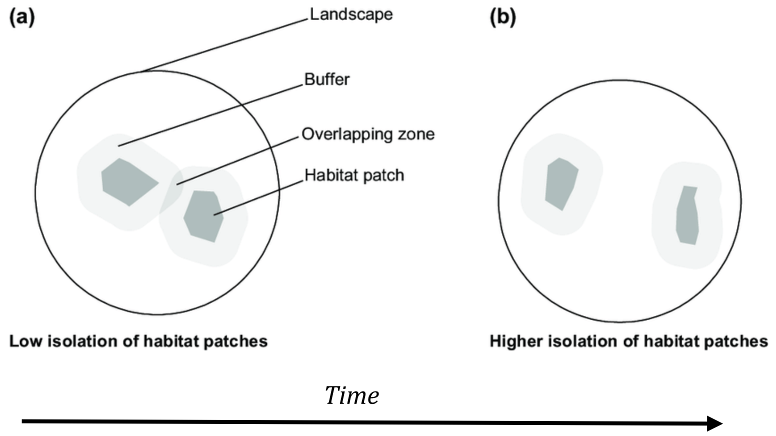


Figure 3- Calculation of the proximity index, showing examples of low habitat isolation (a) and high habitat isolation (b). A buffer zone was created around each habitat patch per habitat type (100 m) (Carrié et al., 2017). The proximity index is the ratio of the area of buffer overlap/total buffer area. In this example the proximity index would be 4% for (a) and 0% for (b).

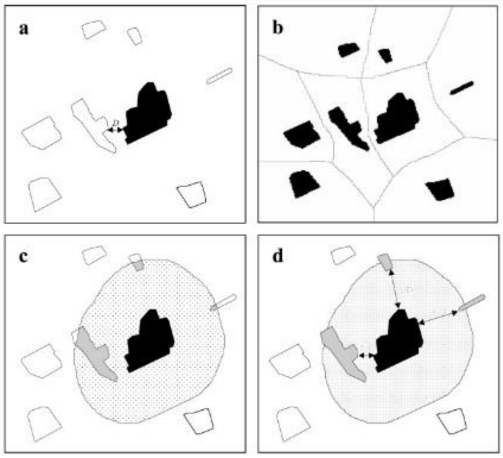


Figure 4- (a) nearest-neighbour distance (D); b) a spatial tessellation which produces many Voronoi polygons around each; c) buffer area, which is the amount of habitat that occurs within a fixed distance of the perimeter of a patch (grey polygons); and d) the proximity index which sums the ratios of patch area/distance (A/D) for all patches of habitat located within a fixed distance of a central patch of interest (source: (Bender et al., 2003a).

2.4. THEORETICAL FRAMEWORK AND RESEARCH METHODOLOGY

The analysis has been done by monitoring three selected ecological patches by using remote sensing and geographic information system (GIS) over a 20-year period in the selected area, from 2000 to 2020. The increased patch isolation index as explained the literature review is used to analyze the selected area. Remote sensing field method were used as the primary analysis method as it has the least-cost path for an analysis of this nature with some inaccessible places. Four components of patch isolation (Figure 5) are used as the measuring tools. Relevant formulas and calculations are shown in the case study section.

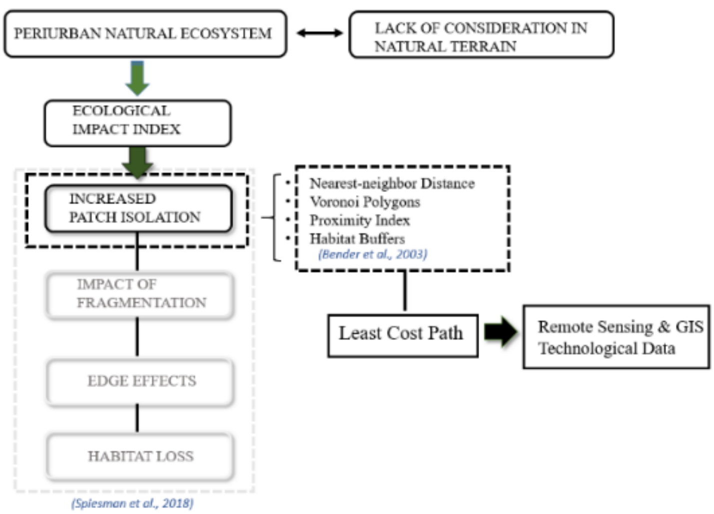


Figure 5- Theoretical Framework (Source: Compiled by Author)

The methodology of the study is formulated (Figure 6) by considering the previous studies done on the similar subject and with the type of data needed for the analysis of the study. The mixed method was used which includes both qualitative and quantitative data. Remote sensing software used to analyze and generate main data.

