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The Impacts of Land Use Changes on Ecological Connectivity in the Makassar City

Ibrahim Djamaluddin[a]*, Poppy Indrayani[b,c], Yoenus Osman[a], Yasuhiro Mitani[b], Hiro Ikemi[b]

[a]*Faculty of Engineering, Hasanuddin University, Indonesia*
[b]*Faculty of Engineering, Kyushu University, Japan*
[c]*Faculty of Engineering, Fajar University, Indonesia*

Abstract

As the fifth fastest growing city in Indonesia, land use changes in the Makassar region have shown remarkable changes as consequences of urban expansion during the last 15 years. Therefore, environmental management and careful strategic spatial planning in landscape ecological network is crucial when aiming for sustainable development. This paper presents an evaluation of land use change based on 50m grid-mesh scale to characterize land use transition in the Makassar region over the last 15 years. The increasing phenomenon of urban area from 1997 to 2012 have caused the land cover of fishpond (13.5%) and swamp field (2.1%) of the Makassar region existed in 2012. Moreover, about 79% of mangrove forest in Tallo River Area is converted into fishpond. The impacts of land use changes from 1997 to 2012 on the landscape ecological connectivity in the Makassar region are evaluated by using Geographic Information System (GIS). The results have effective performance in identifying the vital ecological areas and connectivity prior to development plan in areas. This study has successfully pointed out the importance of understanding the land use changes of the Makassar region to the protection of environment.
Keywords: Urban development; ecological connectivity; land use; environmental conservation; GIS

1. Introduction

Indonesia is one of the fastest urbanizing countries in Asia. In 2015, population growth in urban areas is estimated to reach 59.35% of the total population (Parasati, 2013). If it is assumed that population growth in urban areas approximately reached 2.75% per year, then the Indonesian population who live in urban areas in 2045 will reach 82,37% of the total population of Indonesia. The impact of population growth on urban sprawl in many major cities in Indonesia has become a major issue in recent years. As the fifth fastest growing city in Indonesia, urbanization of the Makassar region has followed a model characterized by a low density of built-up area, which has revealed itself as tremendously negative for natural habits (Turner, 2005). Geographically, Makassar territory is roughly between 5° and 7° S, and 119° 20′ and 120° 30′ E, including the island of Selayar. In 2016, The Makassar number about 1.8 million, with an average population density of 8000 inhabitants per square kilometer. Fig.1 shows the change in population from 1971 to 2016. Makassar covers total area of nearly 177 km^2 which is divided into 14 districts. It is part of the Mamminasata Metropolitan Area (covering the city of Makassar and the regencies of Gowa, Maros, Takalar) which has a population of about 2.5 million which is expected to grow to around 2.9 million in 2020. The built-up area has expanded far faster than the population, indicating an increasingly lower density of the city. The urban sprawl is a major contributor to the lack of increase in the productivity of the landscapes of the Makassar area. These circumstances, inevitably, have led to a dynamic change in land uses composition and configuration, resulting in ecological processes changing at various spatiotemporal scales (Wuet al., 2011). Recently, the city government of Makassar proposes to create Tallo River Area where the city can strategically manage urban development in the land that is now undeveloped, because it is subject to regular flooding recently (see, Fig.2). Yet close to the city centre, it is the large area on downstream of Tallo River. Nevertheless, this is endorsed in the Mamminasata Spatial Plan (2006) and The Makassar City's Spatial Plan (2012) which identifies the Tallo River as a special development area. Consequently, planning the Tallo River Area will require an spatial analysis of land use changes to ensure that the potential development arising from urbanization are optimized to protect the environment.

In many areas with increasing urban sprawl, fragmentation has turned out to be virtually inevitable. Intensively exploited landscapes often display fragmentation, where patches of semi-natural habitat become progressively diminished and isolated (Selman, 2006). Generally, high ecological connectivity and a well-designed green network are assumed to better facilitate flows of energy, materials, and species, and thus are important for environmental conservation in developing landscapes (Crooks and Sanjayan, 2002). Similarly, green infrastructure (GI) is used with an emphasis on a system of natural areas as a backbone of landscape ecology. Definition of green infrastructure is strategically planned and managed networks of natural lands, working landscapes and other open spaces that conserve ecosystem values and functions and provide associated benefits to human

* Corresponding author
E-mail address: ibedije@gmail.com

populations (Benedict and McMahon, 2006). A green infrastructure network can be used to investigate conservation related to the land use planning. Based on the literatures, a green infrastructure in the United States and the Europe is therefore best achieved through an integrated approach to land use management and strategic planning in ecological network. Ecological landscape theory has provided set quantitative methods namely landscape metrics to characterize landscape pattern. However, there is a lack of quantitative methods to effectively assess ecological connectivity at regional scale, in a way that can be easily incorporated into the land use planning processes and the strategic environmental assessment (Múgica et al., 2002). As suggested by O'Neil et al. (1992) the simplest model that can adequately explain the observed phenomena is the most useful. Marulli and Mallarach (2005) proposed a methodological approach which is used in quantitative landscape ecology, allows turning current theories into useful spatial analysis tools for regional land use planning.

