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THE DYNAMICS OF LAND USE CHANGE IN PADANG CITY FOR HYDROLOGICAL MODELING

*Yudi Antomi[1], Ernawati[2], Triyatno[3], Ikhwan[4] and Siti Fatimah[5]

*1,2 Remote Sensing Technology Program- Universitas Negeri Padang, Indonesia
3,4 Department Environment Science, Universitas Negeri Padang, Indonesia
5 Department of History, Universitas Negeri Padang, Indonesia

*Corresponding Author, Received: 24 May 2019, Revised: 29 July 2019, Accepted: 15 Aug. 2019

ABSTRACT: The purpose of this study is to predict future land use scenarios from a spatial perspective and quantitatively calculate how hydrological balance in Padang City as part of environmental services. This study uses temporal Landsat images, field surveys, focus group discussions, and analysis of the impacts of land-use change and its solutions. Field surveys were conducted to test the accuracy of field interpretation and data collection such as hydrology and morphology (physiography). The result of this study is the wide difference in land use prediction with the free scenario and the bound scenario is not very significant. The results of the research in the hydrological model show that Padang City has experienced an increase in the surplus of surface water due to changes in land use from natural areas to anthropogenic. Land-use scenarios that represent the use of sustainable environmental services are to revise the existing Padang City spatial pattern through environmental service assessments to obtain sub-catchments or sub-catchments that need to be improved (rezoning) in accordance with the application of zoning patterns.

Keywords: Hydrological, Land Use, Environmental Services, Padang City.

1. INTRODUCTION

In harmony with this, socio-economic development has necessarily led to changes in land use from natural areas to cultivated areas. [1-3] mentions that human activity has resulted in the loss of ecosystem services that actually provide the ultimate advantage for humans themselves. Talking about environmental services related to biodiversity, it should all be involved in the preservation of the region (governance of the region) that is essential for well-connected biodiversity to increase the benefits to society both now and for the future [4]. Therefore, sustainable environmental services together with social and economic welfare become essential for human survival [5].

The Millennium Ecosystem Assessment (MEA) [6] defines environmental services as a service for human beings, which can be proven by several things as a provider of food production, carbon uptake, erosion resistance and or as a provider of tourism/recreation services. Although it is very clear how environmental services in terms of ensuring the quality of human life, but the service environment itself is very vulnerable and depend on the quality of ecosystems that tend to decline due to human activities. This phenomenon can be simplified into population growth will increase demand from environmental services, but on the other hand environmental services itself decreases with human growth [7-8]. Some literature suggests that there are various factors that influence supply-demand interactions between environmental services and socio-economic systems that can be analyzed and searched for in the form of interventions, one of the most popular ones is developing land-use policy scenarios [9].

Some forms of policy intervention in local governance planning are still unilateral such as decisions or policies of the agricultural sector in terms of development and improvement of agricultural products, or the extension of settlement areas, or the relocation of development direction orientation caused by potential factors of natural disasters to the rightful regions conserved. Such forms of intervention can negatively impact on environmental services if not assessed in an integrative manner from multiple perspectives [10]. Therefore, in addition to assessing the availability of existing environmental services, it is also necessary to predict the impact of land-use change on future environmental services through various scenarios. These scenarios can serve as reference materials and considerations in the management plan and assist in decision-making to reduce the risk of declining quality of environmental services [11].

Taking into account the physiography condition of Padang City, from the east to the west coast consists of a complex ecosystem region with a unique landscape entity as a provider of environmental services for the people of Padang City. Upstream all the rivers flowing is directed east with hilly topography, bumpy and dominated by forest as buffer area (buffer). Type of soil and rocks in this region is dominated by volcanic to an alluvial fan on the left-right of the river in sloping areas with the type of use of mixed garden, fields, rice fields, and settlements. In the west more dominated by alluvial plains with the highest concentration of settlements in this area.

