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# Spatial-Temporal Analysis of Landscape Ecological Connectivity Changes in Makassar City

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## ABSTRACT

*Urbanization has been experienced in Makassar cities, as the Eastern Indonesia gateway, affecting the Land Uses (LU) and causing the loss of green areas for urban carrying capacity. LU changes are acknowledged to be essential to define the influence of ecological function and structure of the landscape in major cities worldwide. This paper aims to evaluate spatially the natural network, using three available topographic maps in the years 1997, 2012 and 2015 by analyzing vital ecological areas and barriers as the anthropogenic influences at a regional scale. The results of the Ecological Connectivity Index (ECI) have shown significant changes in the entire Makassar region. By further analysis in the ECI matrix, the ECI gradual changes indicated that the connectivity rate decreased due to the high increase of barrier effects and the population rates which are the big factor of the rise of the need in infrastructures in most of the districts. Due to the high fragmentation produced by urban sprawl, the application of green infrastructure concepts should be considered. Hence, all quantifications in the spatial model and temporal analysis can reasonably provide basic information for the government as a guide to the city planning strategies for ecological preservation and ecosystem service in Makassar areas.*

## INTRODUCTION

Land presents a fundamental part of human existence. During the last 300 years, human activities in the world have been expedited and also the conversion of land, such as the yields of agricultural and forest products, has increased due to the human needs (Ramankutty, 2006). Meanwhile, many environmental issues related to the change of the land, both local and global, have been considered by the researchers. Furthermore, land-use change is accountable sectors contributing to 12.2% in global greenhouse gas emissions (Herzog,T,2005) and in the last three centuries, apparent changes have been noticed globally (Millennium Ecosystem Assessment, 2005).

The world's population immigrating to the urban area has increased to be approximately 55% in 2018, mainly in Northern America (UN,2019). Whilst, in Asia, the rate of urbanization drastically raise by triple in 65 years, which can represent around 50% of the population (UN,2019). It has been noticed that Indonesia experiences the fastest urbanization in Asia (Parasati, 2013).

The high rate of urbanization has been especially encountered in Makassar City Area (MCA; Fig. 1), which is the Eastern Indonesia gateway. Therefore, continuous development leads to the creation of a metropolitan city that is characterized by a population of 1.9 million and a surface area of 177 km$^2$ which covers 15 districts. Moreover, the annual rise of both the population and economic growth has brought massive development. Consequently, more decades of land-use (LU) have changed into the built area along with the risk of climate change issues, which has recorded 13% green area of the total surface. Hence, to harmonize the uncontrolled urban sprawl and land reclamation for residence, business and infrastructure, LU planning is to be used. In addition, the existence of green areas must be managed and maintained for natural habitats and urban carrying capacity.

Generally, biodiversity tends to decline with the intensification of urbanization and infrastructure demands. By applying Green infrastructure (GI), we can establish the concept of the interconnected network to mitigate the loss of green area and the growth of risks of climate change. Accordingly, many specific topics related to landscape connectivity in planning literature include the studies on open space network, greenways and ecological networks where the most significant role played by landscape planning has been on the use of ecological networks as a spatial concept (Vuilleumier and Prelaz-Droux, 2002). Furthermore, the quantitative methodology of landscape ecology can easily assess the ecological fragmentation and be incorporated into the planning processes and strategic environmental assessment (Marull and Mallarach, 2005). Therefore, the objective of this paper is to establish ecological connectivity maps and to analyze spatially short- and long-term of change in the different year of 1997, 2012 and 2015 using Geographical Information Systems (GIS) methodology at a regional scale of Makassar regions.

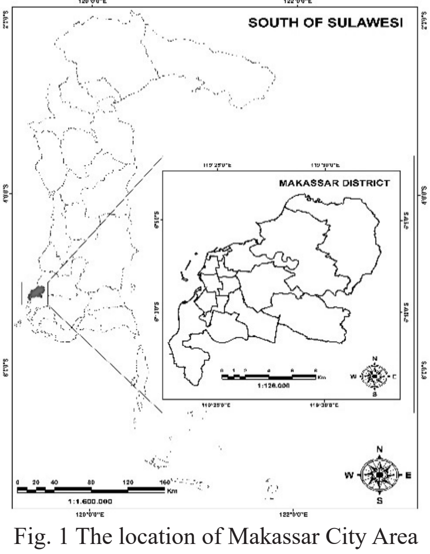



Fig. 1 The location of Makassar City Area and South Sulawesi

Moreover, the result could be used to determine the city planning by local governments considering the natural resources based on the designation in ancient times.

