Habitat Patch Metrics for Restoring Species Flow in Urban Context; Special Reference to Fragmentation of Colombo Wetlands, Sri Lanka.

Maheshika Ekanayake (maheshi92ke@gmail.com)
University of Moratuwa https://orcid.org/0000-0001-8705-5570

Research Article

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HABITAT PATCH METRICS FOR RESTORING SPECIES FLOW IN URBAN CONTEXT; *Special reference to fragmentation of Colombo Wetlands, Sri Lanka.*

M. EKANAYAKE, J. DHARMASENA, I. AROSHANA[1]

[1] *Department of Architecture, University of Moratuwa, Moratuwa, Sri Lanka*

[1] *maheshi92ke@gmail.com*

ABSTRACT

Background: Colombo wetlands (CW) are the last ecological frontier of the Sri Lankan National capital. CW network has Classified as the most vulnerable ecosystem under the Ramsar convention which suffered from severe fragmentation due to human encroachments and urban densifications. Over the past few decades, 31% of habitat loss resulted in the dislocation and extinction of many species in the wetland forest. Currently, restoration efforts are taking place to rehabilitate the ecology through wetland parks and ecological patches. However, promotion of the species movement is not evident through the development of isolated patches due to fewer considerations of the connectivity in the Urban matrix. Therefore, management of ecological network connectivity is a predominant measure to rehabilitate the CW habitats.

Even though the literature suggests that patch metrics are a vital threshold to predict the species flow rates, lack of scientific research involved in such phenomenon in Sri Lanka. Thus, this study experimentally investigates the role of ecological patch metrics towards connectivity index in Colombo urban wetlands. The study equips remote sensing data 2018 to calculate the wetland patch metrics (Configuration) of Total area (TA), Total edge (TE), Shape Index (SI), Core area index (CAI), and Inter-patch distances (IPD) for 3 sample locations. GIS modeled

Least cost paths within CW boundaries are acquired to calculate the Species flow Index (SFI) per patch for common species.

Results: The Pearson correlation test explicitly proves that ($P< 0.05$) the SFI co-related with TA, TE, CAI, and IPD. A strong positive correlation was observed in patch metrics of TA, TE, and CAI and a strong negative in IPD against SFI. Furthermore, based on connectivity contributions, the study proposed three wetland patch classifications as open patches, closed patches, and active patches the which are rated upon the species flow.

Conclusion: In city-level implications, improvement of total area, perimeter, and reduction of interpatch distance for “active wetland patch” will result in re-gaining the species flow for Colombo wetlands. The overall study is an applied model for restoring urban ecological networks to gain maximize connectivity index to preserve species richness in urban ecological networks.

Keywords. *Landscape fragmentation, Ecological networks, Landscape Connectivity, Patch metrics, Species flow index.*

LIST OF ABBREVIATIONS

CW: Colombo Wetlands

TA: Total Area

TE: Total Edge

SI: Shape Index

CAI: Core Area Index

IPD: Inter Patch Distances

GIS: Geographic Information System.

SFI: Species Flow Index

NDVI: Normalized Difference Vegetation Index

DECLARATIONS

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Consent for publication: Not applicable

Availability of data and material: The datasets generated and analyzed during the current study are not publicly available due to the copyright of the data by the University of Moratuwa, Sri Lanka. However, the data can be acquired from the University on reasonable request.

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Authors' information (optional):

L.Arch. M.Ekanayake – Lecturer (Probationary), Department of Architecture, University of Moratuwa, Sri Lanka

Arch. J. Dharmasena- Senior Lecturer, Department of Architecture, University of Moratuwa, Sri Lanka

L.Arch. N.G.I Arosha -Visiting Lecturer, Department of Architecture, University of Moratuwa, Sri Lanka

1. Background

Today, 54% of the world's population lives in urban areas, a proportion that is expected to increase to 66% by 2050 (United Nations, 2019). However, green space is increasingly encroached upon and fragmented as cities' population density increases (Jongman, 2008). With the expansion of cities, disruption of habitats leads to smaller isolate patches resulted in reducing diversity index and lower provision to biodiversity (Xiu, 2017). In addition, fragmentation can affect the supply and flow of different ecosystem services to people, such as the ability to recreation, carbon storage and climate regulation, erosion, and flood control (Harrison, 2016). Therefore, it has been identified that there is a crucial need for novel strategies to mitigate the fragmentation of habitats within an urbanized area.

The Landscape connectivity measures are depending on the ecological components throughout the urban matrix. The ecological network comprises, components such as core areas, ecological corridors, and buffer zones (McHugh and Thompson, 2011). Such networks play a major role in species movement, biological richness and provide ecosystem services to the urban dwellers (Jongman, 2008). Therefore, the development of ecological network connectivity is increasingly considered a suitable approach to improve the ecological function of green space in the Urban Landscape (Najihah et al., 2017).

As a developing country, Sri Lanka does not possess a knowledge base for connectivity considerations in urban planning and development activities (Miththapala et al., 1996; Uphyrikina et al., 2001) and as a result, many species are threatened due to the isolation of forest habitats. Even though the ecological development proposals are suggested in cities in Sri Lanka, the influence on landscape connectivity is not apprehended. Therefore, there is a crucial need to understand the strategies to maximize the species connectivity via fragmented forest patches in terms of rehabilitating the ecological niches and ecosystem services in Sri Lankan urban areas. Thus, this study comprehends the exiting contribution of the urban ecological patches in the species flow index. The generated research findings served to formulate recommendations to rehabilitate the fragmented forest patch network to maximize the landscape connectivity. Research findings will finally serve as guidance in making national planning and design policies to propose ecological-based (ex; Parks, forest-rehabilitations) development in cities.

1.1 Importance of connectivity considerations

In urbanized areas, the Landscape connectivity is constructed as the degree to which the landscape facilitates or impedes the movement among forest resource patches, (Taylor et al., 1993) which depends on the density of the links (Janssen et al., 2006). Landscape connectivity is crucial for many ecological and evolutionary processes, including dispersal, gene flow, demographic rescue, and movement in response to climate change (Heller, 2009). Therefore, the study focuses on investigating how urban forest patches contribute to maximizing the mechanism of Landscape connectivity.

1.2 The impact of fragmentation and severance on Biodiversity

Habitat loss has large, consistently negative impacts on biodiversity. Habitat fragmentation is a landscape-level process in which a specific habitat is progressively subdivided into smaller, geometrically altered, and more isolated fragments as a result of both natural and human activities as shown in fig.01. This process involves changes in landscape composition, structure, and function at many scales and occurs a backdrop of a natural patch mosaic created by changing landforms and natural disturbances (McGarigal and McComb, 1999).

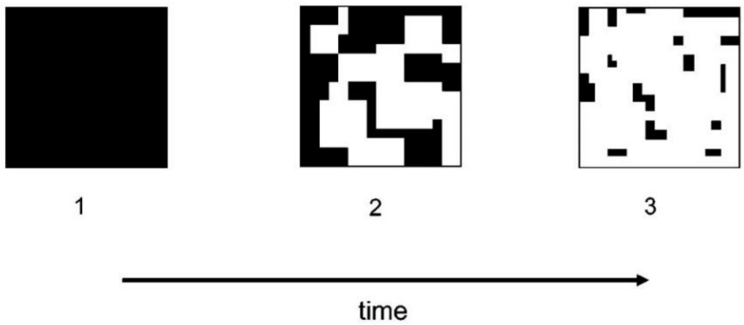


Figure 1; The process of habitat fragmentation, where "a large expanse of habitat is transformed into a number of smaller patches of smaller total area, isolated from each other by a matrix of habitats unlike the original" Source; (Wilcove et al. 1986).

Habitat loss not only reduces the total forest habitable area but also usually fragments the remaining habitat into scattered habitat patches within a wider landscape. Species are varied in their movement ability to successfully cross the matrix between their favored habitat patches (Krosby, 2010) and to cross barriers. Populations of species can be isolated in small gene pools due to the fragmentation. These small isolated populations are less likely to survive and the isolated habitat patches are less likely to be recolonized.

Referring to Gibb's idea, there are three major consequences of fragmentation that resulted in habitat loss and habitat structure alterations by decreasing patch size, increasing edge effect, and increasing patch isolation. (Gibbs, 2007). As to Laurance edge effect is adverse physical and biotic adverse alterations associated with the artificial boundaries of habitat fragments (Laurance et al., 2007). Each of these phenomena decreases the habitable forest area, reduces the rate of species survival, reduction of species diversity, and the inability to carry out genetic inbreeding leading to extinction.

1.3 The impact of fragmentation and severance on ecosystem services

By closely paying attention to the cities and metropolitan areas all over the world, currently, urban forests are highly fragmented into disconnected and scattered patches. In most Cities, the native urban natural environment has been limited to small patches at the city fringes. In a typical society, the health, wellbeing, and economy depend upon sustaining the ecosystem services obtained from the forest cover. Fragmentation can affect the supply and flow of different ecosystem services to people, such as the ability to go for healthy walk-in green surroundings, regulating comfortable and healthier microclimate, and mitigating the natural hazards (Harrison, 2016). Therefore, Landscape connectivity is an important factor for sustaining anthropogenic needs in the urban environment.

1.4 Nexus between Landscape connectivity and ecological networks.

Donaldson and Bennett (Donaldson & Bennett, 2004) defined ecological networks as, the coherent systems of natural or semi-natural landscape elements configured to manage, maintain or restore ecological functions in means of conserving biodiversity, besides providing appropriate opportunities for the sustainable use of natural resources in urban environments. Ecological networks functioned and processes by the level of the landscape connectivity within the matrix. However, as stated by Kindlman and Brural the relationships between landscape connectivity and landscape structure are necessary for predicting the impact of landscape change on its connectivity (Kindlmann & Burel, 2008).

As Taylor et al. stated the landscape connectivity among habitat patches depends on the spatial distribution and the movement of organisms in response to landscape structure'' (Taylor et al. 1993). Therefore, the assumptions are made that the Landscape connectivity is subjective to the structure of the ecological network components; core areas, corridors, and Buffer zones/edges (Bennett & Mulongoy 2006; Jongman & Pungetti 2004), which reflect their existing and potential ecological implications and functions.