From the results of the identification of land use changes originating from Landsat images in 1990-2016, the direction of the development of residential areas has shifted from west to east on more sloping slopes to slopes. This shift in development orientation needs attention since the eastern area of Padang City is a buffer zone with the status of forest areas designated as protected forest and conservation area [12]. Such a development orientation is also pointed to be the cause of the high number of natural sediment and hydrological disasters in Padang City in at least the last 1 decade, besides caused by bad drainage system especially in new settlement areas in the east of Padang City. While so far, there has been no comprehensive research involving multiple perspectives for such cases particularly in the study of environmental services with more integrative methods.

The development trend of land use in Padang City has shifted to the east with the function of the area that should be the buffer zone, not the cultivation area. The narrowness of land availability in the west, coupled with high hazard levels for the earthquake and tsunami disaster, is allegedly the main cause of the shift in the development, although in the eastern region of Padang City itself will be directly adjacent to the protected forest and Conservation area which is designated as a buffer zone to ensure the survival of life including human.

The development of land use in the eastern part Padang City of and buffer zones may threaten the balance of environmental services and cause environmental degradation if land-use patterns do not show a supportive pattern of not being able to become an ideal land use for erosion level, ensuring water availability and food security [13]. Therefore, it is important to examine and develop modeling that can represent patterns and changes in temporal land use so that it can be used as a basis in making land use map in the future with several scenarios through the quantification of hydrological balance as an indicator of environmental services.

The purpose of this study is to predict future land use scenarios in spatial perspective and quantitatively quantify how habitat quality is calculated based on the weighting of land use types and hydrological balance in Padang City as part of environmental services. Through the development of some future land use scenarios, this study is expected to provide stakeholder input on how to design and alternative spatial or spatial management plans in Padang City in the face of changing trends in the development of residential areas friendly to ecosystem balance and environmental services in Padang City.

2. RESEARCH METHODS

The research approach is descriptive quantitative approach with partial data retrieval technique with qualitative approach having a spatial basis. This research starts with the interpretation of Landsat temporal image, field survey, focus group discussion, spatial analysis and modeling. Adds image interpretation was conducted to collect temporal land use data, a field survey was conducted to test the accuracy of interpretation and collect field data such as hydrology and morphology (physiographic). While the analysis and modeling are done quantitative approach by using raster data with pixel value as the unit of analysis in spatial statistics, and quantification (weighting) on qualitative data until putting into the model.

2.1 Land Use

Land use data were obtained from the classification of remote sensing image of medium spatial resolution ie Landsat images. Landsat images data is a data type images of the earth temporal shooting every 16 days in the same location in an area with the division of capture zone through the numerical index path/row. Add this type of data has the advantage of being able to record the surface of the earth surface periodically and can provide convenience in the acquisition of periodic data that can be used as a basis in analyzing land-use change.

Landsat images data is obtained from the official USGS web page http://glovis.usgs.gov. All data IDs listed in Table 1 are downloaded and processed according to the rules of remote sensing data processing. Landsat images data that has been downloaded is data with level 1 that is raw data (raw data) so that before the classified need to be done the various process to reduce the possibility of technical error and natural factor in the image (atmospheric and radiometric effect).

Table 1 Landsat Set Data

Path/Row	Period	Series	Entity ID
127/60	<1990	5 TM	ETP127R61_5T19890725
	1990-2010	7 +ETM	LE07_L1TP_20010531_20170205_01_T1
	>2010	8 OLI	LC08_L1TP_12061_20170722_20170728_01_T1

Landsat images interpretation is done through a supervised classification approach using e-Cognitionrule set mode with multiresolution fragmentation and spectral differences [18] [19] for more details can be seen in the data analysis in Fig 1. The types of land use are determined into four groups: forest, agriculture (moor, mixed plantation, and rice field), bush, built-up areas (settlements and open land), and water body.