## DATA

In this research, data derived from land-use maps (vector data) and an aerial photograph were provided by the local government of Makassar cities and Geospatial Information Agency (BIG) in Indonesia. In contrast, mostly conducted on previous researches, aerial image data used as basic data have been used to classify land use (LU) or land cover (LC) which does not result in significant value. Hence, our basic data relies on LU, 1997, 2012 and 2015, at 1:50,000 and 1:5,000 respectively and the calculation was conducted using Geographic Information Systems (GIS) process. A set of available tools was used to manage data and to calculate the area from topographic maps. By adjusting vector data with aerial photograph in real condition, ten types of LU were reclassified into based on the same allotment and the calculation was conducted by intersecting between LU-polygon with a 50 m grid mesh resulting to the maximum area in each grid feature in Table 1.

## METHOD

The method of analyzing landscape ecological connectivity introduced by Marulli and Mallarach (2005) uses a series of topological analyses of land-use and infrastructure maps (2008) and applies the mathematical language which has been developed and implemented by the use of Cost Distance function of ArcGIS Spatial Analyst toolbox. Furthermore, to get ecological connectivity value in urban scale of MCA, its characteristics should be defined by the combination of both the natural areas and obstacle the movement of individuals. There are three key components of methodological approaches proposed in the quantitative landscape ecology as following:

### Ecological Function Areas

Ecological Function Areas (EFA) resulted from the LU division which indicated the characteristics and vital areas that needed to be connected. In previous studies, EFA has decided to have three classified protocols: “simple ecological function”, “second topology analysis” and “third topological analysis” (Marulli and Mallarach, 2005) and a minimum surface ($S_r$=50) is interpreted as simple ecological function areas according to each land covered (Bender, Contreras, & Fahrig, 1998).

As shown in Table 2, there are 6 types of land cover, classified as mosaics, forest, agricultural or agroforest mosaics (Forman, 1995). As predicted, LU surface of natural and semi-natural habitats to be connected is higher than the combined surface of the ecological areas in three periods of MCA, 1997 (68%), 2012 (32,8%) and 2015 (31%). Spatially, the decrease of EFA depicted in Fig. 3 shows a tremendous drop in 18 years.

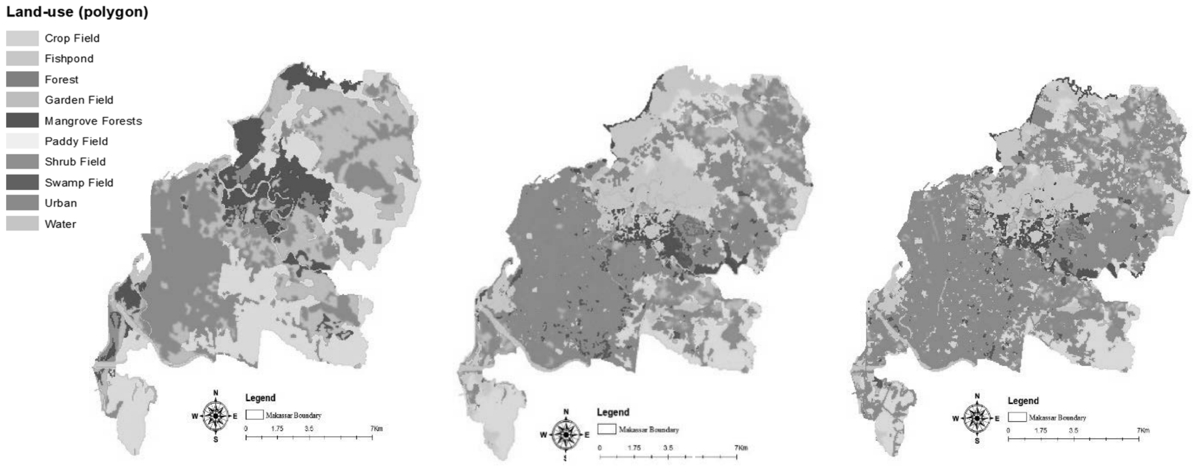
### Barrier Effect Index (BEI)

The barrier effects, as the resistance surface or entire artificial LU, are the obstacles associated with infrastructure barriers that can disrupt “natural process”, including plant dispersal and animal movements. Furthermore, because of most infrastructure barriers, the number of crossing can have a significant impact on animal movements and their habitats. A barrier may also be physical (mountain, river, ocean), linguistic (border), socio-culture (inequality in access to information, religious resistance, and taboos).