Therefore, this study aims to evaluate the impacts of land use changes on the landscape ecological connectivity in the Makassar region by using Geographic Information System (GIS). In order to effectively evaluate the respective goal, land use maps of the Makassar region were developed from availability of the digital topographic maps of 1:50,000 scales. Land use changes during the period from 1997 to 2012 were simulated, and then a number of landscape properties were identified. Adopting the ideas and methodologies in landscape ecology, the study provides a prognosis regarding the impact of land use changes on landscape ecological connectivity. The evolution of the landscape ecological connectivity is assessed using GIS.

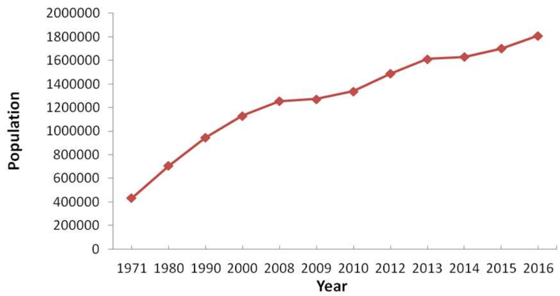
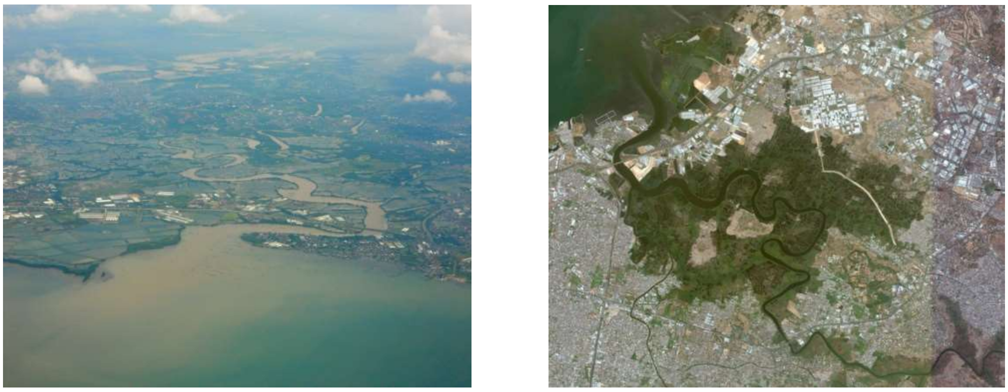


Fig. 1. Change in population of the Makassar City from 1971 to 2016.



(a) (b)

Fig. 2. Picture of Tallo River Area taken from air photo and the Google earth image.