The accuracy of Landsat images interpretation results it was tested by Kappa index (accuracy) using 52 random sample points. The location and type of land use tested is determined through the appearance of land use types on high-resolution images and field survey results. Explain contingency matrices are used to calculate producer accuracy (omission errors), user accuracy (commission errors), and overall accuracy. The higher the accuracy value indicates that interpretation results are more accurate.

2.2 Water Supply Model (Hydrology)

In a spatial perspective, water supply mapping requires models and indicators to estimate the volume of water extracted and utilized in spatial units such as river basins for human consumption. This model uses the Water Yield tool issued by the Natural Capital Project under the name of the Integrated Valuation Ecosystem Services and Tradeoff (InVEST) parent modeller.

Through this model the amount of water flowing from each raster pixel as the total amount of reduction from evapotranspiration. This model requires the following data sets: a) rainfall and evapotranspiration data are processed using the Har-Grieves formula; b) soil depth data; and c) biophysical data containing the depth of rooting for each type of land use and millimetre unit. The Water Yield model is based on the Budyko curve and the average annual rainfall. In determining the water yield $\boldsymbol{Y(x)}$ for each pixel with the formula [14]:

$$Y(x) = \left(\mathbf{1} - \frac{\boldsymbol{AET(x)}}{\boldsymbol{P(x)}}\right).\boldsymbol{P(x)}$$

Where $\boldsymbol{AET(x)}$ is the actual annual evapotranspiration for pixels x and $\boldsymbol{P(x)}$ is the annual rainfall in pixels x. The water cycle is simplified, including only the parameters shown in the colours, and ignores the parameters shown in grey. Results, such as calculated by this model step, then adjusted to other consumptive uses and applied to hydropower energy and value forecasts. For Land Use and Land Cover (LULC), the evapotranspiration part of the water balance, $\frac{\boldsymbol{AET(x)}}{\boldsymbol{P(x)}}$ based on the expression of the Budyko Curve [15]:

$$\frac{\boldsymbol{AET(x)}}{\boldsymbol{P(x)}} = \mathbf{1} + \frac{\boldsymbol{PET(x)}}{\boldsymbol{P(x)}} - \left[\mathbf{1} + \left(\frac{\boldsymbol{PET(x)}}{\boldsymbol{P(x)}}\right)^{\omega}\right]\mathbf{1/\omega}$$

Where $\boldsymbol{PET(x)}$ potential evapotranspiration and $\boldsymbol{\omega(x)}$ are non-physical parameters that characterize the nature of soil-climatic properties [15]. The potential for evapotranspiration $\boldsymbol{PET(x)}$ is defined as:

$$\boldsymbol{PET(x)} = \boldsymbol{K_c(\ell_x)}.\boldsymbol{ET_0(x)}$$

Where $\boldsymbol{ET_0(x)}$ is an evapotranspiration reference of pixels $\boldsymbol{x}$ and $\boldsymbol{K_c(\ell_x)}$ is a vegetation (evapotranspiration coefficient associated with LULC $\boldsymbol{\ell_x}$ in pixels $\boldsymbol{x}$). $\boldsymbol{ET_0(x)}$ reflects local climatic conditions, based on the evapotranspiration of reference vegetation such as alfalfa grass growing at the site. L_d $(\boldsymbol{\ell_x})$ is largely determined by the vegetative characteristics of land use/land cover found in the pixel [15]. $\boldsymbol{K_c}$ set $\boldsymbol{ET_0}$ value to plant or vegetation type in each pixel of land use / land cover map. $\boldsymbol{\omega(x)}$ is an empirical parameter that can be expressed as a linear function $\boldsymbol{A}\frac{\boldsymbol{WC*N}}{\boldsymbol{P}}$, where N is the number of events per year, and $\boldsymbol{AWC}$ is the available volumetric water content (see below for additional details). While further research is underway to find out which functions best describe global data, we use the phrase proposed [15] in the InVEST model, and thus define:

$$\boldsymbol{\omega(x)} = \boldsymbol{Z}\frac{\boldsymbol{AWC(x)}}{\boldsymbol{P(x)}} + \mathbf{1.25}$$