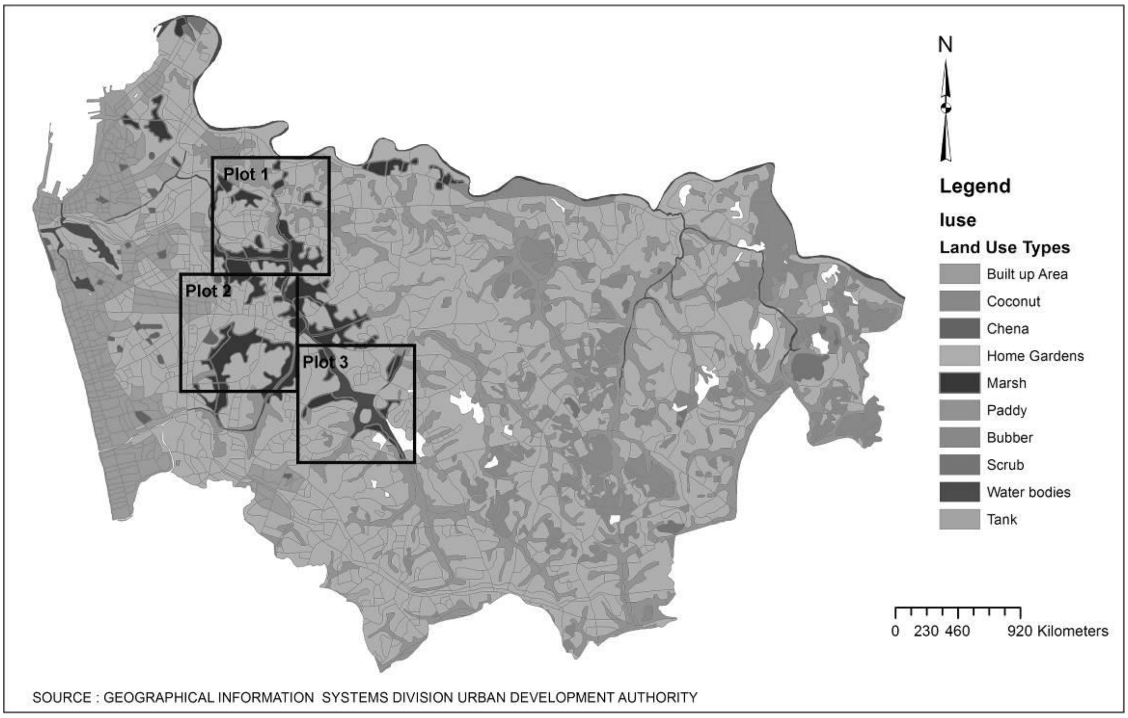
Landscape planning concerns prioritize opinions such as integration of ecological networks into the planning system have been regarded as the spatial expression of the idea of landscape connectivity in planning activities (Jongman & Pungetti,2004). In addition to this, Ignatieva et al. (Ignatieva et al., Stewart & Meurk, 2011) claim that urban ecological networks are one of the most effective tools that could provide physical, visual, and ecological connectivity between urban areas and surrounding natural areas.

IUCN (International Union for Conservation of Nature), National Wetland Directory for conservation and preservation purposes of wetland in Sri Lanka informs an urgent need to accelerate the conservation of the wetlands in Colombo which is facing threatened status (IUCN,2006). The Marsh consists of three interconnected marshes, Kolonnawa marsh, Kotte marsh, and Nawala marsh approximately about 400 ha. These marshes and swamp forests are extremely important in ecosystem services and flood detention in Colombo urban context which was also accredited as a RAMSAR wetland site in 2018.

The land reclamation activities and landfills for large-scale housing schemes due to the increasing urban population are considered as the major threats to the CW. The fragmented and isolated wetland patches resulted in species loss and extinction. In addition, researchers have found that the native, grass-dominated marshy habitats of the wetland are rapidly transforming into a habitat with shrubs and small trees due to a significant reduction in the water-holding capacity of the wetland (Hettiarachchi et al, 2014). There are no proper machinimas to address the biodiversity restoration measures through the Landscape connectivity. Thus, informs the need for investigation of the connectivity measures for the Colombo wetland network will contribute to mitigate the threat status to biodiversity and to preserve the ecosystem services.

2. Methodology

The selected case study area was surrounded by human land use areas such as commercial areas, residential areas, and paddy fields, and chena cultivation plots. Wetland areas contain extensive reed beds and *Annona glabra* dominated scrubland habitats. To measure the connectivity 3000m x3000m Similar plots were chosen from the three interconnected mashed of Colombo wetlands as shown in fig.02. One Plot considers as one unit of an ecological network to quantify the patches and to access the connectivity measures.



Figure; 2 Representation of plot slection from the wetland habitats in Colombo district, Sri Lanka

Figure 3; Plot 1, Kollonawa Marsh

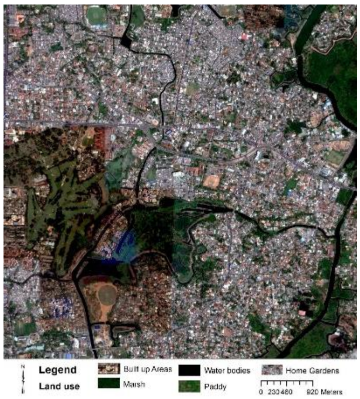


Figure 4; Plot 2, Nawala Marsh

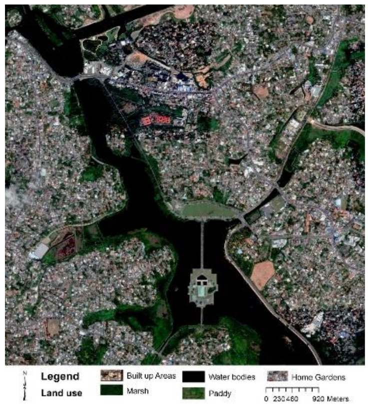


Figure 5; Plot 3, Kotte marsh

2.1 Quantifying Ecological networks

Following the study of McGarigal "Patch metrics" has been identified as an effective measure to calculate the structure of the Ecological network. (McGarigal, 2013). Patch metrics are algorithms that quantify specific spatial characteristics of patches or classes of patches within the entire Landscape (McGarigal, 2013). These metrics fall into two general categories, one that quantifies the composition of the mosaic without reference to individual patch attributes, the other one that quantifies the spatial configuration, requiring spatial information for their calculation (McGarigal and Marks 1995).

This study encompasses the configuration matrices to quantify the individual patches in the ecological network. The Configuration metrics identify the spatial pattern and spatial character of the individual patches. These metrics are spatially explicit at the patch level metrics, not at the class level (land use typologies) or landscape-level metrics. As to McGarigal, The configuration metrics are as follows, (McGarigal, 2013)

2.1.1 Area & Edge metrics

A matrix that conveys considerable evidence of species abundance and acts as an indicator for habitat fragmentation.

Total area- A patch that has a high area had a great deal of ecological utility in itself. There is considerable evidence for species richness and abundance strongly correlated with patch size (Turner et al, 2001).

$$P_{TA} = \text{area } (m^2) \text{ of}$$

Equation 1; Patch area; Source (McGarigal, 2013)

Total edge -For example, one of the most dramatic and well-studied consequences of habitat fragmentation is the increase of the proportional abundance of edge-influenced habitat and its adverse impacts on interior sensitive species (Turner et al, 2001).

$$P_{TE} = \text{perimeter (m) of patch}$$

Equation 2; Total edge; Source (McGarigal, 2013)

2.1.2 Shape Metrics

Patch shape can influence inter-patch movements such as mammal migration (Buechner, 1989) and ungulate foraging strategies (Forman and Godron, 1986). The primary ecological consequence of shape seems to be related to the edge effect.

Perimeter-area ratio -As stated by Turner (Turner et al., 2001) the complexity of patch shape will contribute to high edge effect and reducing the species density in the habitable area.

$$P_{SI} = \frac{\text{area } (m^2) \text{ of patch } P_{TA}}{\text{perimeter (m)}}$$

Equation 3; Perimeter area ratio; Source (McGarigal, 2013)

2.1.3 Core Area Metrics

The patch core area is the area unaffected by the edges of the patch (McGarigal, 2013). While a patch may be large enough to support a given species, it still may not contain enough suitable core area to support the species.

Patch core area index-The percentage of the patch that is comprised of a core area. Patches with greater shape complexity have less percentage of the core area.

$$P_{CAI} = \frac{\text{Core area } (m^2)}{\text{area } (m^2)} (100.)$$

Equation 4; Core area Index; Source (McGarigal, 2013)

2.1.4 Proximity Index

Isolation of a particular path can be formulated in terms of proximity of neighboring patches within a local neighborhood. The original proximity index was formulated to consider only patches of the same class (same habitat type) within the specified neighborhood.

Inter-patch distance - Inter-patch distance calculates the direct distance between two patches or patch centroids.

$$P_{IPD} = \text{Direct distance (m) of patch Pa. and Pb}$$

Equation 5; Inter-patch distance; Source (McGarigal, 2013)

To carry out the quantification, Colombo wetland networks were considered as three individual entities (plot 1,2, and 3) and the patch metrics were calculated using 2018 Geographical Information System (GIS) data.

2.2 Landscape Connectivity modeling and quantification.

GIS stimulation method was equipped to measure the connectivity index. The GIS tools are widely used to predict locations of wildlife movement corridors in complex landscapes (Rainey, 2009). Among all the methods Least-cost path method is a high incorporated tool used by numerous researchers in connectivity modeling of habitats.

2.2.1 Least-cost path methodology

The Least cost path method was adapted to measure the wildlife movement paths among the wetland patches. To calculate the least cost path through GIS; two computational stimulated layers have to be generated. One is the source layer which indicated the wetland patches and the second one is the resistance layer which indicates the land use, terrain weighted values. In GIS Least cost algorithm calculated the cumulative cost to move from one cell to another according to the resistance layer (Park, 2011).

The least-cost path algorithm calculates the best connective path between the patches and stimulates the suitable habitat for wildlife. In generating the input resistance layer, the weighted values for land use and terrain were applied. Table.01 showcases the ratings for weighted value which have acquired referring to the literature (Lee, Chon, & Ahn, 2014). High weighted values have a high resistance to the species movement and low weighted values have a low resistance to species movement. By weighted values, the cost surfaces have been produced.

Table 1; Weighted value table for Least-cost paths ;Source; (Lee et al., 2014)

	Component	Weighted value (1-90)	Influence (%)
	Marsh areas	10	
	Paddy areas	30	
Land use types	Chena cultivated areas	30	50

	Water bodies	50	
	HomeGardens (Residential)	70	
	Built-up areas (Commercial)	10	
Slope	00-05 m	10	50
	05-10 m	30	
	10- 15 m	50	
	15 -20 m	70	
	20- 25 m	90	

As shown in Fig.15 the map shows the cost-surface values for the Colombo area in grayscale. The darker color areas show high-cost paths (hard) and lighter color areas show low-cost paths (easy) for species movement.

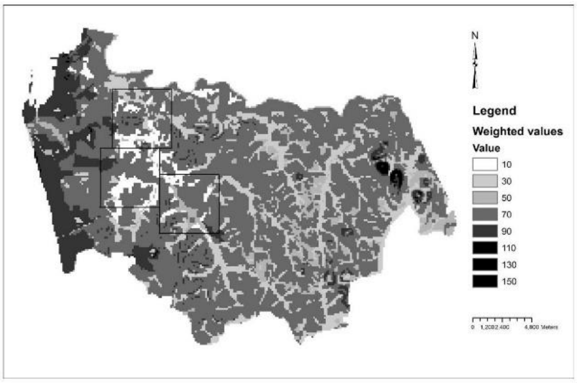


Figure 6; Resistance values GIS generated map; Source; Geographical information systems division UDA. Source Edited by Author

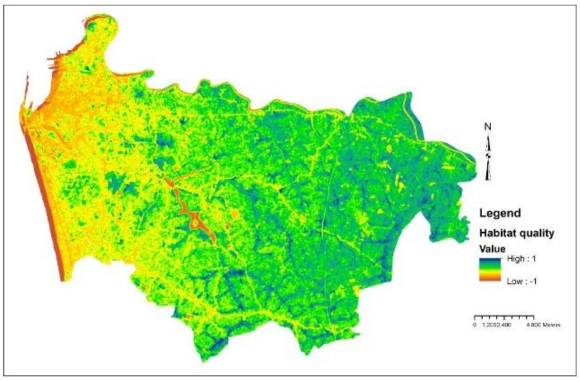


Figure 7; NDVI map for vegetation index Source; Geographical information systems division UDA. Source Edited by Author

To generate Least-cost paths the assumptions are made that the species move from wetland patches (source layer) to one quality habitat. Species destination patches were selected by analyzing the Normalized Difference Vegetation Index (NDVI) as shown in fig.16. NDVI algorithm identifies rich habitat patches within the network. Similarly, the study was hypothesized that species are more likely to move to rich habitat patches referring to the theory

(Laurance, 1997) which theorizes that the population disperses out from the major source into sink populations. Accordingly, habitat quality patches were selected from each plot and destination points were marked. Generation of cost paths stimulated through GIS from CW patches to NDVI stimulated quality patch.