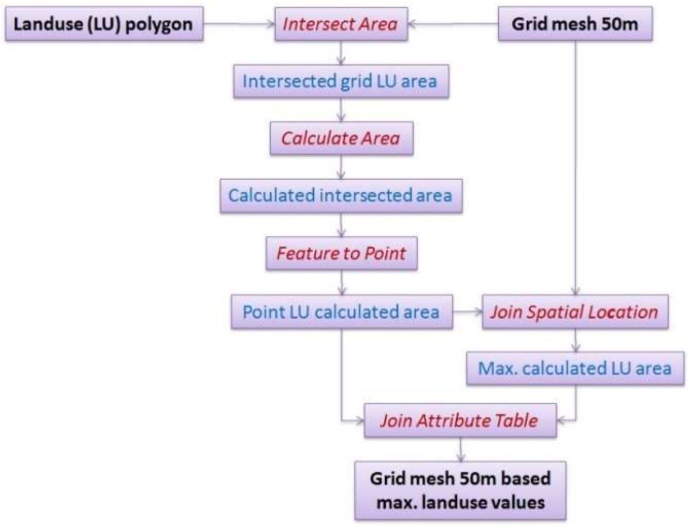
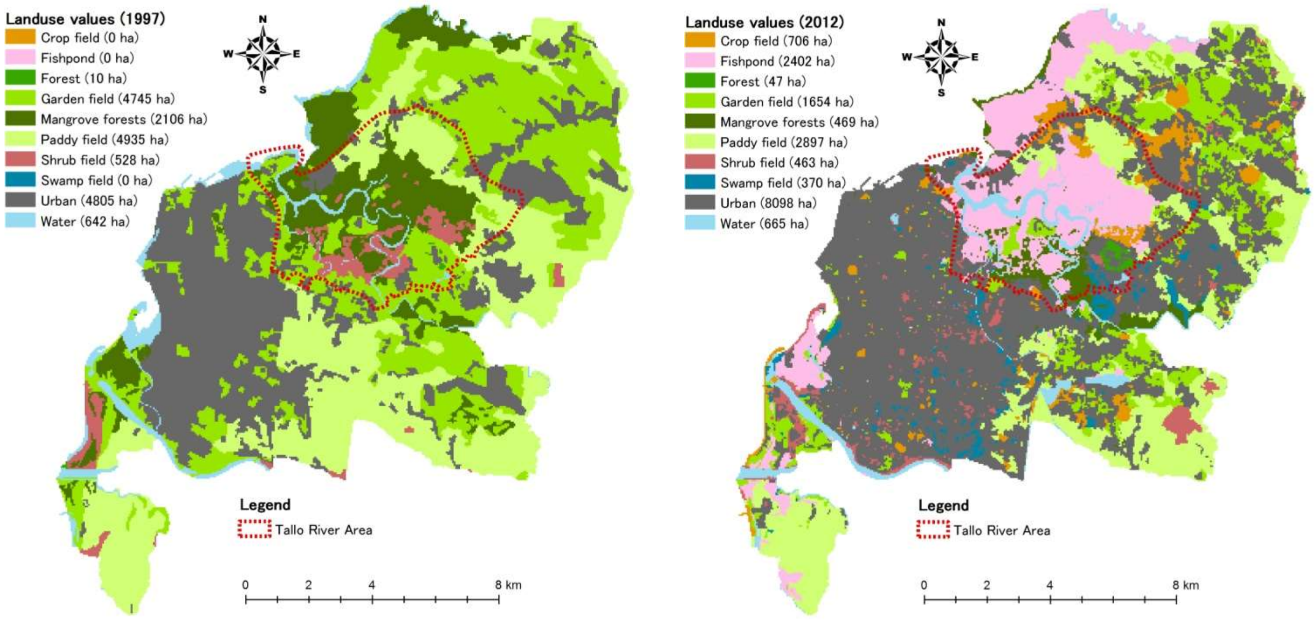


Fig. 3. Flowchart of GIS geoprocessing for creating the land use maps with grid mesh 50m.



(a) (b)

Fig. 4. (a) developed land use map of 1997; (b) developed land use map of 2012.

Table 1. Land use values in the Makassar (1997-2012).

Land use values	1997		2012	
	ha	%	ha	%
Crop field	0	0.0	706	4.0
Fishpond	0	0.0	2402	13.5
Forest	10	0.1	47	0.3
Garden field	4744	26.7	1654	9.3
Mangrove forest	2106	11.9	469	2.6
Paddy field	4935	27.8	2897	16.3
Shrub field	528	3.0	463	2.6
Swamp field	0	0.0	370	2.1
Urban	4805	27.0	8098	45.6
Water	643	3.6	665	3.7
Total	17771	100	17771	100