Where $\boldsymbol{AWC(x)}$ is the available volumetric water (mm) water content [15]. The soil texture and effective root depth define $\boldsymbol{AWC(x)}$, which sets the amount of water that can be retained and released into the soil for use by a plant. Estimated as a plant Product Available Water Capacity (PAWC) and minimum roots limit the depth of the layer and the depth of root vegetation:

$$\boldsymbol{AWC(x)} = \boldsymbol{Min}\ (\boldsymbol{rest.layer.depth.root.depth}).\boldsymbol{PAWC}$$

The depth of the root barrier layer is the depth of soil where root penetration is hampered by physical or chemical characteristics. The depth of harvesting of vegetation is often given as a depth wherein 95% of plant-type root biomass occurs.

PAWC is the available crop water capacity, ie the difference between field capacity and wilting point. z is an empirical constant, sometimes referred to as a "seasonal factor", which captures local precipitation patterns and additional hydrogeological characteristics. This is positively correlated with N, a number of shows annually events. The term 1.25 is the minimum value $\boldsymbol{\omega(x)}$, which can be seen as the value of vacant land (when the root depth is 0), as explained by [15]. Following the literature [15], the value of $\boldsymbol{\omega(x)}$ is limited to a value of 5. For other LULC (open water, urban, wetlands), actual evapotranspiration is calculated directly from the evapotranspiration reference $\boldsymbol{ET_0(x)}$ and has an upper limit determined by precipitation:

$$\boldsymbol{AET(x) = Min(K_c(\ell_x).ET_0(x), P(x)}$$

Where $\boldsymbol{ET_0(x)}$ is the reference evapotranspiration, and $\boldsymbol{K_c(\ell_x)}$ is the evaporation factor for each LULC [15]. Guidelines for estimating $\boldsymbol{K_c}$ factors are provided in the "Data sources" section. The water yield model generates and removes the total and average amount of water at the sub-watershed level.

3. RESULT AND DISCUSSION

Land use is extracted from earth surface objects recorded on satellite images. In this study, the type of land use used consists of eight classes namely primary forest, secondary forest, built area, mixed garden, open land, rice field, bush, and water body. Data sources from land-use classes were derived from the Landsat image classification of 1989, 2001 and 2017 reinforced by classification testing using the sampling method. The number of samples of 50 points was sampled on the date of September 14-17, 2017.

3.1 Projection of Land Use Change

The prediction of land-use change implements land use allocations and changes to meet "demand" based on the mechanism of the attraction of the region (a market mechanism) without any limitation in the utilization of space. Based on the calculation of land-use area in Padang City using Land Change Modeler (LCM) processing equipment, starting from 2017 until 2040 can be seen in Table 2 below.

Table 2 Predicted of Land Use Change.

No	Land Use	2017	2020	2025	2030	2035	2040
1	Primary Forest	88,141	86,109	84,142	82,844	81,519	88,141
2	Secondary Forest	31,878	31,844	31,807	31,512	31,251	31,878
3	Built Area	8,980	9,745	10,494	11,211	11,916	8,980
4	Mixed Gardens	15,360	16,237	17,081	17,685	18,290	15,360
5	Open Land	1,332	1,365	1,398	1,431	1,464	1,332
6	Wetlands	7,831	7,429	7,040	6,680	6,329	7,831
7	Bush	17,248	18,041	18,808	19,407	20,002	17,248
8	Water Body	54,977	54,977	54,977	54,977	54,977	54,977
Total (Ha)		225,747	225,747	225,747	225,747	225,747	225,747

Source: Data Analysis of 2017.