After generating species flow paths towards the wetland patches; the method quantifies the number of Species flow paths per wetland patch to calculate species flow index (SFI). Accordingly, the assumptions are made that the higher number of cost paths indicates a high landscape connectivity index, and a low number of cost paths indicate less landscape connectivity index. Therefore, the study has been carried out to investigate to understand the contribution of urban wetland patch metrics to landscape connectivity. The species are considered to be faunal species that abundance in the Colombo wetland habitats.

3. Results and Discussion

The data analysis was carried out to find the relationship between Ecological network patch metrics and Landscape connectivity. Therefore, the predictor variable has been taken as the patch metrics, and the experimental variable was taken as landscape connectivity index. The study analyzed how Landscape connectivity (cost paths) changes with patch metrics according to the following criteria,

- SPI change with Patch area and Edge metrics.
- SPI change with Shape metrics.
- SPI change with Core-area metrics.
- SPI with Proximity index.

3.1 Least cost paths generated for selected Case study areas

The results were analyzed using graphical representations for each plot under the selected patch matrix criteria.

Plot 1- Kollonnawa marsh

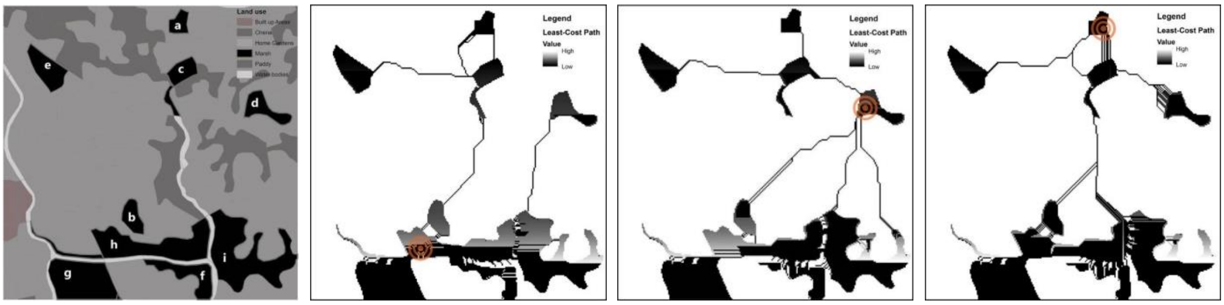


Figure 8; 1) Map represent Land use pattern of Kollonnawa marsh. i),ii) and iii) represent the Least cost paths generated for quality patches

Plot 2 –Nawala marsh

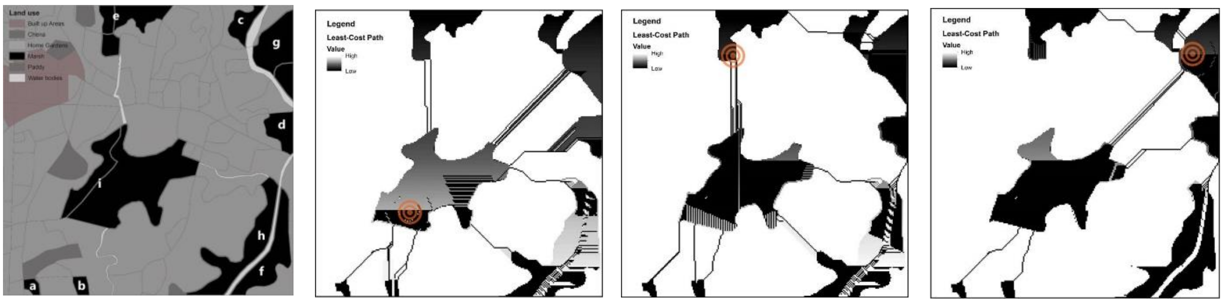


Figure 9; 2) Map represent Land use pattern of Nawala marsh. i),ii) and iii) represent the Least cost paths generated for quality patches

Plot 3- Kotte marsh

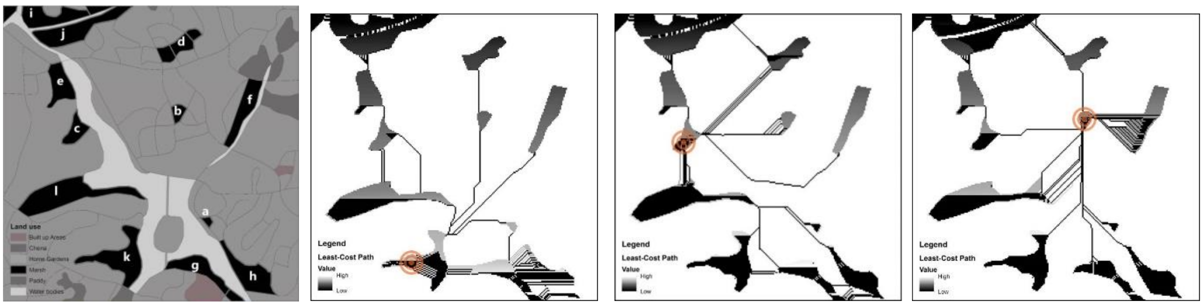


Figure 10; 3) Map represent Land use pattern of Kotte marsh. i), ii) and iii) represent the Least cost paths generated for quality patches

3.2 Quantifying the contribution of the area and edge metrics on Landscape connectivity

3.2.1 Species flow index and the Total area metrics.

The investigation was carried out to understand the co-relationship between the TA and the species likely to move. Accordingly, fig.11, shows the SFI differs from the TA in-between wetland patches.

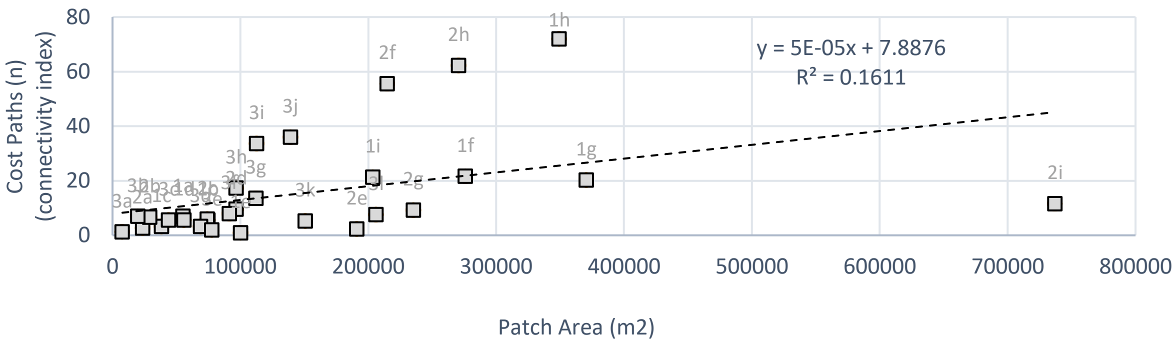


Figure 11; The garph represent the number of cost paths varied with the Patch Area for plot 1, 2 and 3

The results explicitly prove a mean positive co-relation within two variables. The correlation analysis between variables p=0.028 ($P \leq 0.05$) evident a significant positive relationship (R^2=0.401) between the two variables. The patches 2i, 1g, and 2g show a high degree of unnormalized distribution. Looking at the Landscape pattern and the matrix it is evident that these patches have a high patch area and low connectivity which seems to be somewhat isolated in the matrix and hard to cross. Most of the patches which have a low area and high index evident the locational advantage has taken from the species. Thus, the Analysis emphasis that the patch TA is an important metric to increase the species movement. However, this variable can be dependent on the availability of the core area within the patch.

3.2.2 Species flow index and the Patch perimeter metrics.

Fig. 12 evident the co-relationship between the Species flow index and the total edge perimeter metrics.

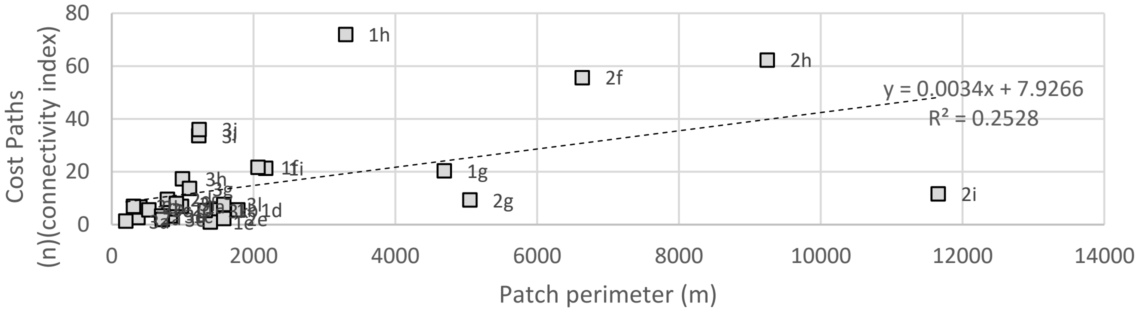


Figure 12; The garph represent the number of cost paths varied with the Patch Area for plot 1, 2 and 3

SFI and TE evident P= 0.005 signification medium positive relationship with the value of R^2= 0.503. However, as TA is an expression of TE, similarly the analysis shows that 2i, 1g, and 2g shows deviation from the normal distribution. The results inform that the high TE of patches nearby contributes to high species movement.

3.3 Quantifying the contribution of shape metrics on Landscape connectivity

This section contains the results of the study in terms of species flow index and the perimeter area ratio. Fig.13 evident the distribution of SFI which plotted over the SI.

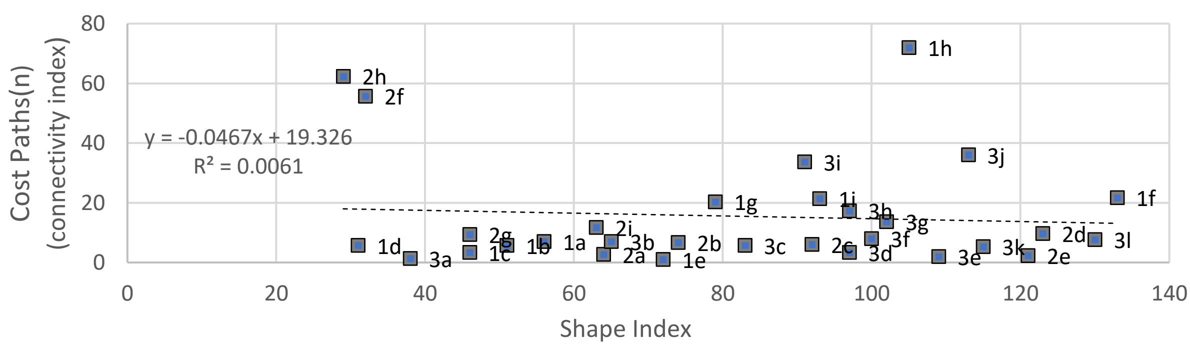


Figure 13; The graph represents the number of cost paths varied with the Shape index for plot 1, 2 and 3

Fig.13 shows that there is no significant connection between SFI and SI due to the multi-dependability of the shape complexity. When the SI increases the complexity of the shape drops. Normally the "edge effect" happens when the complexity of the patch increases. When the edge effect happens, the buffer zones of the ecological networks increases and the core areas drop. Therefore, the inhabitable areas for the species are limited.