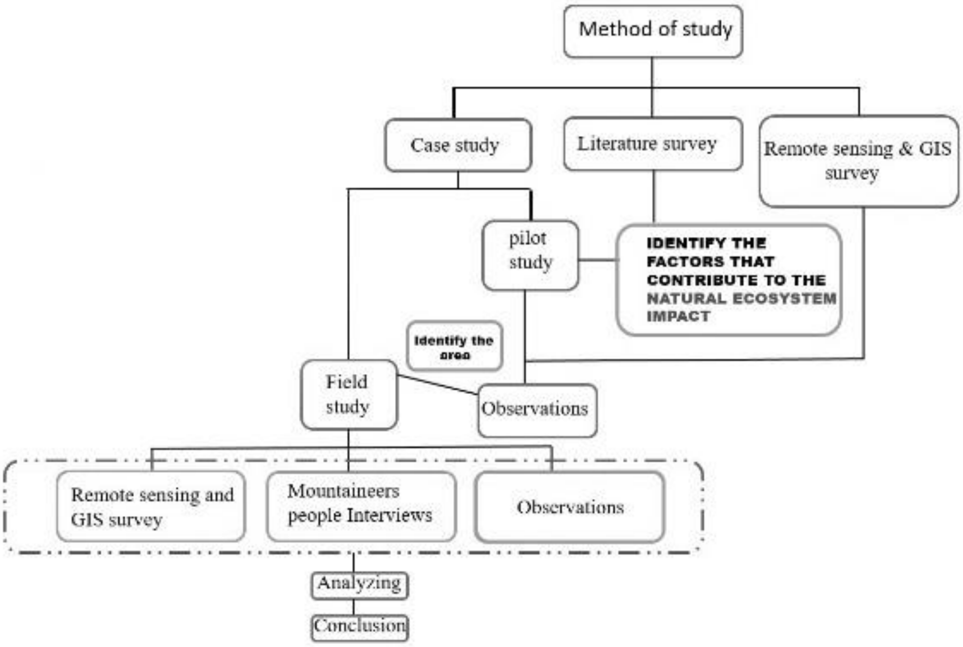


Figure 6- Research Methodology Chart, (Source: Compiled by Author)

The study consists of three components; peri-urban natural ecosystems, ecological impact index and peri-urban natural ecosystem impact. To complete the analysis theses three components, have to be addressed. The First task of the study is to identify a peri-urban natural ecosystems from Sri Lankan context as the case study. Second step is to identify the ecological impact index which are suitable for the analysis. Final step is to quantify the peri-urban natural ecosystem impact using remote sensing.

3. Data Presentation of the Case Study Analysis

3.1. CASE STUDY

Bahirawakanda is a natural terrain consisting of peri-urban natural ecosystems which is in the vicinity of the Kandy town. During the last two decades the ecosystem of this area bored the brunt of the effects of the rapid urbanization process in the Kandy city area. Two and half Square kilometre (2.5km^2) area in Bahirawakanda is chosen for this investigation (Figure 7). Area was limited to this patch only due to time and accessibility constraints which did not allow further investigations in to adjoining several patches.

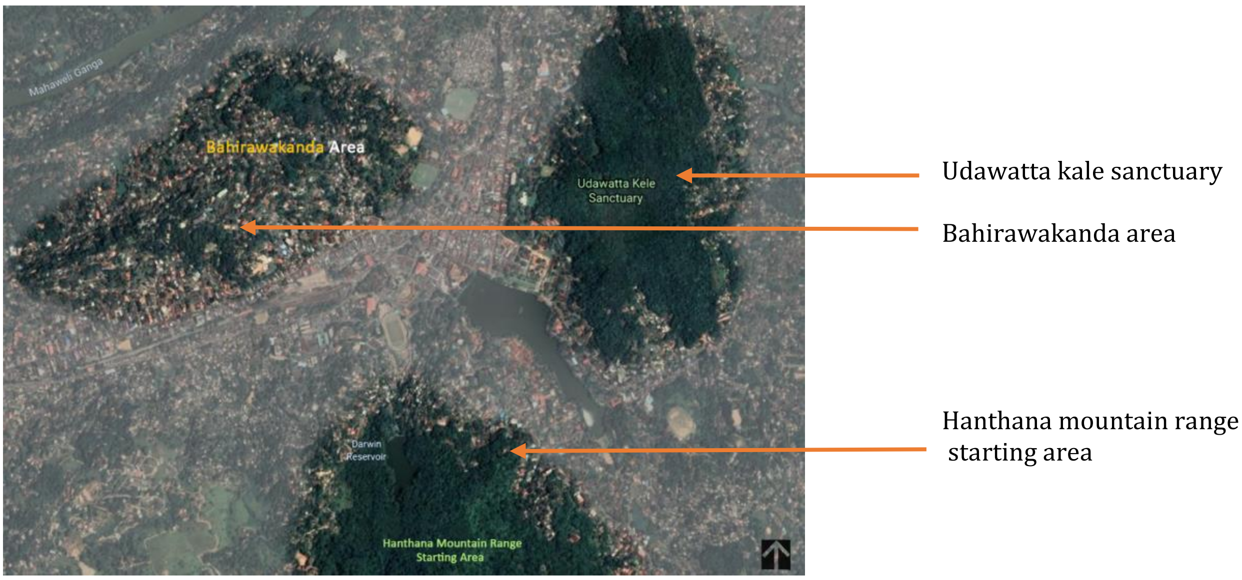
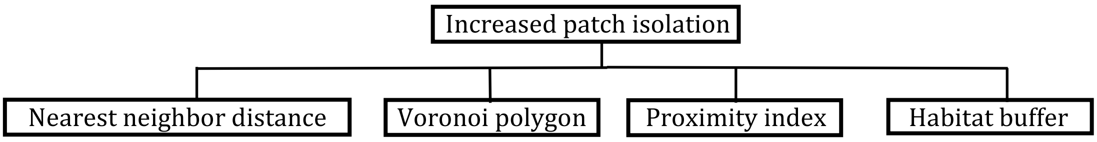


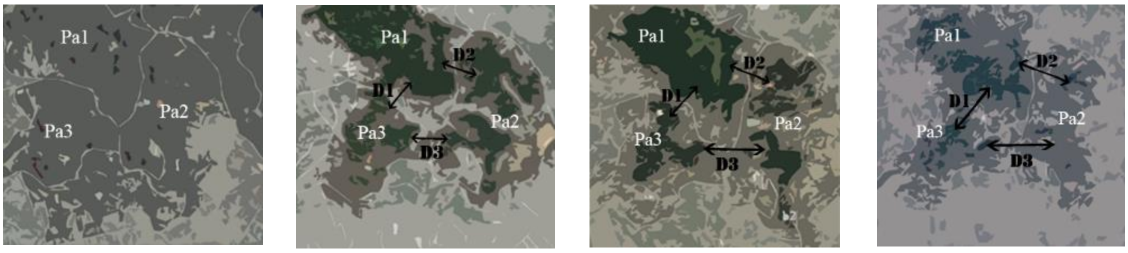
Figure 7- Case study selection criteria (Source: compiled by author)

3.2. INCREASED PATCH ISOLATION



3.2.1. Nearest neighbor distance

The basic distance-based metric, such as the Nearest-neighbor distance, is the first form of isolation measure. The simplest (and most widely used) of all the measures to be looked at is nearest-neighbor distance: it's simply a measurement of the distance between a patch and its closest neighbor. (Bender et al., 2003b) According to the selected area. The distances between Pa1 and Pa3, Pa1 and Pa2, Pa2 and Pa3 are respectively represented by D1, D2, and D3 (Figure 8).