2. Land Use Analysis

2.1. Land use maps with grid mesh 50 m

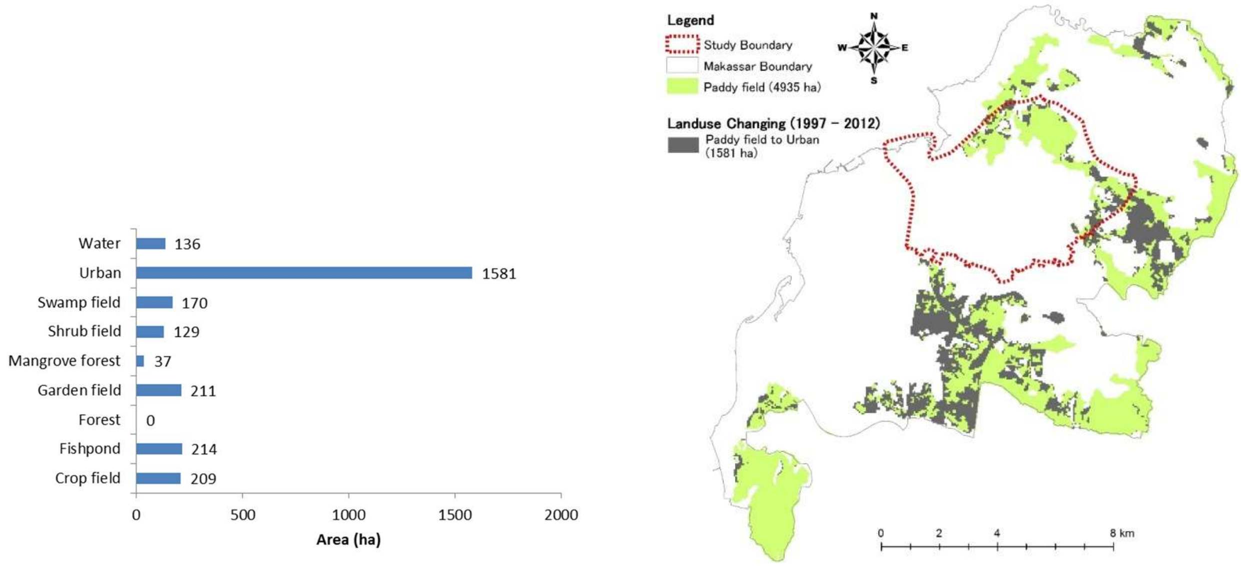
Geoprocessing is one of the most powerful components of a GIS. Geoprocessing is a framework and set of tools for processing geographic and related data. The large suite of geoprocessing tools can be used to perform spatial analysis in an automated way. In this research, the digital topographic maps of 1:50.000 scales provided by the city government of Makassar are proceed by using geoprocessing to create land use maps using grid mesh 50m. Land use division was determined based on land use boundary line of the topographic maps. The land use divisions for 1997 and 2012 are reclassified into 10 categories to provide identical class for spatial matrix analysis. Fig.3 shows the GIS methodology for creating land use map with grid mesh 50m. In geoprocessing, the land use polygons from the topographic maps are intersected with grid-mesh 50m from grid division analysis in which the grid-mesh has orientation of the world grid system. Intersected land use polygons are calculated to obtain the maximum area in each grid feature. Land use value for each grid is dissolved based on maximum area analysis in GIS. Therefore, the grid-mesh 50m based land use values can be obtained. Furthermore, Fig.4 shows the developed land use maps of 1997 and 2012 which is obtained from conversion of land use polygon into land use with grid-mesh 50m.

2.2. Land use changes simulation

The land-use maps have been developed to carry out an analysis of land-use changes using a GIS technology. By utilizing land-use maps of 1997 and 2012, the analysis of land-use pattern changes in the Makassar area can be performed based on 50m mesh scale. In the land-use map of 1997, the existence of crop field, fishpond, swamp field has not been clearly visible. In this year, the population is not affected extensively urban area development. In the land-use map of 2012, large fishpond area is developed due to conversion of mangrove forest for local peoples to do fishery. It is perhaps that in the recent year, the impact of large scale of regular flooding in the vicinity of Tallo river basin as natural drainage area which supported the local peoples to make the fishpond as a livelihood. In 1997, it is found that urban was occupied 27% of the Makassar area, paddy field was occupied 27.8 %, garden field was occupied 26.7% area, and mangrove forest area was occupied 11.9% (Table 1). It is noted that in the Eastern part of Makasssar, the land area was bordered by the sea, some of the sea area was assumed as future reclaimed land. In 2012, urban has increased to 45.6% of the Makassar area, in contrast to the decrease of paddy field to 16.3% and garden field to 9.3%. The increasing phenomena of urban area from 1997 to2012 have caused the land cover of fishpond (13.5%) and swamp field (2.1%) has existed in 2012. In addition, the occurrence of swamp field and fishpond which was counted as 15.6% from the Makassar area, has transformed the pattern of lowland mangrove forest, shrubs field in the vicinity of Tallo River.