2f and 2h patches with high shape complexity show a great contribution to landscape connectivity. The assumptions are made that here the species accessible edge towards the patch is to be comparatively higher. The patch 1h has a high SI is that this patch may be more preferred by most of the species, as this patch has a higher core area and lower buffer zones. Thus, it is apparent that the shape matrices can have a two-dimensional impact on the species flow and landscape connectivity.

3.4 Quantifying the contribution of Core Area metrics on Landscape connectivity

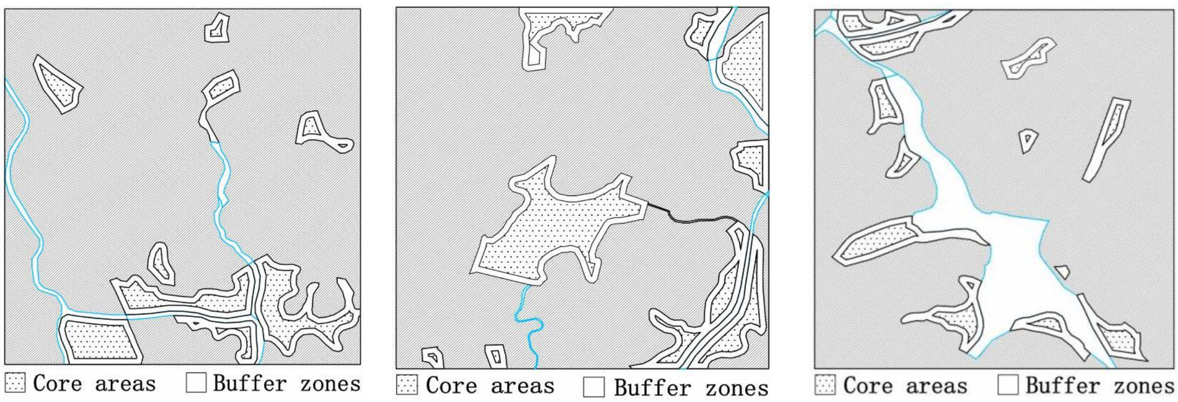


Figure 14; Indication of Core areas and buffer zones for plot 1, 2 and 3

The predicted buffer zones and core areas (Bennett & Mulongoy,2006) are represented in fig.14. Accordingly, the co-relationship between SFI and Core area Index is shown below.

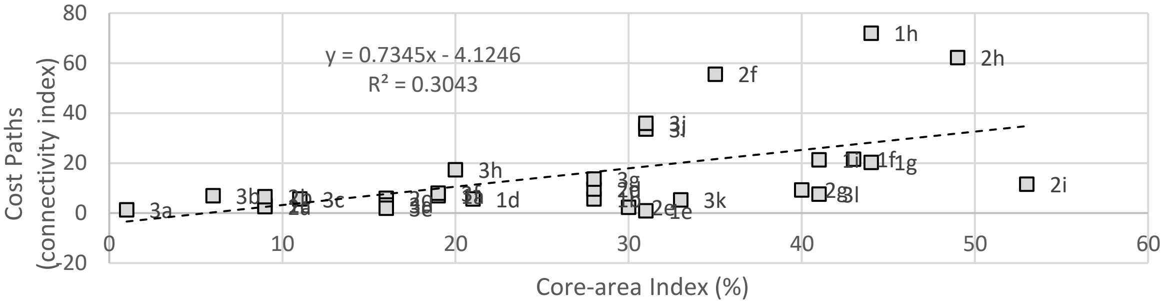


Figure 15; The graph represents the number of cost paths varied with the Core area Index for plot 1, 2 and 3

The two variables evident high significance of P= 0. 002 with medium positive co-relationship with R^2=0.552. The patches 1h, 2h, and 2f with high core areas evident high SPI towards the patches whereas 3a and 3b with low core areas evident low SPI. Considering the CAI the assumptions can be made that there is a special attraction of species for wetland patches that have a higher core area. The metapopulation model theory (Laurance, 1997) can be related to justify that the higher density of species flows from the major source into sink populations.

3.5 Quantifying the contribution of proximity Index on Landscape connectivity

The following figures represent the identified links between the patches and the distance calculated among the patterns.

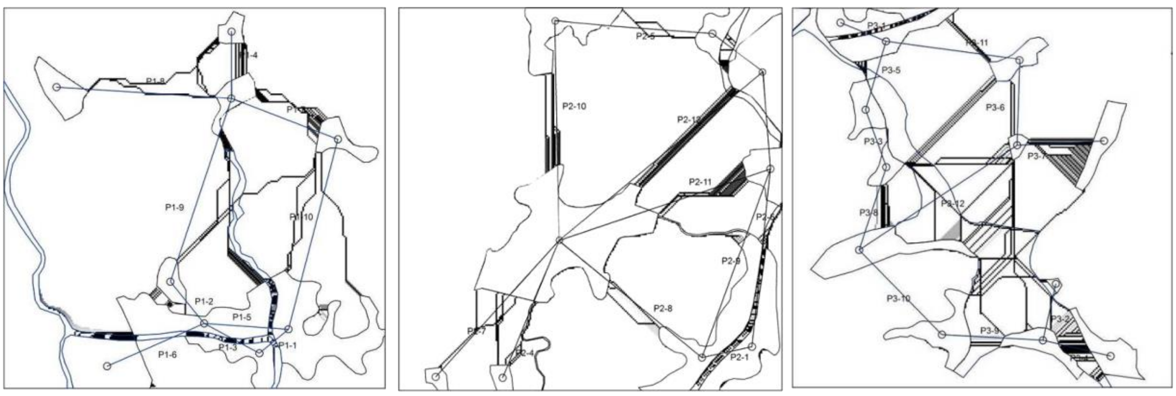


Figure 16; Inter-patch distance for wetland plot 1,2 and 3

Fig.15 represents the distribution of the results among the SFI and IPD.

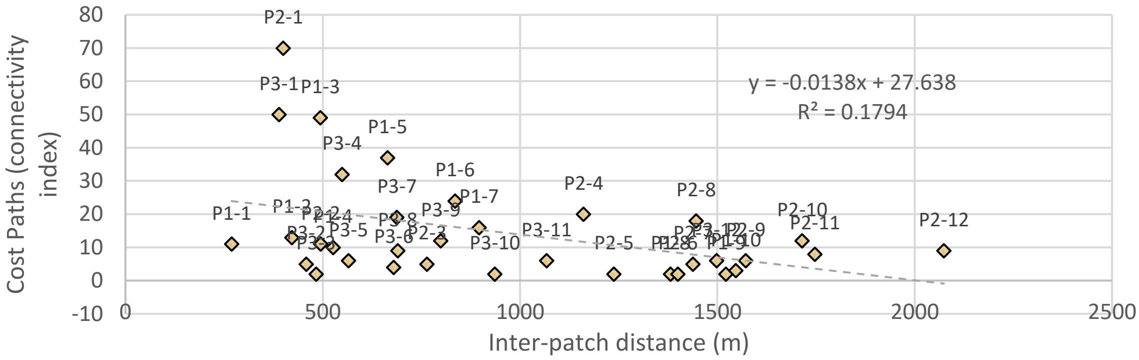


Figure 17; The graph represents the number of cost paths varied with the Inter patch distance for plot 1, 2 and 3

The results are evident that two variables hold a negative regression of R^2= -0.424 with a significant co-relationship of P=0.013. The P2-1 and P3-1 evident high connectivity considerations when the distance is comparative law. Whereas P2-12 and P2-11 represent low SFI indexes due to large distances (D<1500m) among them. Therefore, the species flow index fluctuated with Inter-patch distances and it could state that the distance has a direct strong influence on Landscape connectivity. If the patches are nearby, the wetland patches could have a high level of species distribution. If the patches are in a high distance; even though the patches are high in the area the interchange of the species flow and ecological processes would be reduced due to low Landscape connectivity.

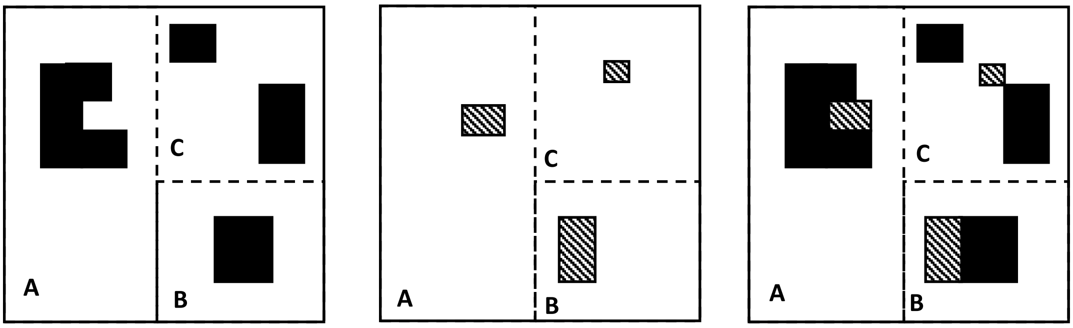
4. Conclusion

The study focuses on exploring the contribution of ecological network patch metrics to restore Landscape connectivity in terms of spatial interpretations of the patches in Urban Matrix. The investigation was carried out using series of patch metrics applied to the Colombo wetland network to assess the species likability to move through GIS-stimulated cost paths.

The correlation analysis is evident that the patch TA and TE has a positive contribution to species flow and simultaneously IPD has a negative co-relation with SFI. It was proven that the increase in patch size and decrease in inter patch distances would enhance the Landscape connectivity. In addition, CAI contributes to landscape connectivity based on the size of the core area. Accordingly, the wetland patches having a lower edge effect and higher core areas are most attracted by the species in the matrix.

Through the analysis, the study interprets three patch typologies according to with there contribution to Landscape connectivity. Those are open patches, closed patches, and active patches. The patches which have a very small core area that is less attracted by species were defined as “open patches” which have less contribution to landscape connectivity. In addition, the patches that have a higher core area also have less landscape connectivity identified as “closed patches”. Therefore, it was assumed that the isolated habitats, which have a higher core area contribute to species adaptation and resources to survive within the patch. Further, there are “active patches” which contributed to higher species movement between the patches. These patches were located near each other and enable species to move from one habitat to another and eventually resulted in habitat diversity. The investigation concluded that “active wetland patches” are important in Urban areas for species movement.

The research findings mainly support the connectivity considerations of the wetland network in Colombo Sri Lanka. However, the general findings will applicable for random urban habitat patches for faunal movement whereas the limitations are imposed by the character of the matrix and the forest habitat. Fig. 16 shows some strategies to implement the landscape development for open patches, closed patches, and active patches by identifying the existing habitat patch metrics. Describing patch (A-High SI) (B-High IPD)and (C-Low TA & TE) the spatial positioning of the landscape development is in fig.16-2. Hereby the proposed forest habitats for A; shape complexity could be reduced, B; Area can be increased, and C; The IPD can be reduced. Likewise, the solutions to restoring landscape connectivity can be taken according to the spatial



1-Existing habitat patches

2-Proposed ecological base landscape developments

3-Habitats with improved patch metrics

Figure 18; The figure shows design implementation solutions to enhance patch metrics and restore landscape connectivity

formation of the patches and measuring patch metrics.

Study findings can be utilized to rehabilitating the natural landscape connectivity in the Urban matrix. Therefore, in Landscape planning and design, one of the effective ways to establish Landscape connectivity within fragmented forest habitats is by introducing ecological-based developments adjacent to the existing habitats with referring to the spatial formation. The strategy used to bypass these proposed areas would depend on the existing habitat typology; open patch, closed patch, active patch. When it comes to ecological networks, small forest patches to large forest patches are serving various important ecosystem functions. Accordingly, the study opinion describes that every forest patch in the city is important to the ecological process. Therefore, every habitat link needs to be restored and enhanced to establish a healthy ecological network to gain maximum ecosystem services and maintain sustainable cities.