3.2 Scenario Boundary (RTRW) and Business as Usual (BaU)

Predicted of land use in 2030 in Padang City using Business as Usual (BaU) and boundary scenario (RTRW) difference is not significant in each class. The area of the primary forest using the free scenario is 84,136 Ha, while using boundary scenario of primary forest area is 84,141 Ha. Furthermore, to predict the area of the secondary forest using a free scenario that is 31,811 Ha, whereas by using boundary scenario by the area of secondary forest 31,806 Ha. To predict the built-up area using the free scenario that is 10,493 Ha, while using boundary scenario of the area built 10,494 ha. Furthermore, the prediction of the area of mixed gardens using the free scenario is 17,081 Ha, while using boundary scenario of mixed gardens area is 17,082 Ha. To predict the area of open land using the free scenario of 1,398 Ha, while using boundary scenario 1,397.97 Ha. To predict the area of the wetlands using the free scenario is 7,040 Ha while using boundary scenario wetland area of 7,039 Ha. To predict the extent of bush using the free scenario is 18,809 Ha, while using boundary scenario bush 18,808 Ha, whereas for prediction of water body area from both scenarios remain is 54,977 Ha. For more details can be seen in Table 3 and Fig 1 below.

Table 3 Predicted Land Use Change Year 2030.

Land Use	2030 "BaU"	2030 "RTRW"
	Area (Ha)	
Primary Forest	84,137	84,142
Secondary Forest	31,811	31,807

Land Use	2030 "BaU"	2030 "RTRW"
	Area (Ha)	
Built Area	10,493	10,494
Mixed Gardens	17,081	17,082
Open Land	1,398	1,397
Wetlands	7,040	7,039
Bush	18,809	18,808
Water Body	54,977	54,977
Total (Ha)	225,746	225,746

Source: Data Analysis of 2017.

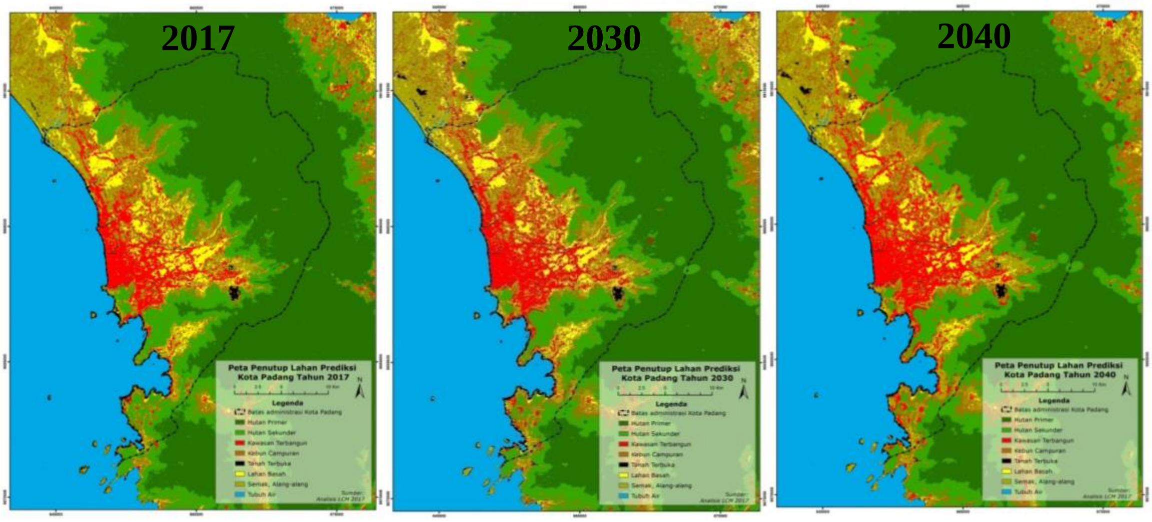

Fig 1 Predicted Land Use Maps of 2017, 2030 and 2040
Source: LCM Analysis Results (BaU).

3.3 Water Availability Model

Models of aquatic products, excluding estimates of the volume of pure water absorbed or left on a land or basin (Watershed). Explain this model is a function of the magnitude of falling rainfall to earth that is reduced by evapotranspiration and root depth (infiltration) in a type of land use. So this model can represent the volume of water that is not absorbed by the soil and does not evaporate so it is the quantity of surface water which when analyzed can further to measure the potential for erosion and flooding. In addition, the volume of water that is too large can provide losses if not managed properly because it can indicate the high pollution of water carried by sediments especially upstream areas identical to agricultural and forest areas.