By evaluating ecological connectivity, a group of artificial types was formed with different weights (Table 3) depending on relative influence from all landscapes.

Table 1 Comparison of land-use values for each year

| Code | Types | Total area (ha) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1997 | % | 2012 | % | 2015 | % |
| $B_1$ | Urban | 4805 | 27.03 | 8098 | 45.56 | 9740 | 54.80 |
| $B_2$ | Water | 643 | 3.61 | 665 | 3.74 | 627 | 3.52 |
| $B_3$ | Fishpond | 0 | 0 | 2402 | 13.51 | 1809 | 10.17 |
| $C'_1$ | Forest | 10 | 0.05 | 47 | 0.26 | 40 | 0.22 |
| $C_2$ | Mangrove forest | 2106 | 11.85 | 469 | 2.63 | 580 | 3.26 |
| $C_3$ | Swamp field | 0 | 0 | 370 | 2.08 | 224 | 1.26 |
| $C_4$ | Paddy field | 4935 | 27.76 | 2897 | 16.30 | 2136 | 12.01 |
| $C_5$ | Garden field | 4744 | 26.69 | 1654 | 9.30 | 1285 | 7.23 |
| $C_6$ | Shrub field | 528 | 2.97 | 463 | 2.60 | 406 | 2.28 |
| $N_1$ | Crop field | 0 | 0 | 706 | 3.97 | 924 | 5.19 |
| | Total | 17771 | 100 | 17771 | 100 | 17771 | 100 |

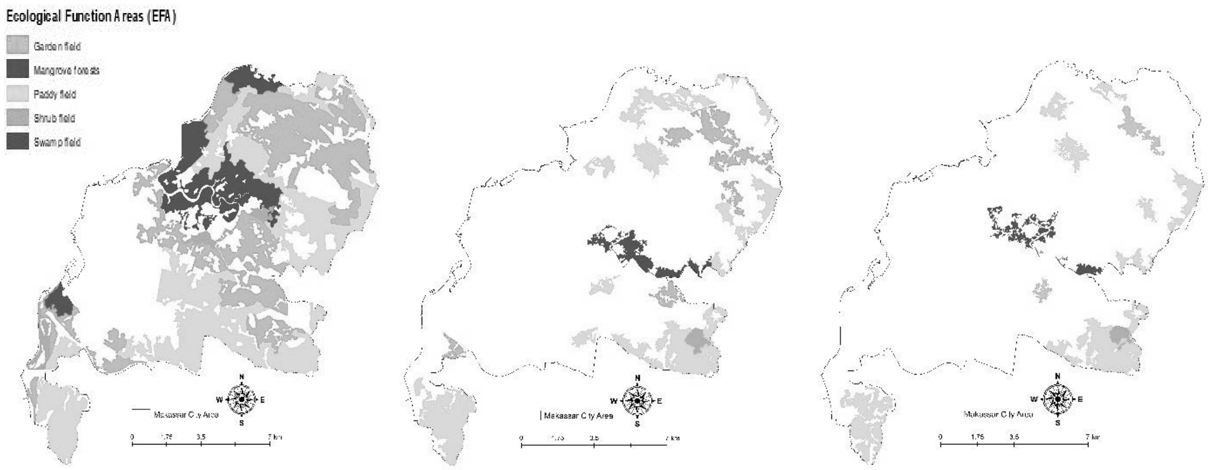



(a) 1997 (b) 2012 (c) 2015

Fig. 2 The establishment of land-use based on grid-mesh

Table 2 Ecological functional area results from topological analysis in land cover categories

| Code | Land Cover | Class | Total area (ha) | | |
|---|---|---|---|---|---|
| | | | 1997 | 2012 | 2015 |
| C'1 | Forest | Forest | 8.58 | 44.52 | 39.72 |
| C'2 | Mangrove forest | Mangrove forest | 2088.57 | 471.69 | 403.11 |
| C'3 | Swamp field | Swamp field | 0 | 382.74 | 269.47 |
| C'4 | Paddy field | Agriculture mosaic | 4805.79 | 2795.54 | 2345.49 |
| C'5 | Garden field | Agroforest | 4705.47 | 1663.63 | 1410.22 |
| C'6 | Shrub field | mosaic | 520.2 | 476.58 | 383.28 |
| | Total | | 12128.6 | 5834.7 | 4851.3 |