(1) (2) (3) (4)

Figure **8** - Illustrations of the nearest-neighbour distance metrics tested in this study. (1)By 2005, (2) by 2010, (3) by 2015 and (4) by 2020 (Source: Landsat Remote sensing data through, compiled by author)

Considering the figure 8 RS data, Nearest-neighbor distance metrics graphs can be presented as follows (Figure 9).

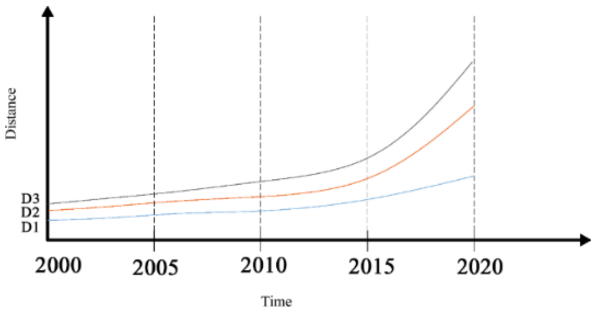
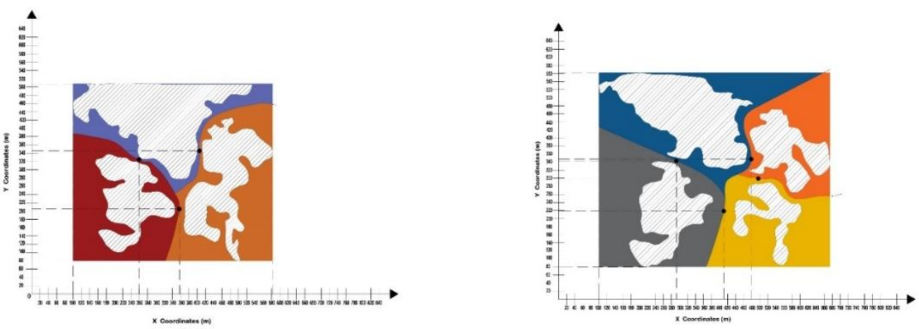


Figure 9 -The nearest neighbour distance deviation. (Source: Above data through, compiled by author)

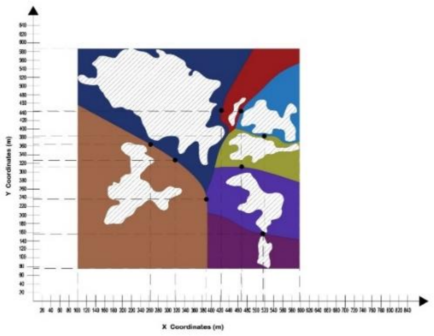
Graph in figure 9 shows that patch isolation has increased in the last two decades. Gap between Pa3 and Pa2 ecological patch distance (D3) has increased rapidly, having the largest distance in 2020 as compared to the two distances D1 and D2. The reason is that Pa2 ecological patch was the most decreased patch from 2000 to 2020.

3.2.2. Voronoi polygon

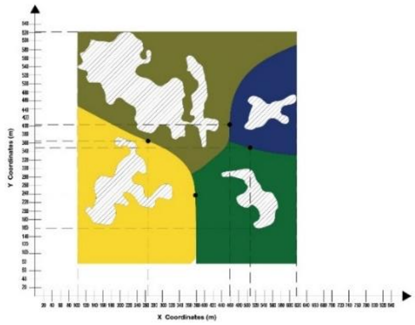
In this analysis the "area of influence" surrounding each patch is defined by calculating the distance between all nearby patches, dividing each distance in half, and utilizing this information to create Voronoi polygons (Bender et al., 2003b). Voronoi polygons are calculated by calculating the distance between all proximate patches in the landscape, and the size of a Voronoi polygon reflects the proximity of neighbouring patches: small polygons indicate many proximate neighbours, whereas large polygons indicate a greater degree of isolation.



(1) (2)



(3)



(4)

Figure 10 - (1) from 2000 to 2005, (2) from 2005 to 2010, (3) from 2010 to 2015 and (4) from 2015 to 2020 Voronoi polygon diagrams (Source: Landsat Remote sensing data through, compiled by author)

Above Voronoi-polygon diagrams show that from 2000 to 2020 polygons sizes were generally increased with an intermediate temporary decrease due to fragmented and vanishing small patches (3 in Figure 10) indicating the increasing patch isolation.

3.2.3. Proximity index

The proximity of neighboring patches within a local neighborhood can be used to define the isolation of a given path. Only patches of the same class (same habitat type) within the chosen neighborhood were considered in the initial proximity index. The island biogeographic perspective on landscape patterns is reflected in this binary depiction of the landscape (McGarigal, 2013). The patch area/Square distance (A/D^2) ratios for all patches of habitat within a defined distance of a central patch of interest are summed together to form the proximity index (Bender et al., 2003b).

Using the remote sensing technology to calculate the patch areas and patch distances the proximity index can be calculated as follows. (The reason for using the minimum distance is because then the highest proximity index can be calculated.)

Equation 1- proximity index equation

$$Proximity\ Index = \sum_{s=1}^{n} \left(\frac{A_{ps}}{D^2_{ps}} \right) \qquad (1)$$

A_{ps} = Area (m^2) of patch *Ps* within specified neighborhood (m) of patch *P.*
D^2_{PS} = Distance (m) between patch *Ps*, based on patch edge –to-edge distance, computed from cell center to cell center.