In this study, water yield analysis is only used to measure and represent how the conditions of a land-use contribute to maintaining the hydrological balance between evaporation and soil absorption. Where the hypothesis for this section is, the greater the volume of water from the analysis of the water yield model then the soil type conditions are not good for the hydrological balance.

To be able to discuss this section then the area of Padang City is divided into 7 watersheds based on the appearance of the river objects using a digital elevation model (DEM) data. In general, in Padang, the highest rainfall falls on the west (coastal) area with eastward degradation ranging from 4500-3000 mm/year. On the results map Fig 2 and 3 of Habitat Quality of Padang City Year 2030 Bussiness as Usual Scenario (BaU) and RTRW, it is seen that upstream (east of Padang) is the region with the lowest water yield. In this area is relatively filled by the type of land use of primary forest and secondary forest and dryland farming (mixed garden). In addition, in the upstream area, the slopes are relatively steeper so that the root depth will also be lower, but it is filled by forest plants so that the evapotranspiration value is also high, as well as its infiltration is also high. For more details can be seen in Table 4 and Fig 2 below.

Table 4 Habitat Area Scenario.

Watersheds	Water Volume (M^3)		Surplus BAU	
	BAU	RTRW	M^3	Percentage
1	288,045,007	287,608,288	436,719	0.15
2	470,070,262	469,900,826	169,436	0.04

3	105,893,571	105,771,299	122,272	0.12
4	23,566,244	23,537,855	28,388	0.12
5	63,639,336	63,617,152	22,183	0.03
6	540,933,216	541,169,043	-235,827	-0.04
7	421,476,801	421,714,985	-238,184	-0.06

Source: Data Analysis of 2017.

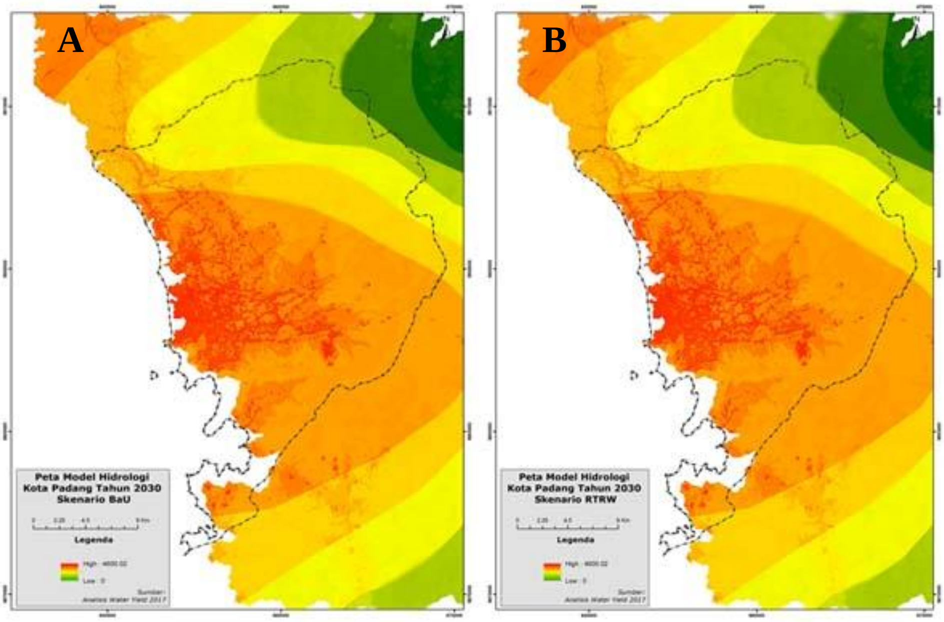

Fig 2 Map of Habitat Quality of Padang City Year 2030: A) Bussiness as Usual Scenario (BaU) and Intervention Scenario (RTRW).