(a) 1997 (b) 2012 (c) 2015

Fig. 3 Distribution of the main ecological functional areas in the Makassar City Areas

In this research, we defined 4 types of barrier as obstruction for the related fragmentation of habitat (Table 3). The impact matrix (Table 4) gives a significant effect of the distance on BEI calculation.

According to the expression of BEI calculation by Marulli & Mallarach (2005), the effect of artificial barriers on ecological and landscape connectivity was identified, as followed:

$$BEI = Y_i/Y_{max} \quad [1]$$

where $Y_i$ is value of the barrier effect in a pixel and $Y_{max}$ is the maximum value of the barrier effect calculated on a given area. In addition, Table 5 is ranking of BEI to easily measure the barrier value within an ordinal scale from 1 to 10.

The use of the BEI to the MCA resulted to the recognition of the areas that have been affected by the barrier as shown in Fig. 4 and has led to the establishment of the maps on Fig. 5. The result, at least 70.42% in 1997, was under negative impact from built-up areas and raised to over 88.77% and 92.23**%** respectively in 2012 and 2015.

Table 3 Barrier types (Bs) in Makassar Area

| Code | Type | Weight | $ks_1^a$ | $ks_2^a$ |
|---|---|---|---|---|
| $B_1$ | Urban | 100 | 55.520 | 0.051 |
| $B_2$ | Road | 80 | 44.420 | 0.063 |
| $B_3$ | Water | 60 | _[b] | _[b] |
| $B_4$ | Fishpond | 60 | _[b] | _[b] |

[a] constants for a logarithmic decrease of 30% (α=0.3)
[b] for s = 2, there is not surrounding spatial affectation

Table 4 Impact Matrix (MA)

| Code | Type | Weight | $(a_n)^b$ | $(A_n)^c$ |
|---|---|---|---|---|
| $V_1$ | Neutral | $N_1$ | 1000 | 0.1 |
| $V_2$ | Agriculture | $C_4$, $C_5$ | 750 | 0.13 |
| $V_3$ | "Natural" | $C_1$, $C_2$, $C_3$, $C_6$ | 500 | 0.2 |
| $V_4$ | Barrier | $B_1$, $B_2$, $B_3$ | 250 | 0.4 |
| $V_5$ | Corridor | $R_1$ | 1 | 100 |

[a] class description in previous table/is found in Table
[b] a1 the value resulted from existing literature with the maximum significantly affected distance by each type
[c]an affection value resulted b1 divided with $a_n$

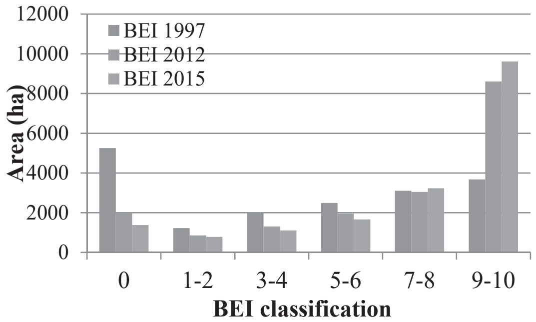



Fig. 4 Results of the application of Barrier Effect Index (BEI) to the City Areas of Makassar

As illustrated in the diagram, the influence of barrier from no existence (0) to high level (5-6) impacted area in 1997 decreased in 2012 and 2015; meanwhile, the outcome of the barrier index result in critical impact (9-10) rose in 2012 and 2015. It indicates that the high density of urban region has been increased in MCA. However, Tallo area was slightly changed which has been slightly affected by the barriers and in contrast to the critical impacts spread the central side of MCA, particularly the eastern part of the city.

## Ecological Connectivity Index (ECI)

In connectivity quantification, the least-cost distance and map algebra are main model versions of landscape ecological connectivity modified by Marulli and Mallarach, 2005 in spatial scales. According to the model, we adapted the calculation due to this paper setting using GIS method for estimating the ecological network in MCA. The landscape involves rapid urban sprawl and a simultaneous need for natural remnants conservation.