Following tables (Tables 1, 2, 3,4) show the Proximity Index results for each time frame from 2000 to 2020.

Table 1- From 2000 to 2005 proximity index
(Source: Remote sensing data and above equation no.2 through, compiled by author)

Name of the Patch	Minimum Distance (D) (m)			D^2 (m^2)			Area of the Patch (m^2)	Proximity Index $\sum_{s=1}^{n}\left(\frac{A_{ps}}{D^2_{ps}}\right)$
	Pa1	Pa2	Pa3	Pa1	Pa2	Pa3		
Pa1	-	10.5	12.8	-	110.25	163.84	49502.8	**751.14**
Pa2	10.5	-	24.4	110.25	-	595.36	31179.0	**335.20**
Pa3	12.8	24.4	-	163.84	595.36	-	23250.7	**181.00**

Table 2- From 2005 to 2010 proximity index
(Source: Remote sensing data and above equation no.2 through, compiled by author)

Name of the Patch	Minimum Distance (D) (m)				D^2 (m^2)				Area of the Patch (m^2)	Proximity Index $\sum_{s=1}^{n}\left(\frac{A_{ps}}{D^2_{ps}}\right)$
	Pa1	a	b	Pa3	Pa1	a	b	Pa3		
Pa1	-	19.0	56.2	15.6	-	361.0	3158.4	243.3	48143.2	**446.40**
a	19.0	-	25.6	112.2	361	-	655.3	12588.8	20784.8	**91.02**
b	56.2	25.6	-	55.7	3158.4	655.3	-	3102.5	13395.4	**28.98**
Pa3	15.6	115.2	55.7	-	243.3	12588.8	3102.5	-	22305.2	**100.50**

Table 3-From 2010 to 2015 proximity index
(Source: Remote sensing data and above equation no.2 through, compiled by author)

Name of the Patch	Minimum Distance (D) (m)							D^2 (m^2)							Area of the Patch (m^2)	Proximity Index $\sum_{s=1}^{n}\left(\frac{A_{ps}}{D^2_{ps}}\right)$
	Pa1	a1	a2	a3	b1	b2	Pa3	Pa1	a1	a2	a3	b1	b2	Pa3		
Pa1	-	39.2	18.5	18.0	56.8	208.7	21.4	-	1536.6	342.3	324	3226.2	43555.7	457.9	44234.9	**405.7**
a1	39.2	-	8.5	12.5	92.3	238.4	198.9	1536.6	-	72.3	156.2	8519.3	56834.7	39561.2	6701.7	**142.2**
a2	17.7	8.5	-	22.1	24.5	170	130.6	313.3	72.3	-	488.4	600.3	28900	17065.4	5280.0	**109.9**
a3	18	12.5	22.1	-	111.8	263	185	324	156.2	488.4	-	12499.2	69169	34225	824.7	**9.6**
b1	56.8	92.3	24.5	111.8	-	9.5	100.6	3226.2	8519.3	600.3	12499.2	-	90.3	10120.4	7520.5	**100.3**
b2	208.7	238.4	170	263	9.5	-	204	43555.7	56834.7	28900	69169	90.3	-	41616	1730.1	**19.4**

Table 4- From 2015 to 2020 proximity index
(Source: Remote sensing data and above equation no.2 through, compiled by author)

Name of the Patch	Minimum Distance (D) (m)				D^2 (m^2)				Area of the Patch (m^2)	Proximity Index $\sum_{s=1}^{n}\left(\frac{A_{ps}}{D^2_{ps}}\right)$
	Pa1	a1	b1	Pa3	Pa1	a	b	Pa3		
Pa1	-	60.9	72.5	30.9	-	3708.8	5256.2	954.8	37646.4	**56.70**
a1	60.9	-	92.6	220.5	3708.8	-	8574.7	48620.2	5436.9	**2.20**
b1	72.5	92.6	-	120.8	5256.2	8574.7	-	14592.6	7464.1	**2.80**
Pa3	30.9	220.5	120.8	-	954.8	48620.2	14592.6	-	15035.1	**17.03**

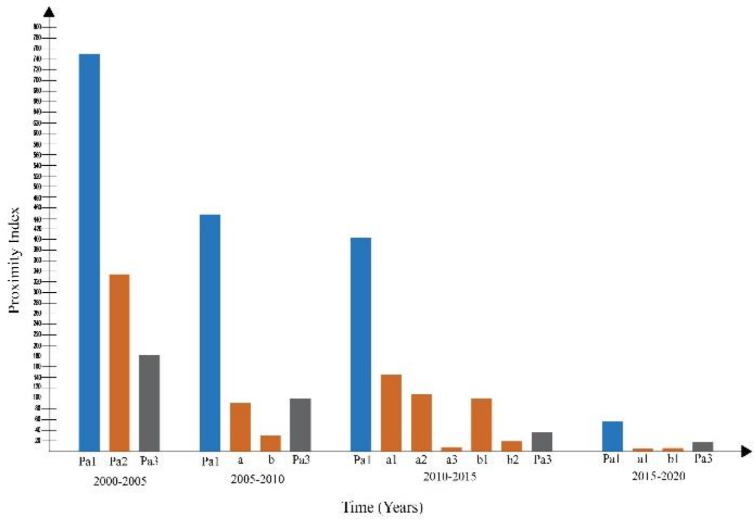


Figure 11 - Graph showing proximity index change from 2000 to 2020 based on the above tables.
(Source: Above analysis through, compiled by author)

According to Figure 11, the ecological patch proximity indices for all three patches (Pa1, Pa2, Pa3) have declined through the study period, with the highest impact on Pa1 with a deduction of 694.47 from 751.17 (the highest value for a patch) to 56.7. The proximity index of Pa2 ecological patch decreased from 335.20 to 5.00. It is the lowest proximity index compared to other two patches. Pa3 proximity index from 2000 to 2015 is lower than the Pa2 and Pa1 proximity indexes, by 2020 it's decreased from 181.00 to 17.03. But in 2020 it is higher than the Pa2 proximity index. Considering the above analysis, Pa1, Pa2 (a, b, a1, a2, a3, b1, b2) and Pa3 ecological patches proximity index decreased rapidly as a whole from 2000 to 2020.