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Figures

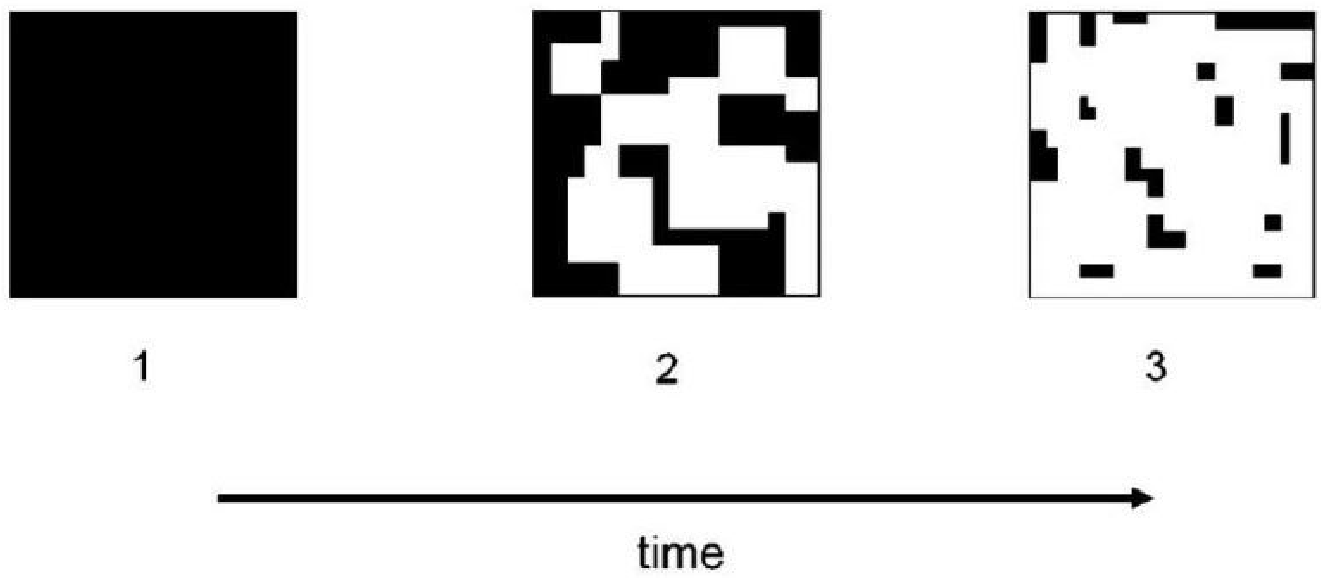

Figure 1

The process of habitat fragmentation, where “a large expanse of habitat is transformed into a number of smaller patches of smaller total area, isolated from each other by a matrix of habitats unlike the original” Source; (Wilcove et al. 1986).

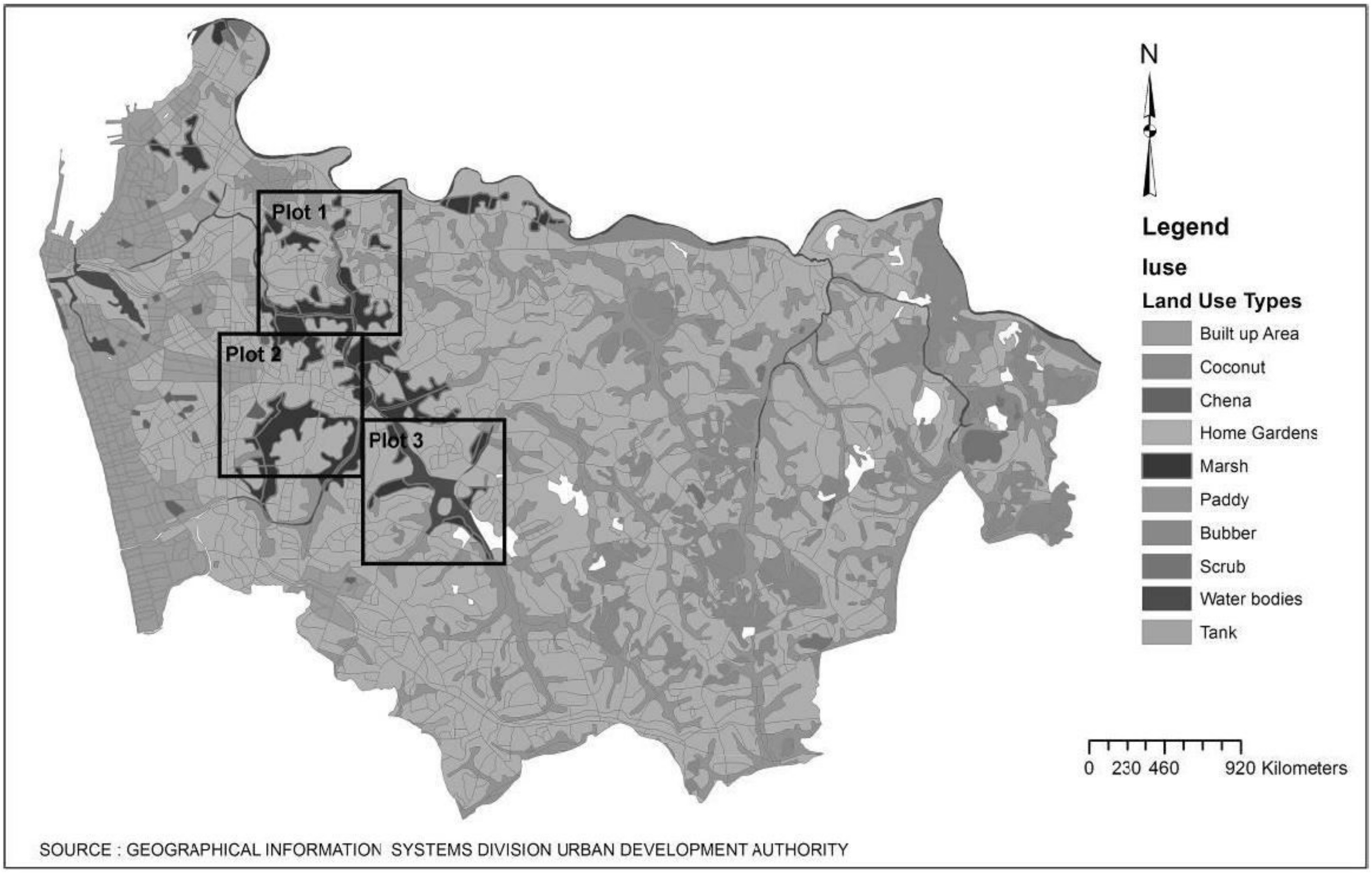

Figure 2

Representation of plot slection from the wetland habitats in Colombo district, Sri Lanka. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 3