Unlike the downstream areas where most of them are filled by anthropogenic areas such as settlements, wetland and dry farming areas. In this area, water yield has the highest value with the comparison between 2 scenarios, BaU and RTRW (see Table 4). In the table shows that the highest difference between the two scenarios lies in the basin number 1 which includes Koto Tangah sub-district with a magnitude of 0.15% difference. In areas where using the RTRW scenario, water yields will be reduced by 0.15% more when compared to non-intervention scenarios (BaU), or equivalent to 436,719 m^3 of water. The ability of the RTRW role in reducing the rate of land-use change, in this case, is clearly seen, where the results of the analysis of land-use change show that in Koto Tangah sub-district is estimated to change land use from natural areas to anthropogenic areas from 2017-2030 of 197.40 Ha in scenario BaU, while in the RTRW scenario is only 195.45 Ha.

Tabel 5 LULC Change Scenario.

Watersheds	Change LULC (Ha)	
	BaU	RTRW
1	197.40	195.45
2	258.69	258.54
3	46.59	46.11
4	9.36	9.09
5	89.16	89.79
6	143.43	141.51
7	99.15	98.40

Source: Data Analysis of 2017.

Similarly, 2 watershed to 5 watershed which equally shows the water volume surplus in the BaU scenario. 5 of these watersheds need special attention because their future land-use change rates potentially disrupt the hydrological balance and can adversely affect surface water conditions in the form of flooding, erosion and sedimentation from upstream areas. When carefully considered, the rate of land-use change in each watershed has a strong relationship with the amount of water yield.

3.4 Land Use Scenarios that Represent Sustainable Services

The Spatial Plan Map used in the model in this study is a map of the 2010-2030 Padang City Space Pattern designed for the purpose of zoning arrangements in the Padang City area for a period of 20 years. In the process of drafting the zonation, of course, inputs that are not only sourced from stakeholders such as government elements and the interests of conservation organizations are needed. The sub-chapter in this study entitled land-use scenarios representing sustainable environmental services from the results of the evidence through modeling as discussed earlier through water availability modeling shows that the intervention scenario by applying the zoning pattern of the spatial pattern is a very good step in protecting the has been proven by the type of environmental service model. It is proven that the RTRW scenario can reduce the rate of land-use change especially in the natural area from the opportunity of the change to the cultivation area (anthropogenic).

In fig 3^{A} the 2010-2030 year spatial pattern zoning arrangement is applied properly then the land use pattern should look like on the map with the BaU scenario (Fig 3^{B}) where the green belt area and the protected forest area are not really used for cultivation because it is a buffer zone for the continuity of ecosystem services for Padang City. Ideally, the land use pattern that represents sustainable environmental services is as presented on the map under the BaU scenario, but in fact, it is very difficult to make it happen using the RTRW scenario in the model only able to bring up land-use patterns on the map under the RTRW scenario. For more details can be seen in Fig 3 below.