Based on the decrease in proximity index, it can be concluded that the isolation of ecological patches has increased.

3.2.4. Habitat buffer

The amount (area) of habitat within a certain distance of a patch is the fourth isolation metric. The patch is deemed to be less isolated if the area surrounding it is larger. However, this measure must be parameterized by choosing a threshold distance that determines how close the buffer region will be to the source(Bender et al., 2003b). Each Patch (Pa1, Pa2 &Pa3) is analyzed against other 2 in the following sub sections.

3.2.4.1. Pa1 ecological patch

Pa1 patch is considered as the main patch and changes in habitat patches from the year 2000 to 2020 within a certain distance are indicated in Figure 12.

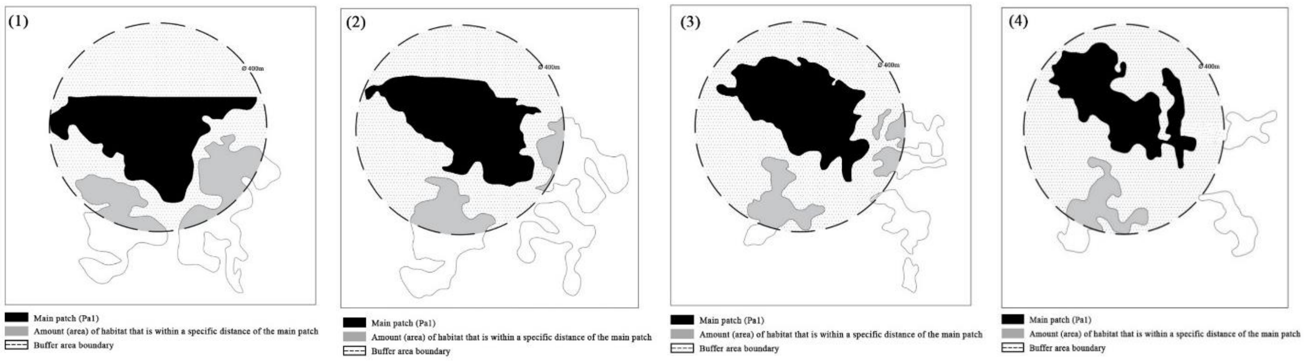


Figure 12- The change of amount of habitat patches that are at a specific distance from the main patch Pa1, (1) from 2000 to 2005, (2) from 2005 to 2010, (3) from 2010 to 2015, (4) from 2015 to 2020.
(Source: Remote sensing and GIS data through, compiled by author)

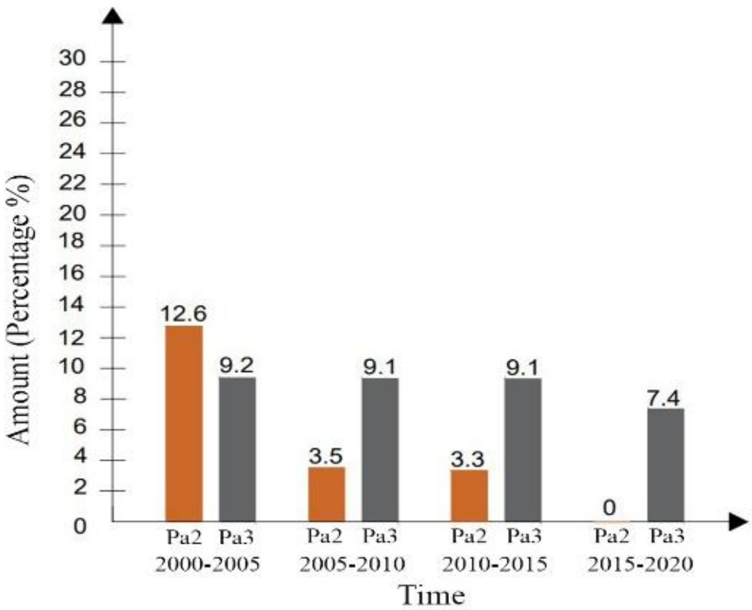


Figure 13 - The change of amount of habitat patches (Pa2 & Pa3) that are at a specific distance from the main patch (Pa1) from the year 2000 to 2020. (Source: Compiled by author)

Using the altered remote sensing pictures in Figure12, it is possible to determine the amount of change in habitat patches within a certain radius of the main patch Pa1. According to this graph, while Patch (Pa3) has reduced by 5.2 % only Patch (Pa2) has completely moved out of the buffer zone (0%) during the period from 2000 to 2020. Pa3 habitat patch amount at a specific distance from the main patch (Pa1) was maintained about 9% until 2015 and then started to decline.

3.2.4.2. Pa2 ecological patch

Pa2 patch is considered as the main patch and changes in habitat patches from the year 2000 to 2020 within a certain distance are indicated in Figure 14.

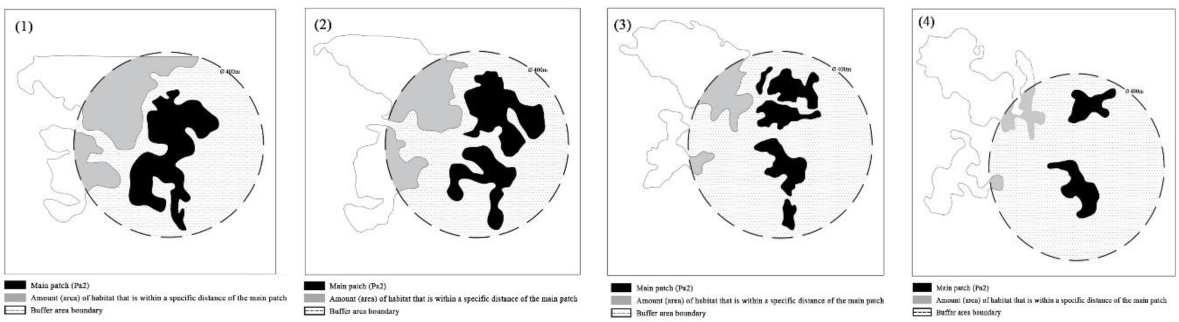


Figure 14 - The change of amount of habitat patches that are at a specific distance from the main patch Pa2, (1) from 2000 to 2005, (2) from 2005 to 2010, (3) from 2010 to 2015, (4) from 2015 to 2020. (Source: Remote sensing and GIS data through, compiled by author)