Plot 1, Kollonawa Marsh. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

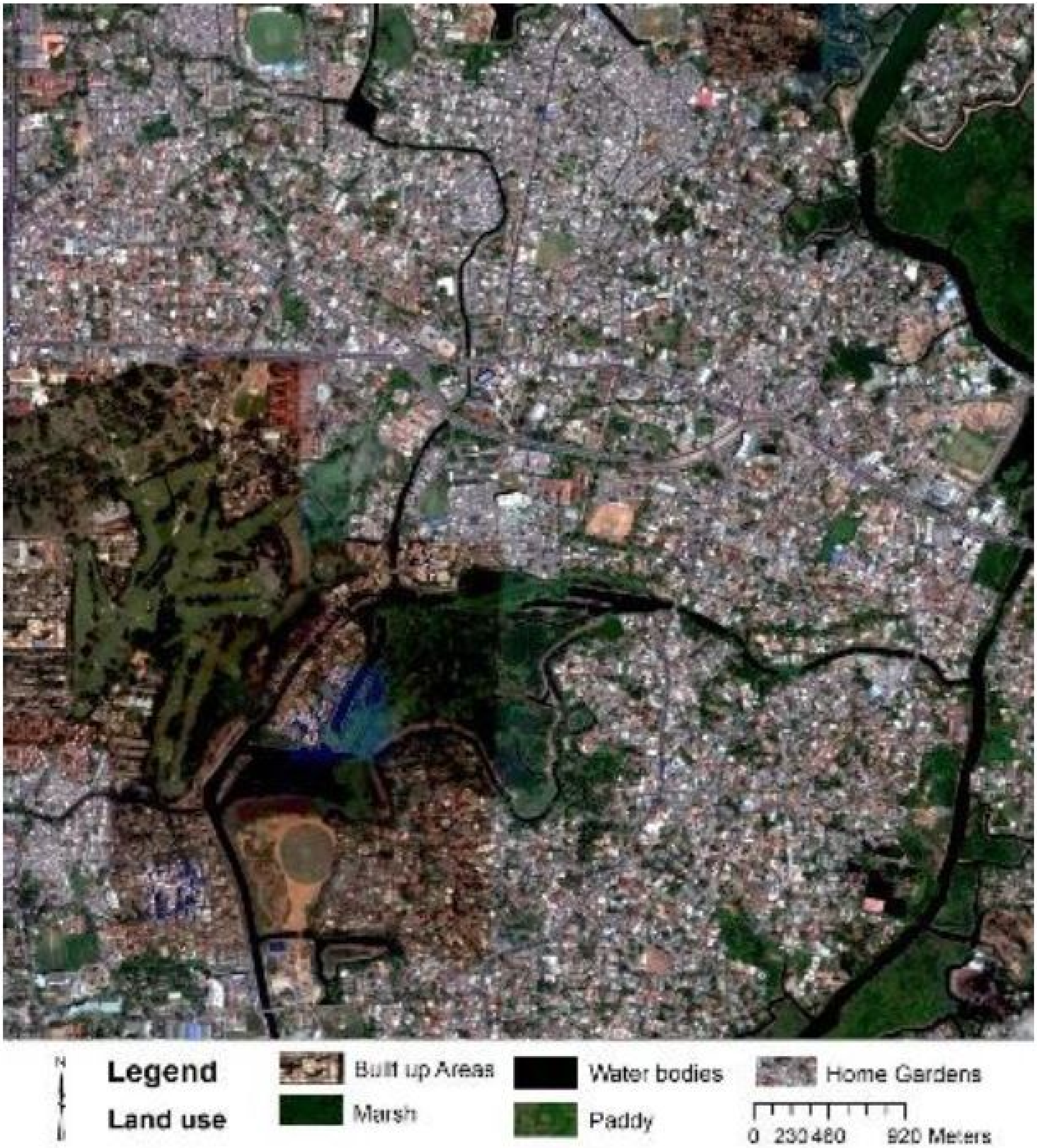

Figure 4

Plot 2, Nawala Marsh. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

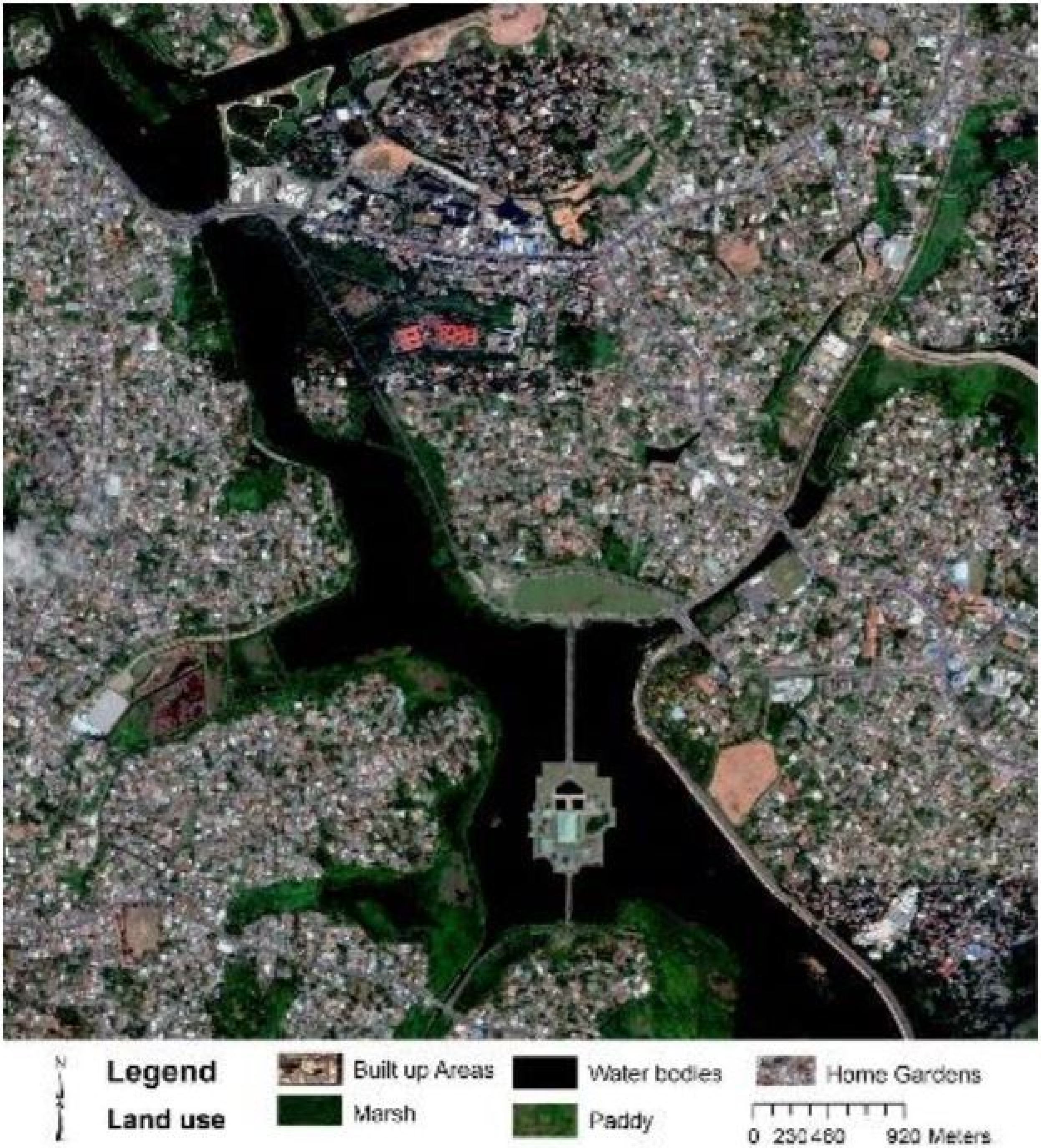

Figure 5

Plot 3, Kotte marsh. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

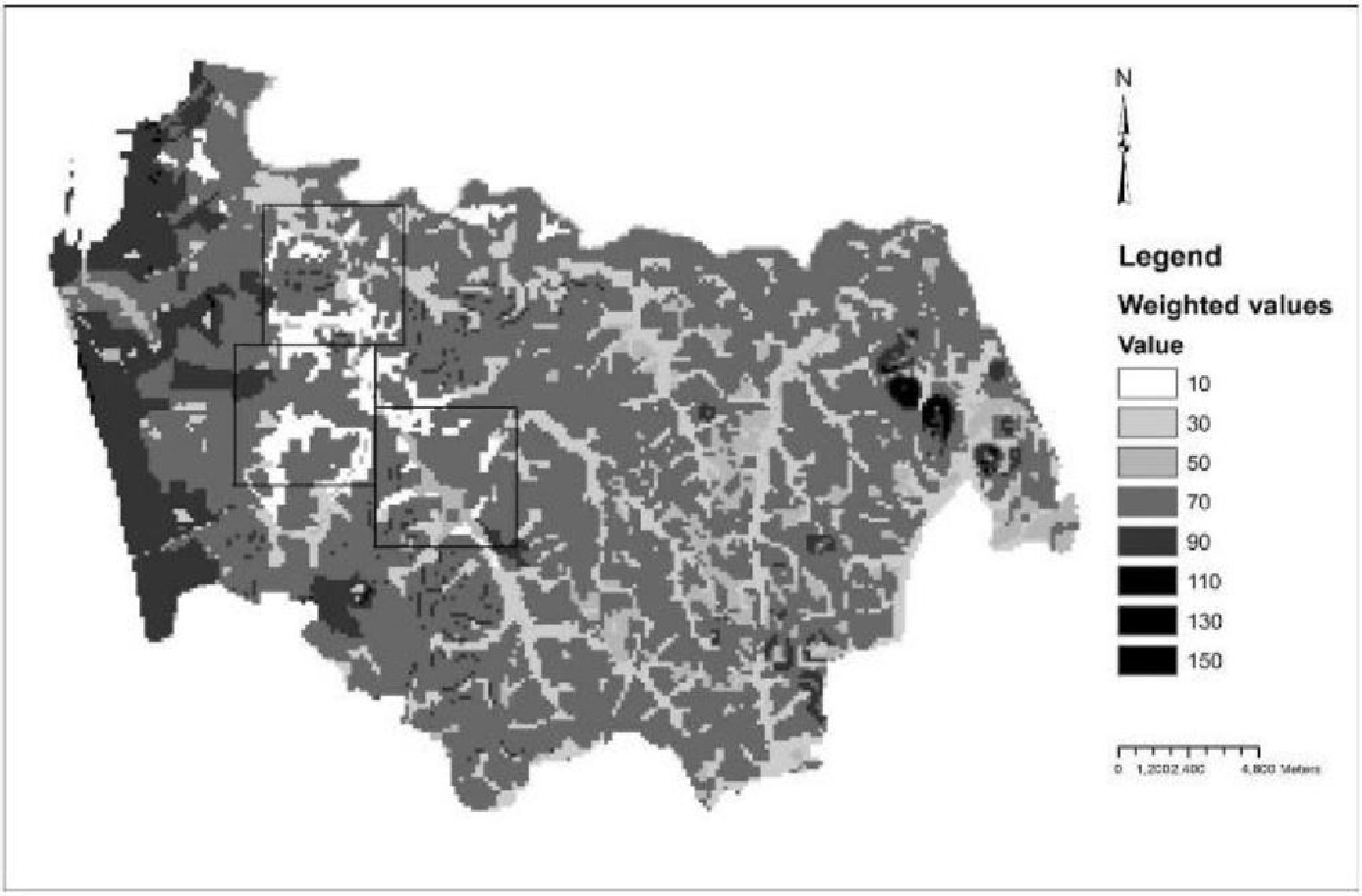

Figure 6

Resistance values GIS generated map; Source; Geographical information systems division UDA. Source Edited by Author. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

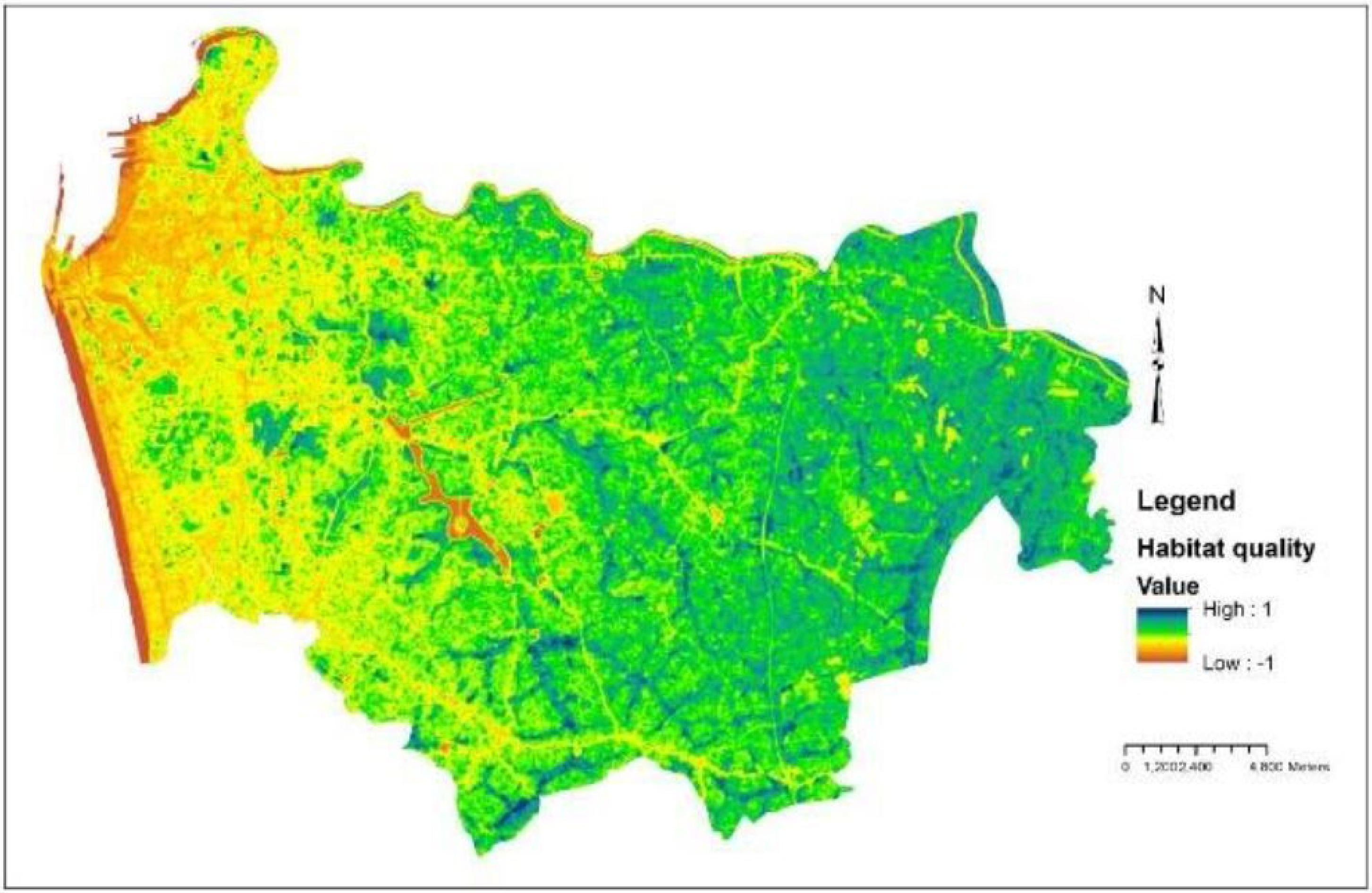

Figure 7

NDVI map for vegetation index Source; Geographical information systems division UDA. Source Edited by Author. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