The least-cost distance method, as the principle algorithm underlying cost distance analysis provided in GIS program, computes the cumulative costs to move from one cell to another in all landscapes (Adriaensen et al., 2003). Moreover, two databases utilized in cost distance functions, "ecological function areas" as an origin surface and "an impedance surface" from the implication of the barrier effect ($Y$) and a potential affinity matric ($M_C$). According to Marulli and Mallarach (2005), to convert the continuous costs of cost distance for discrete values based on a decimal scale, the following expression of ECI Index defined as below:

ECI = $10 - 9\,(\ln(1+(xi - x_{min}))/\ln(1+(x_{max} - x_{min}))^3)$ [2]

where xi the adjusted cost-distance value in a pixel, $x_{max}$ are the maximum and $x_{min}$ are the minimum adapted cost-distance values on a presented area. To compare different alternatives of ECI features which has a relativistic distribution of value, the feature gives a scale between 0 and 10 (Marulli and Mallarach,2005). By ranking the allocation of ECI, it can identify areas with both having low absolute values to link the existing ecological functional areas and high ecological fragmentation, which is in central area of the economic activities.

## RESULTS AND DISCUSSIONS

### Land-Use converted into Urban

LU-maps show the changes and 4 types of land which have experienced the conversion, namely urban, garden field, paddy field and mangrove forest. By further analysis of LU value, significant transition during 3 time periods of 1997-2012, 1997-2015 and 2012-2015. According to those data in Table 6, the overall of LU-value has been converted to urban and influenced the loss of green area. Furthermore, the high rate of modified land to urban surface in 3 trend of change shown in Fig. 4, garden about 7%-27% and followed with paddy field with the percentage around 8%-24%.

As a result, from 1997 to 2015 urban area, not only was dramatically growing up from 4805 to 9740 hectares which indicates more than twice the urban expansion of 18 years period, but also in 3 years of change slightly increased to 1642 ha. Contrarily, the number of green fields of MCA in 2015 have been declined around 43% from 12323 ha to 4671 ha in 1997. Historically, those areas reported having the massive development in built-up areas to fulfill human needs with infrastructures. In consequence of urban expansion, the existence of crop field apparently increased into 924 ha and swamp field into 224 ha in 2015 caused by converting mangrove to fishpond land as a livelihood.

### The impact of LU-changes on ECI

Fig. 7 compares ECI values on five different indexes in MCA with 3 years. It is obviously indicated that the majority of connectivity stands to the lower connectivity: 6529 ha, 8950 ha and 7822 ha respectively in 1997, 2012 and 2015. For 18 years, the number of ecological network in lowest connectivity dramatically rose from 2993 ha to 6929 ha whereas there was a fall gradually in other connectivity, especially medium value and the least value had reached a higher connectivity (591 ha).

Table 5. Ranking of barrier effect in the landscape (Marulli and Mallarach,2005)

| BEI ($Y_i/Y_{max}$) | Effect Level | Type of barriers |
|---|---|---|
| 0 | Non existent | Lack of anthropogenic barriers. Total permeability of matter, energy and information |
| 1<br>2 | Low | Small and scattered barriers, such as isolated farms<br>High ecological permeability remains |
| 3<br>4 | Medium | Small roads or low density residential areas<br>Medium ecological permeability remains |
| 5<br>6 | High | Main roads, scattered urban, commercial or industrial areas<br>Low ecological permeability |
| 7<br>8 | Very High | impact Synergic combination of urban areas and highways or other transport corridors<br>Very low ecological permeability |
| 9<br>10 | Critical Impact | Synergic combination of large, high density urban areas with main transport corridors<br>Minimum ecological permeability |