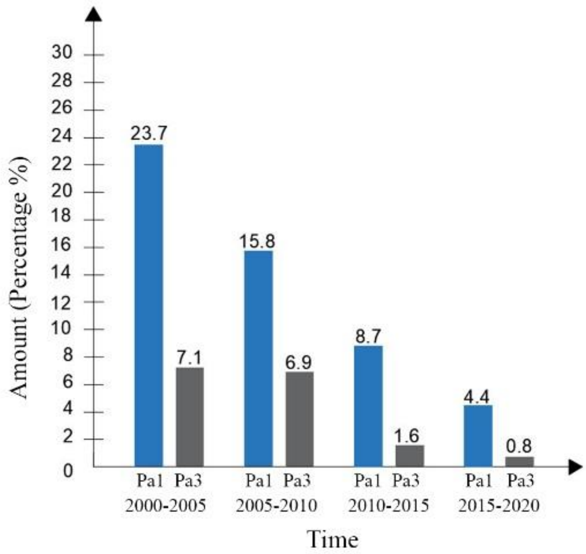


Figure 15 – The change of amount of habitat patches (Pa1 & Pa3) that are at a specific distance from the main patch (Pa2) from the year 2000 to 2020. (Source: Compiled by author)

The change in the amount of habitat patches that are at a specified distance from the main patch (Pa2) can be recognized using the remote sensing data shown in figures 14. It is noted that Pa2 patch has fragmented to several sub patches during this period. The Pa1 habitat patch amount of the specific distance from the main patch (Pa2) was significantly higher than the Pa3 habitat patch amount but both patches (Pa1 & Pa3) have decreased significantly in percentages during the study period (200 -2020). Rate of decline in Pa1 is more compared to Pa3 (Figure 15).

3.2.4.3. Pa3 ecological patch

Pa3 patch is considered as the main patch and changes in habitat patches from the year 2000 to 2020 Within a certain distance are indicated in Figure 16.

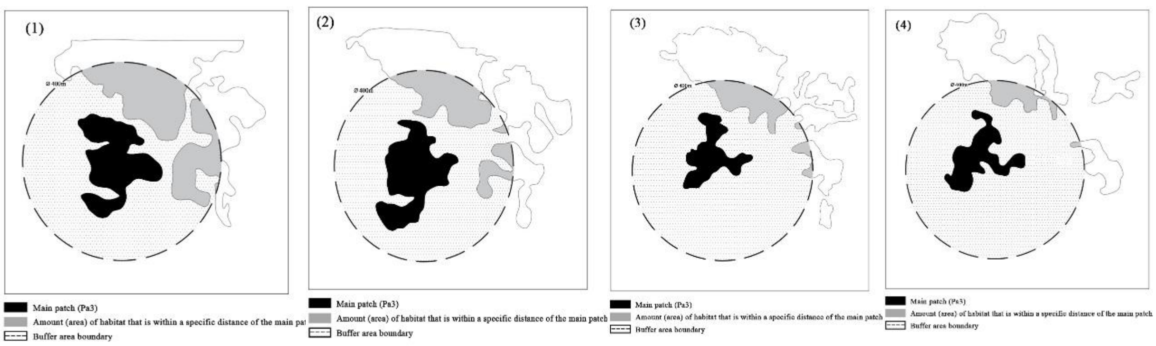


Figure 16- The change of amount of habitat patches that are at a specific distance from the main patch Pa3, (1) from 2000 to 2005, (2) from 2005 to 2010, (3) from 2010 to 2015, (4) from 2015 to 2020.(Source: Remote sensing and GIS data through, compiled by author)

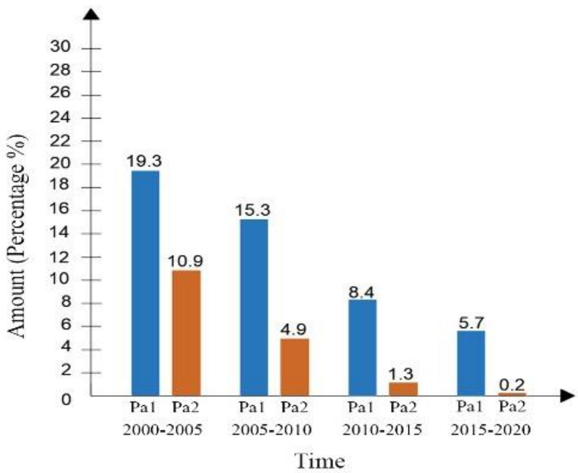


Figure 17 - The change of amount of habitat patches (Pa1 & Pa2) that are at a specific distance from the main patch (Pa3) from the year 2000 to 2020. (Source: Compiled by author)

As per graph in Figure 17 the amount of Pa1 habitat patch located at a specified distance from the main patch (Pa3) is more than the amount of Pa2. Percentages for both patches (Pa1 & Pa2) have decreased in relation to Pa3. However, Percentage decrease in more rapid for the Patch Pa1 (Figure 17) with a difference of 13.6%. While the rate of decrease for Pa2 is less it has practically moved out of the buffer distance with a final value of 0.2 % in 2020.According to the preceding remote sensing and GIS analyzed data, (Figures 12 to 17) the amount of habitat patches within a certain distance of the main patch has decreased consistently and continuously during the study period. Considering that, it's fair to presume that patch isolation has increased.