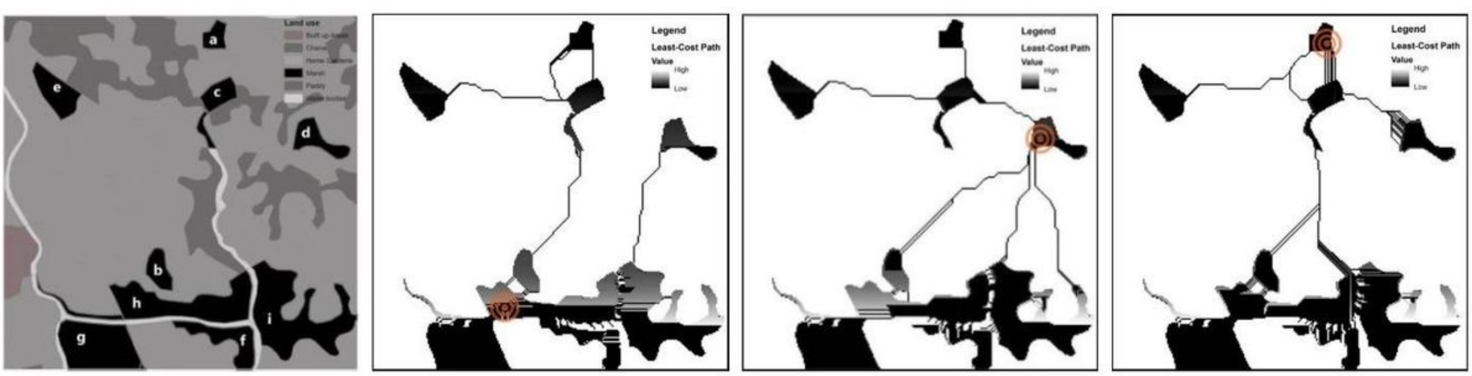

Figure 8

Map represent Land use pattern of Kollonnawa marsh. i),ii) and iii) represent the Least cost paths generated for quality patches. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

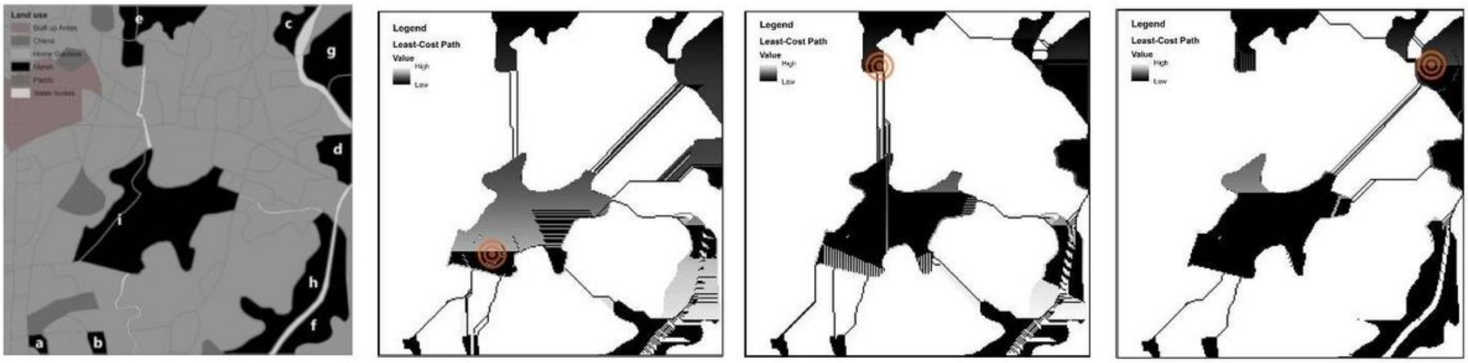

Figure 9

Map represent Land use pattern of Nawala marsh. i),ii) and iii) represent the Least cost paths generated for quality patches. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

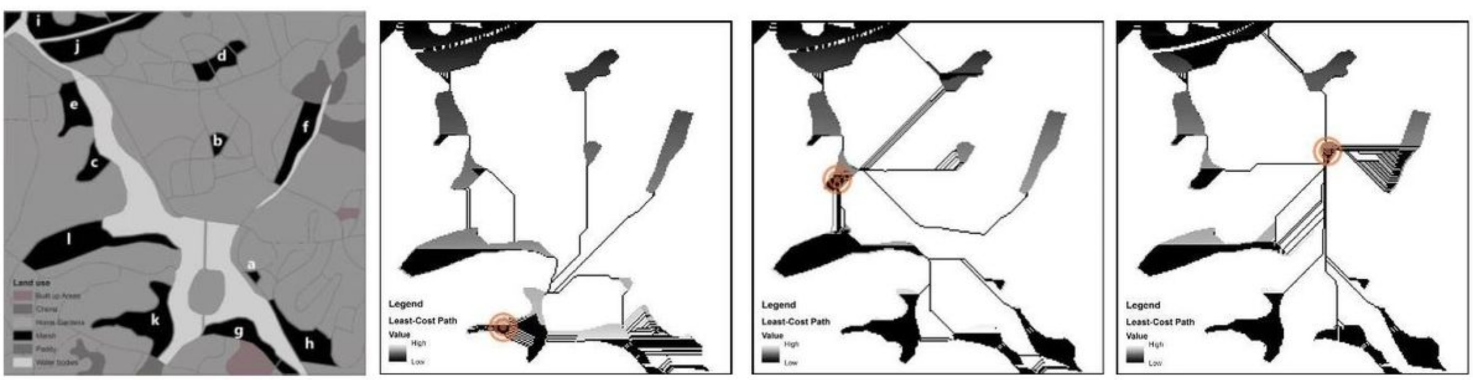

Figure 10

Map represent Land use pattern of Kotte marsh. i), ii) and iii) represent the Least cost paths generated for quality patches. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

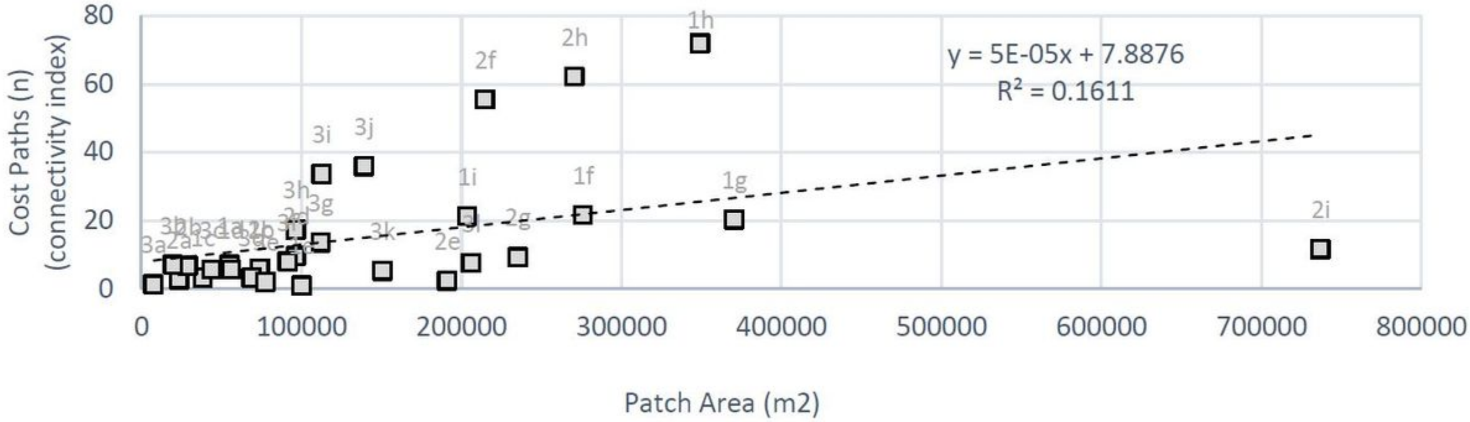

Figure 11

The garph represent the number of cost paths varied with the Patch Area for plot 1, 2 and 3

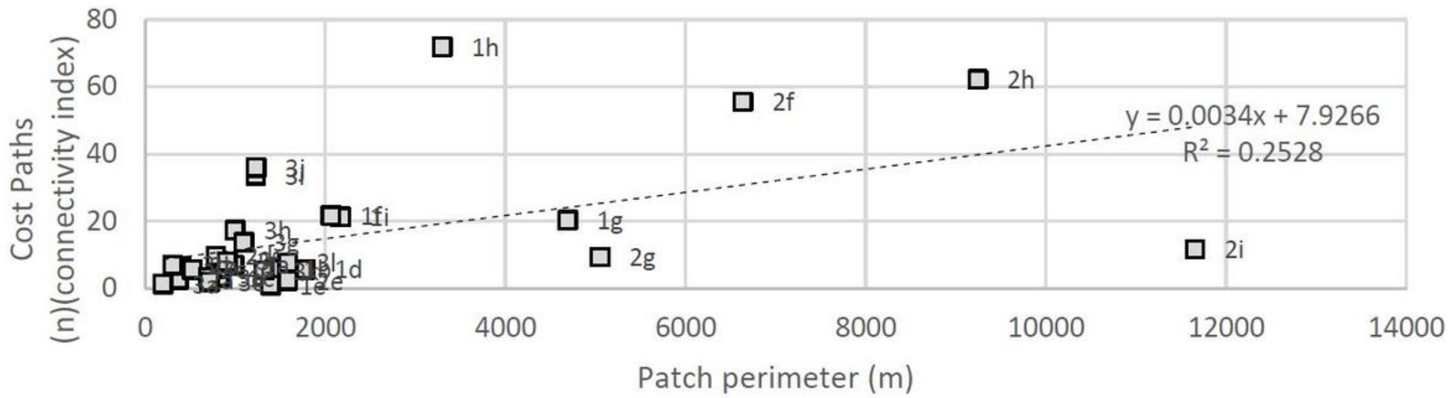

Figure 12

The garph represent the number of cost paths varied with the Patch Area for plot 1, 2 and 3

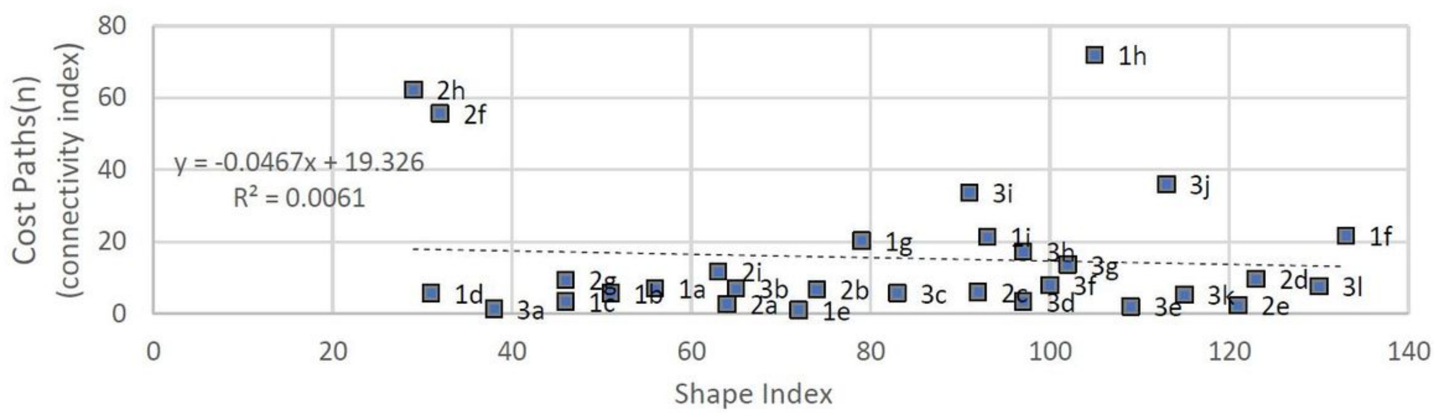

Figure 13

The graph represents the number of cost paths varied with the Shape index for plot 1, 2 and 3