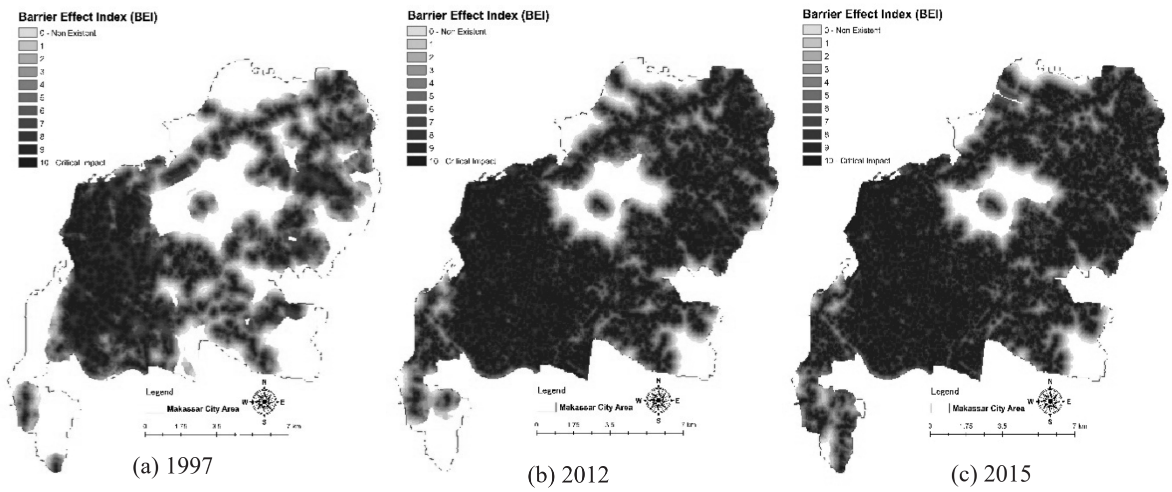



Fig. 5 Map resulting of Barrier Effect Index (BEI) distribution in the Makassar City Areas

It caused by the EFA values which have been deteriorating continuously and the increase of number of barrier will be affecting the cost value of connectivity. The highest connectivity rate was remained in Tallo areas with signed by Fir green in Fig. 5 where there is the existence of mangrove and garden until 2015 and become the natural landscape. Significantly, the evaluation on the Fig. 8 that has been declined the change of connectivity values that was founded from highest and higher to lower and lowest around in the coastal area which has the infrastructure demands for center of recreation. In addition, the land conversion has been experienced in industrial zone located in surrounding both districts of Tamalanrea and Biringkanaya and contributes to the effect of value connectivity, from medium to lower and lower to lowest connectivity.

Massive development has been noticed in MCA planning of 2015-2035 regarding land acquisition of the most agriculture area converted to built-up areas for living, education, recreation and socialization. Moreover, the construction of campus areas located in Mamminasata Metropolitan (covering the city of Makassar and the regencies of Gowa, Maros and Takalar) which will impact the large residential and settlement demand in borderland of Rappocini district and Gowa and the most greenery area have sited in these areas in 1997. However, it leads to economic growth in the suburbs.

Landscape change is not random and centered in a vacant area where having the large-scale of green area. The type of LU influenced the spatial patterns of landscape change, underlying ecological process and species distribution in different ways. Furthermore, for more than decades, MCA has been encountering rapid fragmentation and transformation of the natural landscape. It is visibly shown in 2015 that mostly urban surface occupied 55% of total surface of MCA comparing in 1997 and 2012.

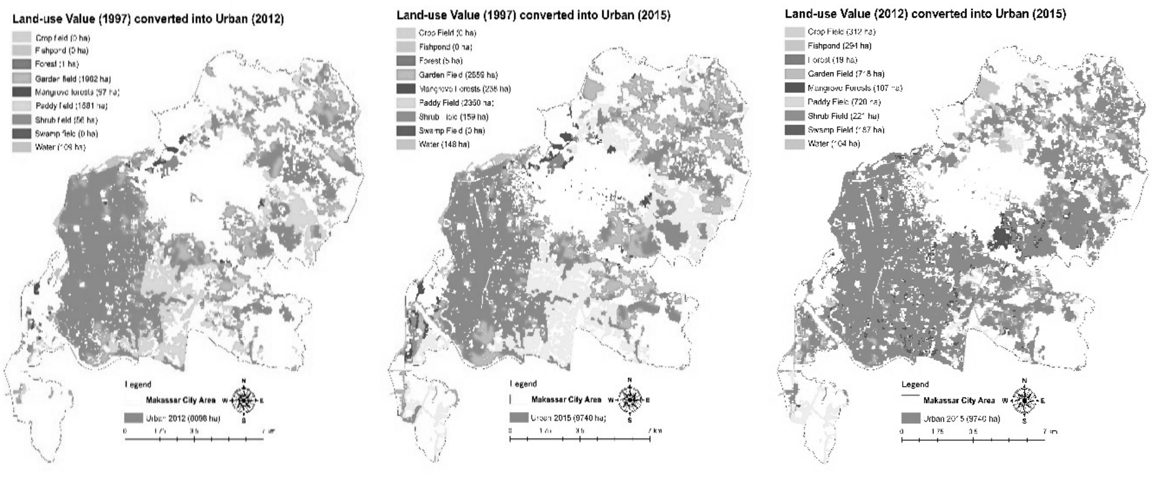
Consequently, it will cause increases in smaller patches and disconnected habitats. The minimum ecological permeability can have the influence water management such as water shortage for agriculture field. As further, the disadvantage found from the lack of green area in urban ecosystem will influence on urban capacity for human life and increase the temperature into 0.8°C-0.9°C as well as the outcome of climate change affecting detrimental human health such as dehydration caused by extreme heat events (Glaser et al. 2016) and flood vulnerability arisen by removal mangrove area (Poppy,2018).