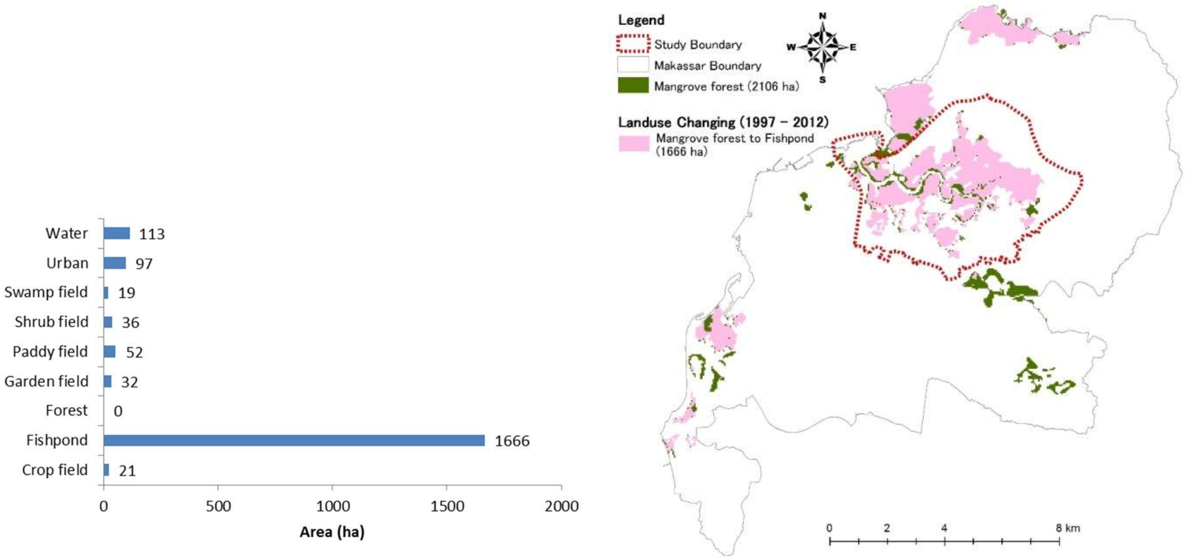
2.3. Detail land use change analysis

Fig.5 (a) shows the paddy field in 1997 changed to other land-use categories in 2012. In 2012, urban has increased to 32.0 % of the total area of paddy field. The increasing phenomena of urban area from 1997 to 2012 have caused the land cover of crop field (4.2%), fishpond (4.3%) and swamp field (3.4%) has existed in 2012. Spatial distribution of paddy field converted into urban areas is shown in Fig.5 (b). It is shown in the maps that agriculture field mostly occupied by urban area in the South and East part of the Makassar City. This is because that during the past one and half decade, Makassar City has experienced rapid urban transformation, represented by significant changes and large-scale expansion of the urban landscape on agriculture field. Declines in the intensity of agricultural land use and farmland abandonment have been discovered in many areas. This has posed additional challenges for the preservation of natural agriculture ecosystems.



(a) (b)

Fig. 5. (a) paddy field converted into other land use values; (b) spatial distribution of paddy field converted into urban area.



(a) (b)

Fig. 6. (a) mangrove forest converted into other land use values; (b) spatial distribution of mangrove forest converted into fishpond area.

Table 2. Urban area in 2012 resulted from the changed of land use values in 1997.

LU Value			LU Changing	
Name	Area (ha)	Area (%)	Name	Area (ha)
Crop field	0	0.0	Urban	8098
Fishpond	0	0.0		
Forest	1	0.0		
Garden field	1962	24.2		
Mangrove forest	97	1.2		
Paddy field	1581	19.5		
Shrub field	56	0.7		
Swamp field	0	0.0		
Urban	4292	53.0		
Water	109	1.3		
Total	8098	100.0		

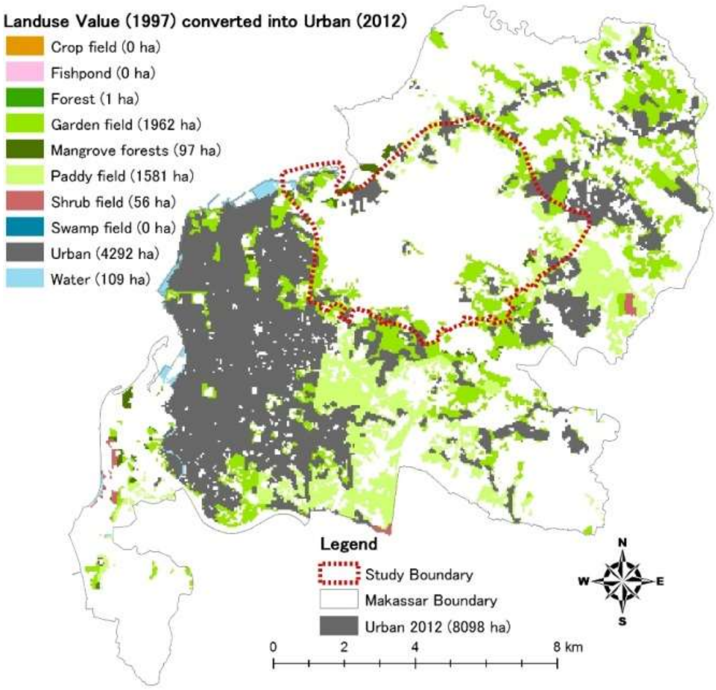


Fig. 7. spatial distribution of land use values of 1997 converted into urban area in 2012.

Fig. 6 (a) shows the mangrove forest in 1997 changed to other land-use categories in 2012. Based on the spatial data analysis, it is found that mangrove forest has changed into fishpond area about 79.1%. At the same time, some of mangrove forest converted into urban area (4.6 %). The Makassar City has lost around 2036 hectares (ha) of mangroves since 2012, equivalent to 96.7% loss of total mangrove area according to land use changes assessment study (see, Fig.6 (b)).