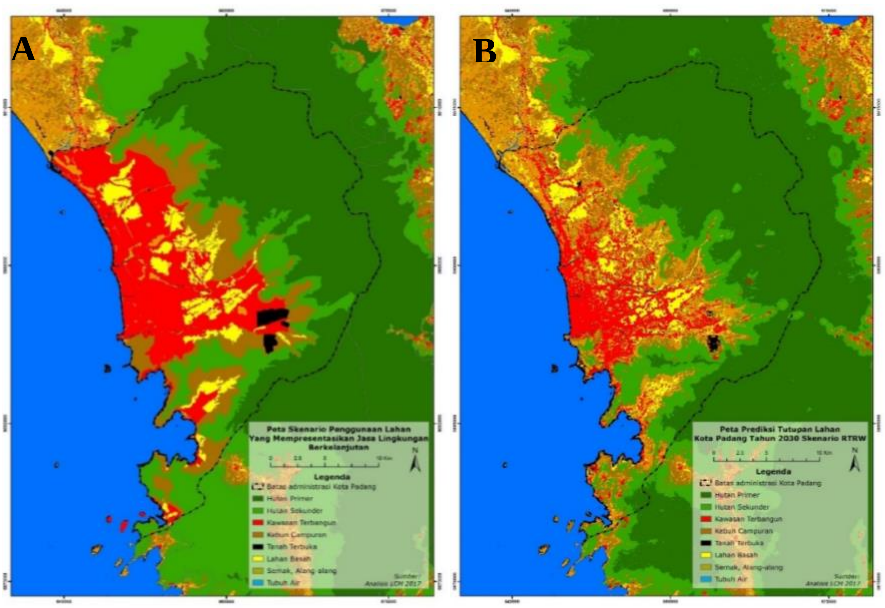

Fig 3 A) Land Use Map Representing Sustainable Services Until 2030 Scenario BaU and B) Land Use Map of Padang City Year 2030 Intervention Scenario (RTRW).

However, the prediction results in this research, although using the scenario of RTRW since 2017 has not been able to realize spatial pattern like on the map with RTRW scenario. This comparison of two types of land use proves that some improvements in zonation, especially in sub-districts covering upstream areas such as Koto Tangah Subdistrict, which in recent years have shown a very real development increase. In addition to Koto Tangah sub-district, there are also other sub-districts such as Kuranji, Lubuk Begalung, East Padang, West Padang, South Padang and Pauh. These sub-districts are sub-districts with topographic conditions that become watershed catchments (watershed) upstream areas, where such conditions are very sensitive to land-use change.

Inappropriate management of land use can lead to environmental services conditions for Padang city within the next 2 decades. Therefore, the point of view in this study focuses more on how types of land use offered as zoning spatial patterns not only prioritize anthropogenic aspects but also known anthropogenic aspects that more to the provision of opportunities in other living things other than humans to be able to live and multiply through corridors and habitat areas to suit their respective lives.

The results of this study are consistent with [16] research, where land use management through reducing or efficient use of land by humans can reduce ecological risks and also achieve fuller and more sustainable environmental services benefits in the future. The process of analyzing and using several scenarios for land use has also been done by [17], where they identified the appropriate options for land use planning in Sumatra and then modeled and calculated the conditions of their environmental services under the RTRW scenario. So also with [18] where they identify and define 5 future land use scenarios involving more realistic stakeholders in southeastern Australia.

The main conclusion of their research is that the framework of environmental services with the instruments used also in this study can be a framework in assessing the accuracy and choosing which scenarios are best applied in future land use planning. Not much different from the research [19] where they use the full environmental service instruments using InVEST tools to measure the accuracy of spatial patterns in land use planning so that various alternatives for future land use planning are obtained. Understanding that, for Padang City area, it is also necessary to do an assessment as it is out in this research that land use planning is a planning, it is necessary to simulation to see how the plan can run so that it needs a modeling using a more integrative service environment instrument in run the system.

4 CONCLUSION

So it can be concluded that the wide difference in land use prediction using free scenario and the bound scenario is not very significant. Water modeling shows that Padang City experienced an increase in surplus of surface water caused by high land-use change from natural area to anthropogenic area especially in Koto Tangah sub-district, Pauh, East Padang, Bungus Teluk Kabung, Kuranji, and Lubuk Begalung, sub-districts it has a surplus of surface water with the highest difference of 0.15% or 436,719.19 m^3/year between the BaU and RTRW scenarios, so that the RTRW function can reduce the impact by 0.15%.

The land-use scenario representing the use of sustainable environmental services is by improving (revising) the existing spatial pattern of Padang City through the assessment of environmental services to obtain which sub-watersheds or sub-watersheds need to be improved (re-zoning) considering the environmental service model in this study, of course, all sub-districts or sub-catchments will be in accordance with the application of zoning spatial pattern.

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