## CONCLUSION

The establishment and evaluation of LU changes and landscape network were created with three different topographic maps of 1997, 2012 and 2015 in MCA. GIS software was applied to simulate the spatial-temporal LU changes from 1997-2012, 1997-2015 and 2012-2015 based on grid mesh 50m, and used the cost distance tools for ECI. For ECI calculation, LU types were identified to define the vital ecological areas which consist of simple ecological function and adopting the landscape metrics method from Marulli and Mallarach to create and analyze the BEI and ECI in 3 time periods. As a result, the trend of LU values converted into urban area has been experienced in the entire region for long and short periods. The conversion of LU types has resulted into different levels of impact on the ECI. Therefore, it formed the large-scale of patches of habitat in the ecological impact involved in the rapid urban sprawl in these cities. In the future study, green infrastructure strategies for ecological preservation and restoration of ecosystem service need to be considered and guidance for city planning in MCA as a capital city should be led.

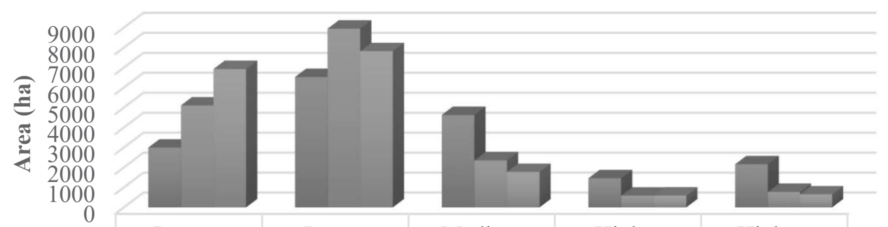
Table 6 Transition land use values to urban area

| Types | Total area (ha) of Land-Use to Urban area | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1997-2012 | | Urban Expansion | 1997-2015 | | Urban Expansion | 2012-2015 | | Urban Expansion |
| | ha | % | ha | Ha | % | ha | 2015 | % | ha |
| Crop field | 0 | 0 | | 0 | 0 | | 312 | 3 | |
| Fishpond | 0 | 0 | | 0 | 0 | | 294 | 3 | |
| Forest | 1 | 1 | | 5 | 0 | | 19 | 0 | |
| Garden field | 1962 | 24 | | 2659 | 27 | | 718 | 7 | |
| Mangrove forest | 97 | 1 | 4935 | 238 | 2 | 3293 | 107 | 1 | 1642 |
| Paddy field | 1581 | 19 | | 2351 | 24 | | 720 | 8 | |
| Shrub field | 56 | 1 | | 159 | 2 | | 221 | 2 | |
| Swamp field | 0 | 0 | | 0 | 0 | | 187 | 2 | |
| Urban | 4292 | 53 | | 4180 | 43 | | 7058 | 73 | |
| Water | 109 | 1 | | 148 | 2 | | 104 | 1 | |
| Total | 9740 | 100 | | 9740 | 100 | | 9740 | 100 | |