Land uses for the period of 1997-2012 have showed important changes, urban surface has grown up from 4,805 to 8,098 hectares which represents almost twice the urban expansion of a 15 years period. Table 2 shows the land use values in 1997 converted into urban area in 2012. From the land-use transition analysis, it can be noted that in 2012, garden field (24.2%) and paddy field (19.5%) mostly occupied by urban area of the Makassar City. Spatial distribution of land use values in 1997 converted into urban areas in 2012 is shown in Fig.7. It is illustrated that most of area in the Makassar City occupied by urban settlement since 2012. Increased economic development and population pressure on Makassar City are the major drivers for the transformation of land use values to urban areas. Moreover, the influences of cross-regional migration in the Mamminasata region are issues, recently.

3. Landscape Ecological Connectivity Analysis

Forman (1995) describes landscape connectivity as a degree of spatial connectedness among landscape elements such as patches, corridors, and matrix. Patch connectivity focuses on amount and arrangement of habitat patches, and thus effective distance between the patches becomes an important issue (Broquet et al. 2006). Corridor connectivity identifies linear features to promote dispersal through connectivity restoration (Graves et al. 2007). Matrix connectivity evaluates overall landscape mosaic, including landscape matrix to maintain maximum landscape continuity of non-built areas (Levin et al. 2007). Various methods are developed from general landscape ecological principles to measure landscape connectivity. Although there are a wide range of proposed connectivity measures and geometric analyses from very simple to highly sophisticated (Selman, 2006), categorizing the approaches into four groups (connectivity metrics, least-cost analysis, empirical models and graph-based models). The use of least-cost analysis has been increasing in recent landscape and ecological connectivity research because it calculates effective distance, a measure for distance modified with the landscape resistance (Adriaensen et al. 2003). Least-cost analysis formalized using mathematical language depend on a series of topological analysis of land use maps. This method can be easily implemented in GIS. The landscape ecological connectivity analysis consists of four steps including identification of ecological functional areas, calculation of barrier effects index (BEI), and evaluation of landscape ecological connectivity index (ECI).

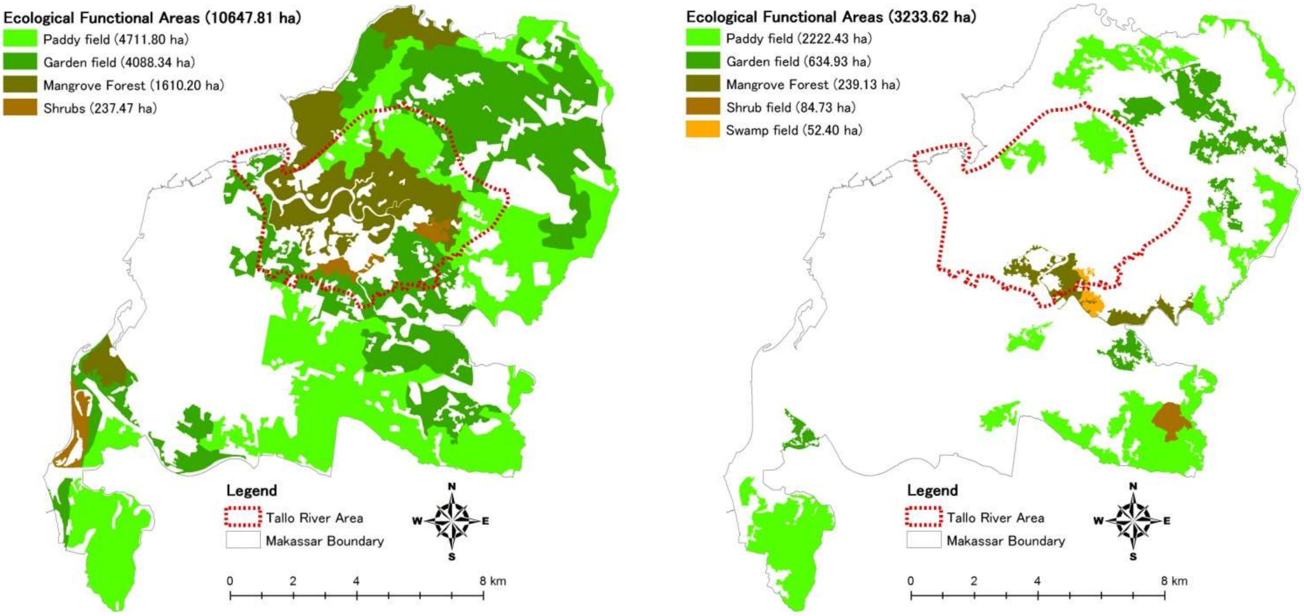
3.1. Identification of ecological functional areas