4. Results

Four key parameters were analyzed in sub section 3.2 of section 3 and the findings are presented in this section (Figures 18 to 21).

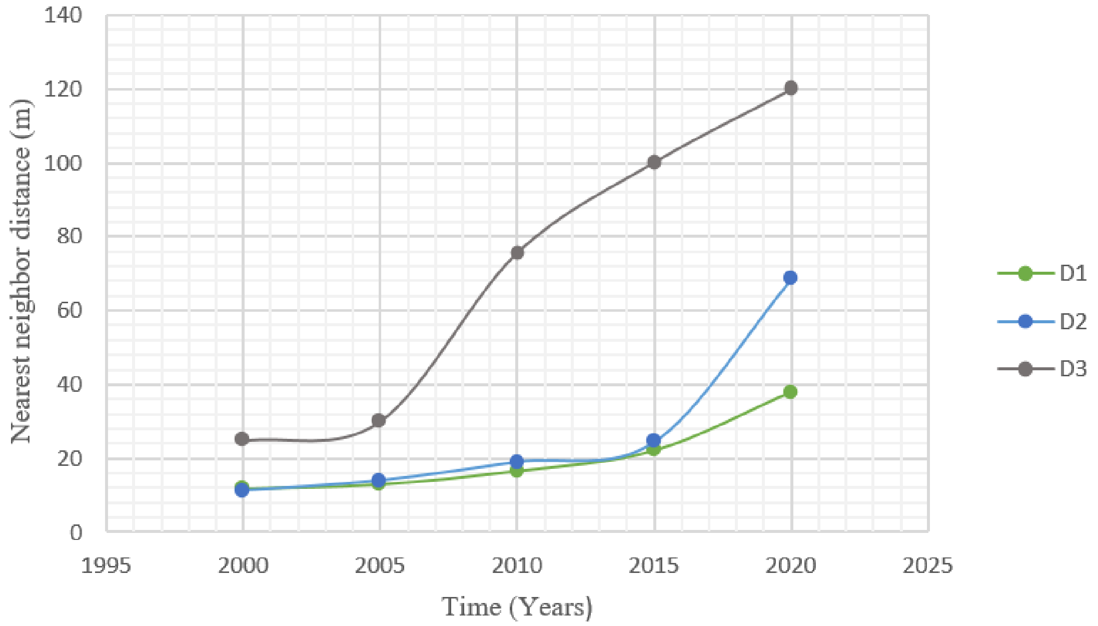


Figure 18 – Changes in the nearest neighbour distance fluctuations of main patches over the study period (2000-2020). (Source: Section 3 analytical remote sensing data through, compiled by author)

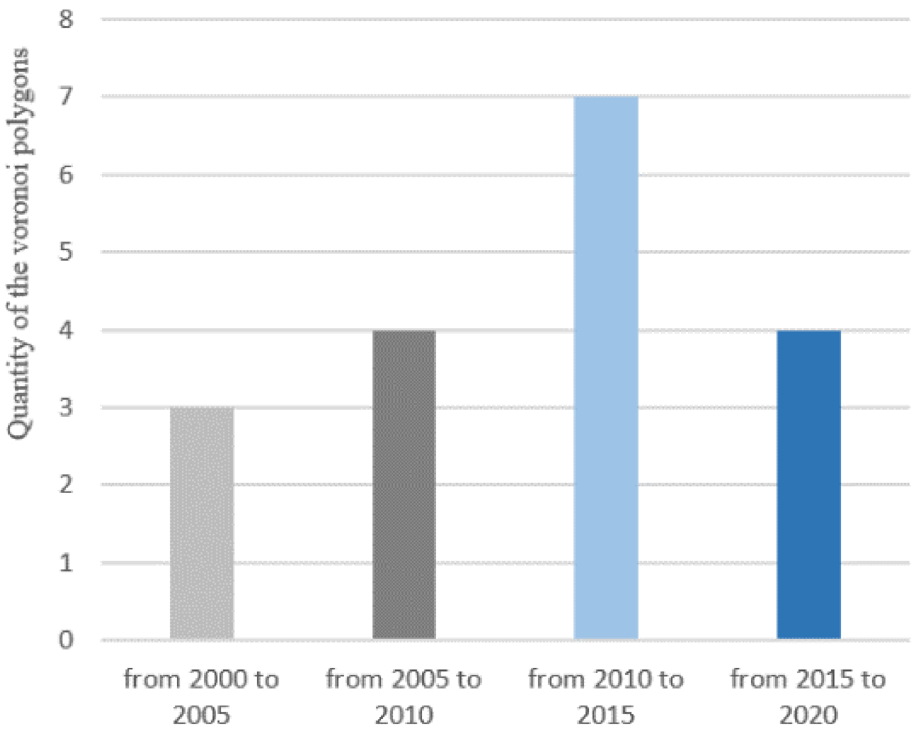


Figure 19 - the variations of the voronoi polygons over the study period (2000-2020). (Source: Section 3 analytical remote sensing data through, compiled by author)