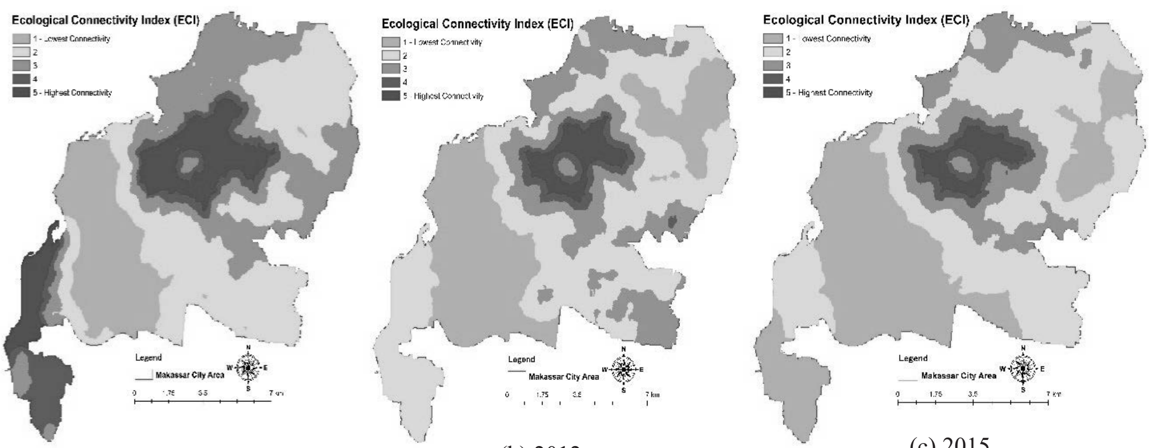

(a) 1997-2012 (b) 1997-2015 (c) 2012-2015

Fig. 6 Spatial Distribution of LU-values converted into urban area




| | Lowest Connectivity | Lower Connectivity | Medium Connectivity | Higher Connectivity | Highest Connectivity |
|---|---|---|---|---|---|
| 1997 | 2993.5 | 6529.25 | 4628.75 | 1459 | 2160.25 |
| 2012 | 5103.75 | 8950 | 2356 | 587.75 | 773.25 |
| 2015 | 6929.5 | 7822.5 | 1775 | 591 | 652.75 |

Fig. 7 Results of the application of Ecological Connectivity Index (ECI) to the City Areas of Makassar




(a) 1997 (b) 2012 (c) 2015

Fig. 8 Ecological Connectivity Index (ECI) distribution in the Makassar City Areas

## REFERENCES


Adriaensen, F., Chardon, J.P., De Blust, G., Swinnen, E., Villalba, S., Gulinck, H. and Matthyse, E. The application of least-cost modelling as a functional landscape model. Landscape and Urban Planning, 64, pp. 233-247 (2003).

Bender, D.J., Contreras, T.A. and Fahring, L. Habitat loss and population decline: a meta-analysis of the patch size effect. Ecology, 79, pp, 517-533 (1998).

Forman, R. T. T. Land Mosaics: The Ecology of Landscapes and Regions. Cambridge, UK: Cambridge University Press (1995).

Glaser, J., et al. Climate change and the emergent epidemic of CKD from heat stress in rural communities: The case for heat stress Nephropathy. Clinical Journal of American Society of Nephrology Vol 11: 1472-1483 (2016).

Herzog,T. World greenhouse gas emissions in 2005. WRI Working Paper. World Resources Institute. 2005.

Indrayani, P. A. Thesis: A GIS-based analysis approach for evaluating green infrastructure plan: A plan case study of Makassar region. Fukuoka, Japan: Kyushu University. (2018)

Marulli, J. and Mallarach, J. M. A GIS methodology for assessing ecological connectivity: application to the Barcelona Metropolitan Area Landscape Urban Plan, 71. pp.243-262 (2005).

Marulli, J. and Mallarach, J. M. Impact assessment of ecological connectivity at the regional level: recent developments in the Barcelona Metropolitan Area. Beech Tree, vol. 24, pp. 127-137 (2006).

Millennium Ecosystem Assessment. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC (2005).

Parasati, H. Program Pembangunan Perkotaan Nasional. Konferensi e-Indonesia Initiative forum IX/2013 (2013).

Ramankutty, N., Frederic, A., Graumlich, L., Alves, D. S. Global Land-Cover Change: Recent Progress, Remaining Challenges, Springer (2006).

United Nations. World Urbanization Prospects: The 2018 revision. United Nations. (2019).

Vuilleumier, S. and Prelaz-Droux, R. Map of ecological networks for landscape planning. Landscape and Urban Planning, 58, 157-170 (2002).