Decision about the ecological functional areas that need to be connected is important for assessing the ecological connectivity (Girvetz et al. 2008). Using the land use maps, topological analyses of the land cover categories were performed (Fig.8). Depending of each land cover, simple ecological functional areas are defined by a minimum surface (Sr = 50 hectares), based on a review of existing literatures (Bender et al., 1998). The areas that could not be considered simple ecological functional areas can be grouped into forest mosaics or agricultural mosaics or agroforest mosaics, based on existing literatures (Forman, 1995). The GIS spatial analysis allowed obtaining six types of ecological functional areas, as shown in Table 2. Forest is relative small spectrum size (less than 50 hectares), thus it is not included in the ecological functional areas. All remaining areas were considered fragmented areas.

3.2. Barrier Effects Index (BEI) and Ecological Connectivity Index (ECI)

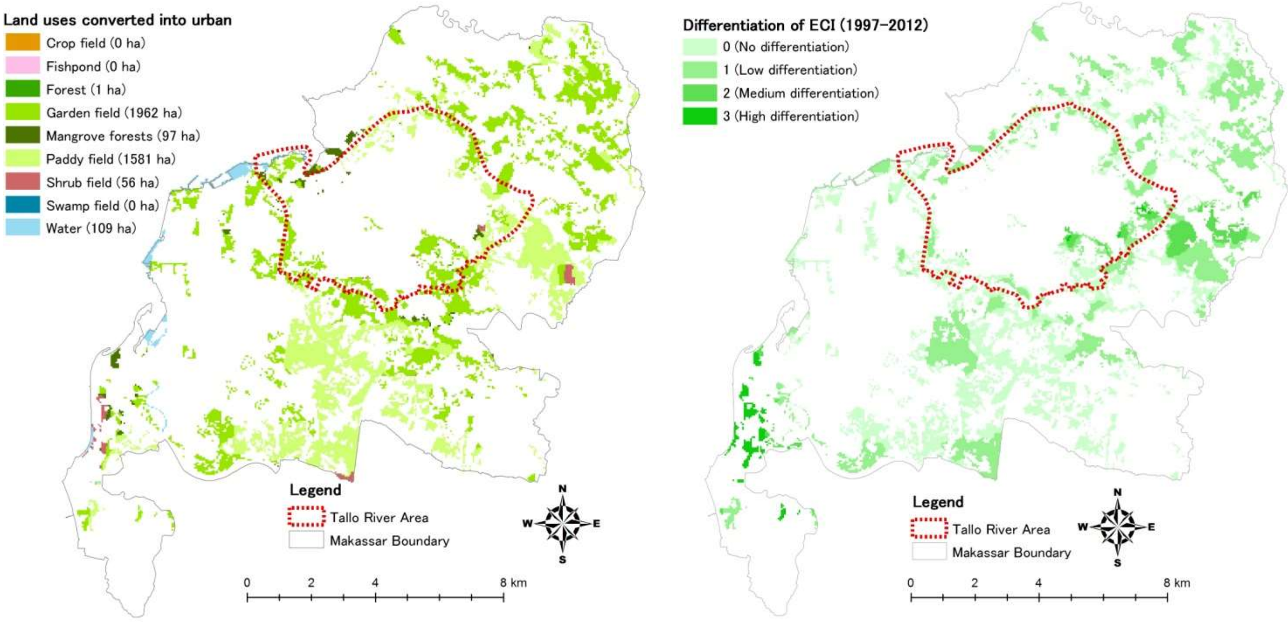
Urban development often hinders the movement of ecological processes. Barriers include all artificial land uses that create obstacles to the flow of energy, information, or matter across the matrix, in other words, the landscape resistance. To reflect the barrier effects in measuring ecological connectivity, a group of artificial attributes were designated with different weights on each attribute depending on the relative influence on the entire landscape. The maximum level of weight was given to the built-up areas comprised of high and medium-density residential development because the built-up areas are for the most time impermeable to movement of many species (Fahrig, 2003). Since this study does not consider water body related species, water bodies such as rivers, lake and fishpond were counted as medium-level barriers. The ecological connectivity model is primarily based on the least-cost analysis that considers the ecological functional areas and an impedance surface which incorporates the barrier effect and a potential affinity matrix.