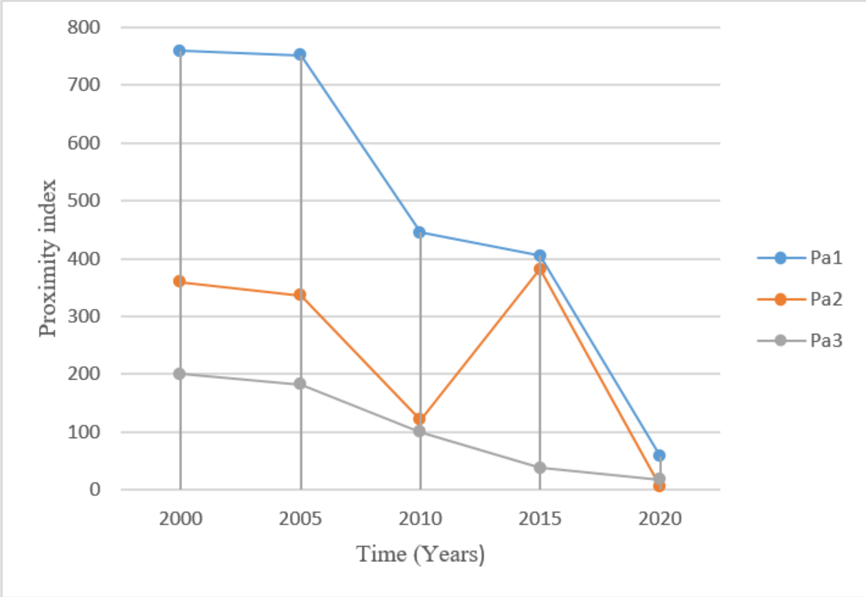


Figure 20 - The overall proximity index fluctuations of main patches over the study period (2000-2020). (Source: Section 3 analytical remote sensing data through, compiled by author)

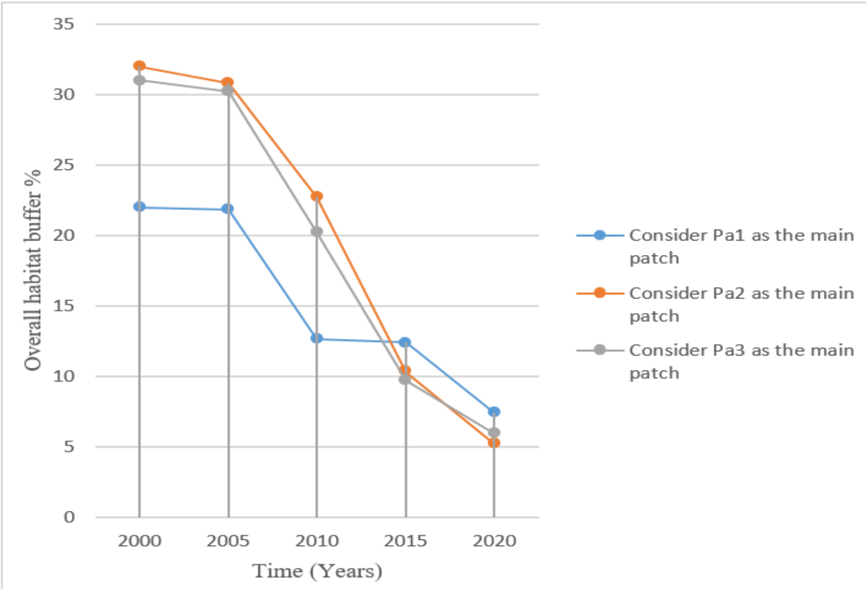


Figure 21- The overall habitat buffer percentage fluctuations of the selected area over the study period (2000-2020). (Source: section 3 Analytical remote sensing data through, compiled by author)

All 4 indicators show an increase in patch isolation. The nearest neighbour distances and the Voronoi polygons have increased (increase of these factors indicates an increase in patch isolation). The overall proximity index and the overall habitat buffer percentage have dramatically decreased (decrease of these factors indicates an increase in patch isolation).

It is observed in Figure 20 that Pa2 patch's overall proximity index has dramatically increased and fallen back between 2010 in 2020. This is due the fragmentation impact in the Pa2 patch has been increasing in those years, and as a result, the patch amount has fluctuated greatly.

Table 5 indicates that there was a moderate ecological impact from 2005 to 2010, but the influence of the four key things has completely changed between 2015 and 2020. During this period the overall nearest neighbour distance has significantly increased with time and the habitat buffer and proximity index have significantly decreased with time. All these are negative indicators. However, the result indicates that the number of Voronoi polygons have increased at the mid period and then decreased again this is not an improvement of the situation and purely due to the fact that several polygon patches have totally vanished. It can be concluded that, due to these negative indicators the ecological patch isolation in that area is significantly increased throughout the analyzed period.

Table 5 - Comparison of the impact of four key parameters of patch isolation on the main ecological patches Pa1, Pa2 & Pa3. (Source: Author)

	From 2000 to 2005			From 2005 to 2010			From 2010 to 2015			From 2015 to 2020		
	Low	Moderate	High	Low	Moderate	High	Low	Moderate	High	Low	Moderate	High
Nearest neighbor distance	✓				✓			✓				✓
Voronoi polygon	✓				✓				✓		✓	
Proximity index			✓		✓			✓		✓		
Habitat buffer			✓		✓		✓			✓		

5. Conclusion

According to this research it is evidence that during the study period of twenty years (2000-2020) there was a significant negative impact on peri-urban natural ecosystems in terms on patch isolation. All four measured matrixes of patch isolation show a negative impact. This will have a deep impact not only on the ecology, wildlife and the soil condition but also on the habitats of the area. As this is also a hilly terrain fragmentation of the ecology may lead to additional impact such as landslides.

This research also shows how the remote sensing field can be effectively used for analyzing issues in urban studies which is not extensively practiced in Sir Lanka. This is very much pertinent to current Sri Lankan context as peri-urban developments, especially new residential developments and sub divisions are carried out with little regard to ecological integrity in the area. While there is some protection for government identified ecological reserves there is practically no identification or protection for general integrity and health of broader ecological network of an area. In future, this type of remote sensing-based analysis can be effectively used as the starting point for identifying and protecting ecological regions or networks in urban and peri-urban areas in the future. This method as the further advantage of analyzing inaccessible and difficult ecosystems like glacier ecosystems, dense forests, montane forests, urban wetlands etc.

Such outcomes shall be integrated into the development plan and proposal of an area or a region. This research was limited to analyzing only one aspect; namely Increased Patch Isolation of the Ecological Indices and limited to a small area due to the time and resource constrains. However, a more comprehensive knowledge of the impact on the ecology can be obtained by carrying out further research on other Ecological Indices in combination with Increased Patch Isolation on a much larger area.

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