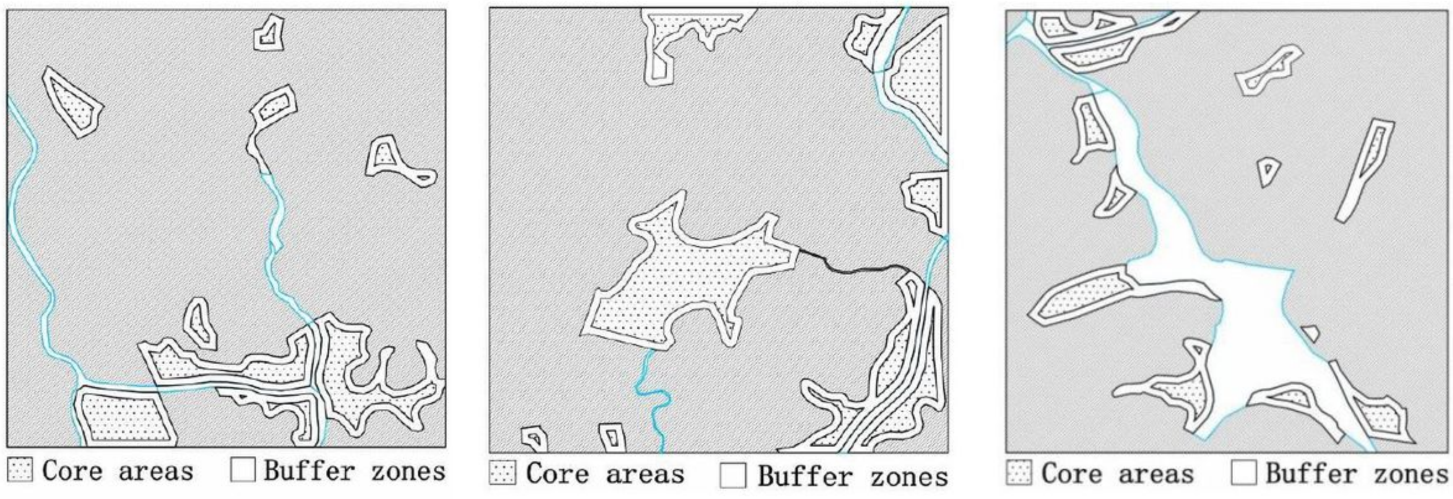

Figure 14

Indication of Core areas and buffer zones for plot 1, 2 and 3. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

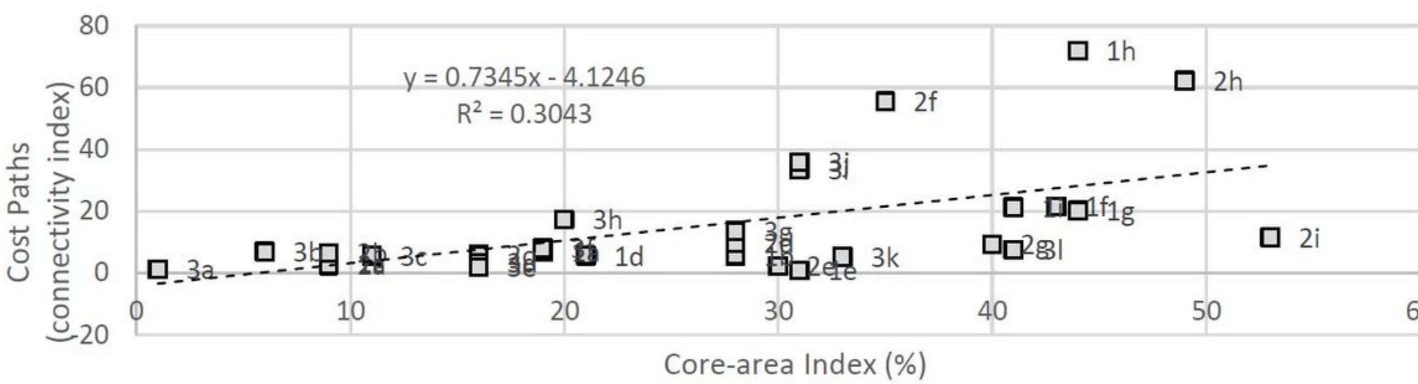

Figure 15

The graph represents the number of cost paths varied with the Core area Index for plot 1, 2 and 3

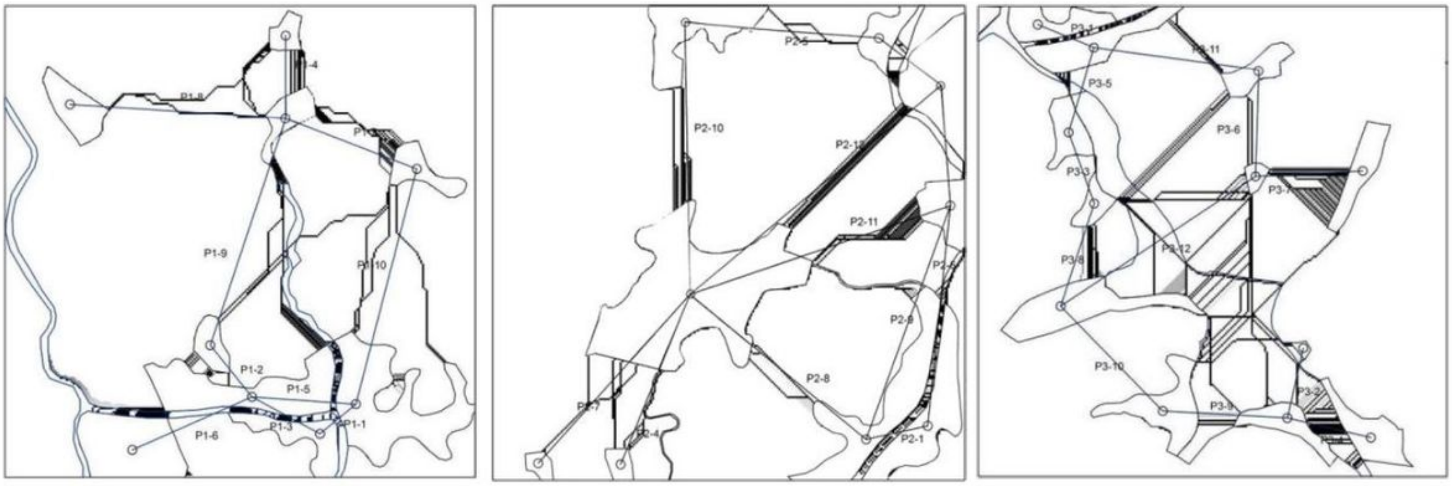

Figure 16

Inter-patch distance for wetland plot 1,2 and 3. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

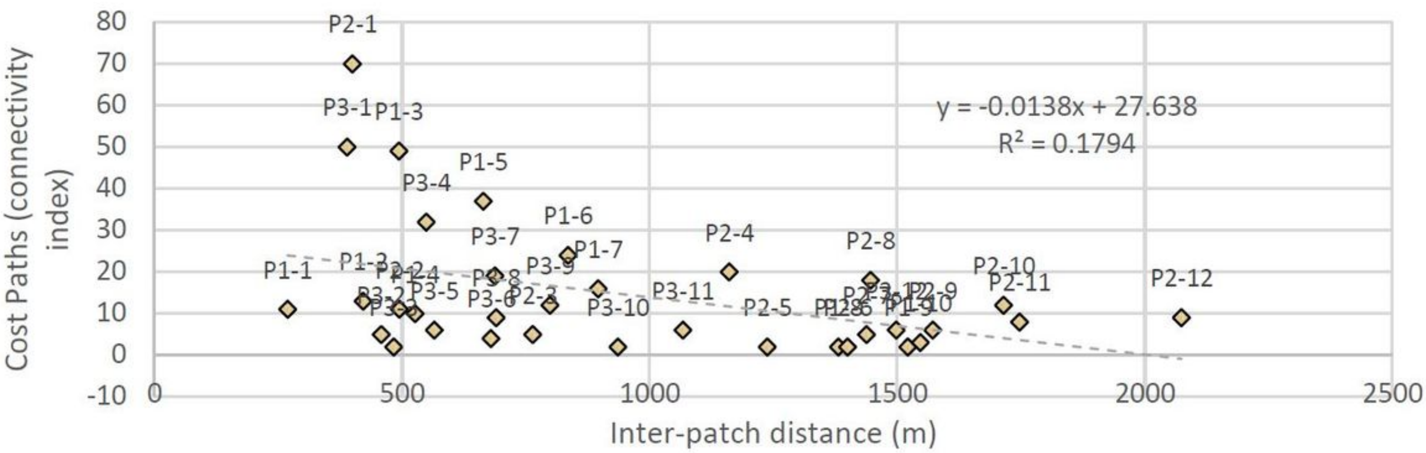

Figure 17

The graph represents the number of cost paths varied with the Inter patch distance for plot 1, 2 and 3

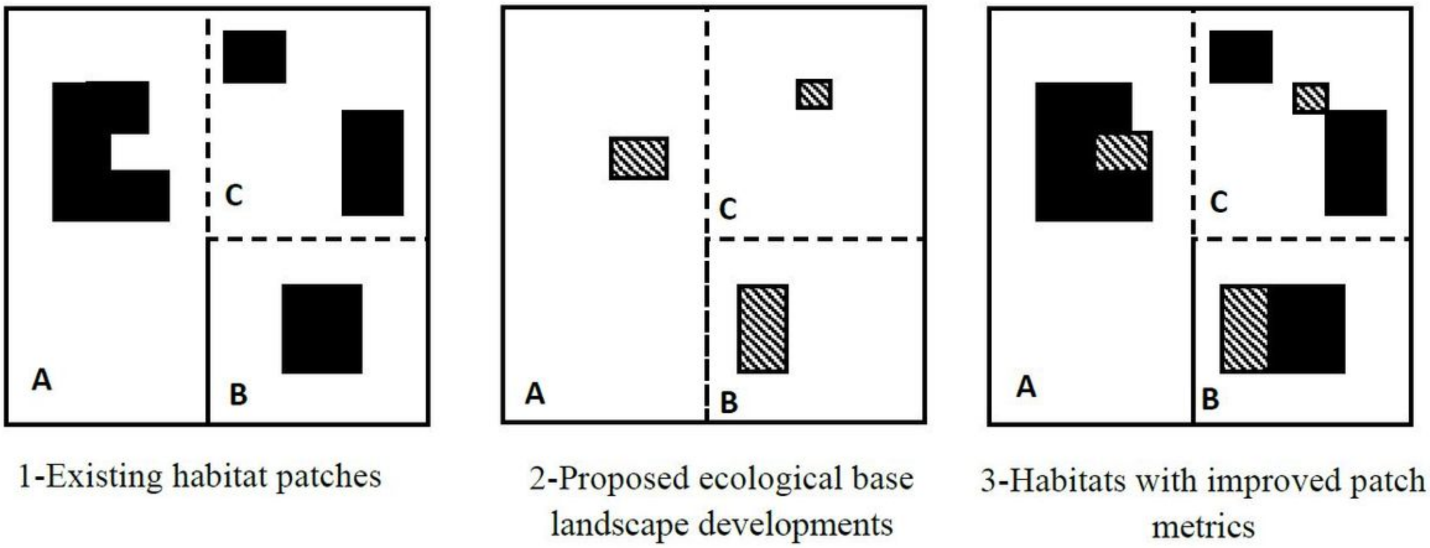

Figure 18

The figure shows design implementation solutions to enhance patch metrics and restore landscape connectivity