Ecological connectivity refers to the functional aspects of the actual connection between the different elements of the landscape. An ecological connectivity index (ECI) is defined based on a cost-distance model that considers the different functional ecological areas and an impedance surface which incorporates the barrier effect and a potential affinity matrix for all the land use types. The model applies the cost distance analysis using two input data: one is origin surface for each type of ecological functional area and second is impedance surface resulting from the application the effect of the barriers. Finally, to transform the continuous values of the cost distance to discrete values based on a decimal scale, the ECI is calculated, according Marulli and Mallarach, (2005).



(a) (b)

Fig. 8. (a) distribution of the ecological functional areas in 1997; and (b) in 2012.



(a) (b)

Fig. 9. (a) Land use values changed into urban; (b) Differentiation of the ECI.

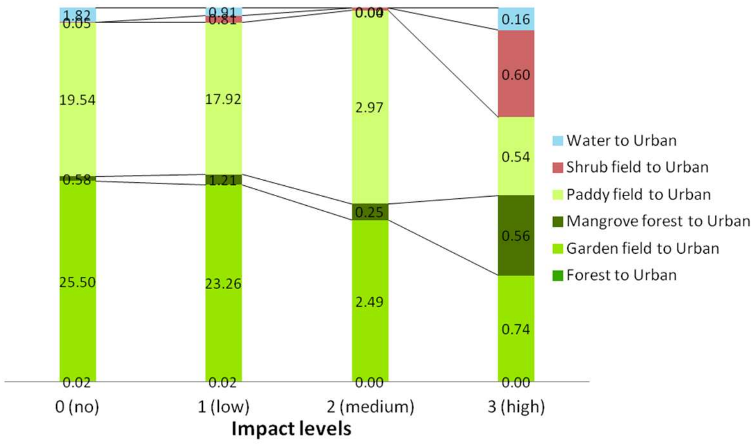


Fig. 10. Differentiation of ECI resulting from the conversion of each land use to urban.

4. Results and Discussion

From the spatial land-use transition analysis, it can be noted that in 1997, agriculture played a predominant role, particularly in the plain area in the Makassar city. Moreover, the availability of water from the river to agriculture irrigation has determined the agriculture development pattern. The population in 1997 was small and distributed in the agricultural villages established to take advantage of the possibilities of irrigation from the Tallo River basin. The population of some sub-districts reflected the urban settlements in the Makassar area. All of the sub-district development was carved out of potentially useful agricultural and garden field; although the area was very large that has dominated the sub-districts at this time. In addition, a decrease in agriculture and garden field use intensity implies more future urban expansion at the expense of other ecosystems. Therefore, understanding how urban land expansion affects agricultural land use intensity will facilitate a better examination of the environmental impacts and the sustainability of the utilization of land resources. The increasing phenomenon of urban area from 1997 to 2012 have caused the land cover of fishpond (13.5% of the Makassar area) existed in 2012.

In addition, the occurrence of swamp field and fishpond was counted as 15.6% from the Makassar region, has transformed the pattern of mangrove forest, shrubs field in the vicinity of Tallo River Area. Mangroves are important forested wetlands in Makassar City have now banned the conversion of mangroves for fishpond and they assess the impact on the environment before using mangrove areas for other purposes. The rate of mangrove loss is significantly higher than the loss of any other types of forests. If deforestation of mangroves continues, it can lead to severe losses of biodiversity and livelihoods, in addition to salt intrusion in coastal areas. Makassar City needs to engage in a more effective conservation and sustainable management of the mangroves and other wetland ecosystems especially around Tallo River Area. Environmental damages caused by the loss of mangroves in Tallo River Area in Makassar City should be urgently addressed recently, calling for better mangrove protection and management programmes.

Conversion of each land use value into urban area such as paddy field to urban, garden field to urban, mangrove forest to urban and shrubs field to urban shows the different levels of impact on the ECI (Fig.9). It is shows that the shrub and mangrove forest has relatively high impact levels to the ECI (Fig.10) than other land use values.

5. Conclusion

In this paper, land use changes analysis has been introduced to investigate pattern of spatial and temporal change in the Makassar City. GIS geoprocessing model was used to develop the land use maps from the availability of topographical data, and GIS integrated analysis is applied to simulate the spatial and temporal land use changes from 1997 to 2012 based on grid mesh 50m. The results of the spatial and temporal analysis showed there is an important change in land use in the 1997-2012 periods. An evaluation of the impacts of land use changes to the landscape connectivity index in the Makassar City was conducted using GIS. The ecological functional areas were identified by topological analysis using the developed land use maps. Landscape ecological connectivity method proposed by Marulli and Mallarach (2005) was adopted to calculate the ECI in the Makassar region. The impact of the conversion of each land use value into the urban area on the differentiation of the ECI level was analyzed using GIS.

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