Cellular Automata Modelling in Predicting the Development of Settlement Areas, A Case Study in The Eastern District of Pontianak Waterfront City

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Abstract. Pontianak waterfront city as water-based urban has the potential of water resources, socio-economic, cultural, tourism and riverine settlements. Settlements areas in the eastern district of Pontianak waterfront city is located in the triangle of Kapuas river and Landak river. This study uses quantitative-GIS methods that integrates binary logistic regression and Cellular Automata-Markov models. The data used in this study such as satellite imagery Quickbird 2003, Ikonos 2008 and elevation contour interval 1 meter. This study aims to discover the settlement land use changes in 2003-2014 and to predict the settlements areas in 2020. This study results the accuracy in predicting of changes in settlements areas shows overall accuracy (79.74%) and the highest kappa index (0.55). The prediction results show that settlement areas (481.98 Ha) in 2020 and the increasingly of settlement areas (6.80 Ha/year) in 2014-2020. The development of settlement areas in 2020 shows the highest land expansion in Parit Mayor Village. The results of regression coefficient value (0) of flooding variable, so flooding did not influence to the development of settlement areas in the eastern district of Pontianak because the building's adaptation of rumah panggung's settlements was very good which have adjusted to the height of tidal flood.

1. Introduction

Cellular automata model is generally used to predict land development [1,2] which is a historical process depending on where the development was done in the past that might influence the future through local interactions among land parcels as studied by Wu and Webster 1998 [3]. explains that some unexpected features can possibly emerge during the simulation by properly defining transition rules. Within the GIS concept framework, spatial analysis focused more on investigating patterns, attributes, and regional overview using modeling to improve understanding and prediction [4]. In order to discover the relevant variables used in this research, we can refer to the spatial and ecological approach [5] or what is called as a complex regional approach combined with the cellular automata model.

In determining the transition rules as well as the determining of pull and push factors of the settlements development which can be determined by the causes of an area can develop. According to Hoyt in Syahar about the sectorization tendency theory [6], that the areas that have the potential to grow rapidly (High Quality Areas) there are 10 locations. But that is associated with this research theme was the settlements tend to thrive in the transportation / towards the centre of the trade,

settlements tend to thrive on the existing transport lines and settlements tend to develop in the same direction for long periods.
In connection with the exposure to the above, this study use several variables as push factors of the settlements development such as; (1) Distance to the main road; (2) Distance to the non-main road (collector road); (3) Areas of potential flooding; (4) Distance to the Keraton Kadariyah, tourism and government centre; (5) Distance to the central business district and services; (6) The distance to facilities such as hospitals and universities; (7) The distance to utilities such as piers and bus terminals; and (8) Distance to the existing settlements.

2. Methods

This research is located in the eastern district of Pontianak, Pontianak City, West Kalimantan Province. This research object is a settlement which located in the waterfront areas of the Pontianak, cultural heritage areas (Masjid Jami' Sultan Syarif Abdurrahman Alkadrie and Keraton Kadariyah Pontianak), and the history of first settlement areas in Pontianak namely Kampung Beting which is the forerunner to the birth of Pontianak [7].

Based on Pontianak Government regulation policies in Spatial Planning which is oriented Pontianak as Waterfront City (A Critical Assessment Act No. 24/1992), describes Pontianak is one of region in province which is an autonomous region that has a typical water town. Settlement areas in this study refers of Law No. 4/1992 on the housing and settlement, settlements are part of the environment outside the protected areas, either in the form of urban and rural areas that serves as a living environment or settlement environment and the activities which support life and livelihood.

The data used in this study such as:

- Satellite imagery Quickbird 2003 from Google Earth
- Satellite imagery IKONOS 2008 from BAPPEDA Pontianak
- Elevation contour interval 1 meter from BAPPEDA Pontianak

This study using satellite imagery from Google Earth downloads, given the difficulty of high-resolution imagery for the study area. In the study Yuanita et al (2013) showed Quickbird image obtained from Google Earth has a low RMSe values in the relatively flat compared to areas that are relatively high, while the study area in this study is the relatively flat region as well.

Satellite imagery is then interpreted in order to obtain landuse cover information. Classification used the classification of Danoedoro (2012) & USGS (2015) which have been modified. Basic modification of the classification is to look at the goals and characteristics of the study area, the modification is done by dividing the cover into three classes, namely settlement, non-settlement can be converted, and non-settlement cannot be converted. Non-settlements can be converted could include landuse cover is vacant land and vegetation areas, while the non-settlement cannot be converted such as land cover in the form of a body of water plus the portion of land cover awakened namely industry and building.

Distance-related variables in this study using analysis Euclidean Distance, while variable potential flood areas constructed of DEM (Digital Elevation Model) created from the data contour interval of 1 meter. According to data from tidal Kapuas River of Meteorology and Climatology of Pontianak (2013) highest tide is 1.9 meters. Therefore, it can be assumed that the terrain with a height of 1.9 meters below is the potential flooding areas.

Moreover, the research also adds the variable density of the building. The building in question such as settlements, buildings and industry. This variable represents one of the factors inhibiting the development of settlement areas in the Eastern district of Pontianak namely fire disaster. Areas with dense buildings have a high vulnerability to fire risk disaster, in addition to density variable of buildings (Hoyt in Syahar, 2012) define settlement areas tends to develop in open area to further development of open country and there is no physical barrier means. Density variable of buildings constructed using Kernell Density analysis.

Geomorphological diversity and intensity of the settlements is the basis in determining changes in the settlement areas, so that each region has waterfront and coastal city characteristics are different, depends on the existing geological processes. A critical factor in the settlement areas is a distance from the water bodies. In modelling settlement patterns is needed to assess the effects of flooding in settlements on the riverbanks, it is due to human behaviour in managing water resources because they have the management capacity to water bodies [7, 8, 9, 10]

In making the prediction model settlement development, this study uses binary logistic regression integration with Cellular Automata-Markov models. This model is used by Wijaya and Susilo (2013) in predicting the development of non-built-up areas in Salatiga within overall accuracy (78.20%) and kappa index (0.48). This research differs from [11], this study did not consider the number of cells to be predictable change.

Cellular Automata-Markov model uses raster based data, therefore all the data used in this study is converted in raster form with a size of 10 meters x 10 meters. Data in 2003 and 2008 will be used as the basis of predicted development of settlement areas in 2014, the result of the prediction will be tested prediction precision, then it can be carried back in 2020 (see figure 1).

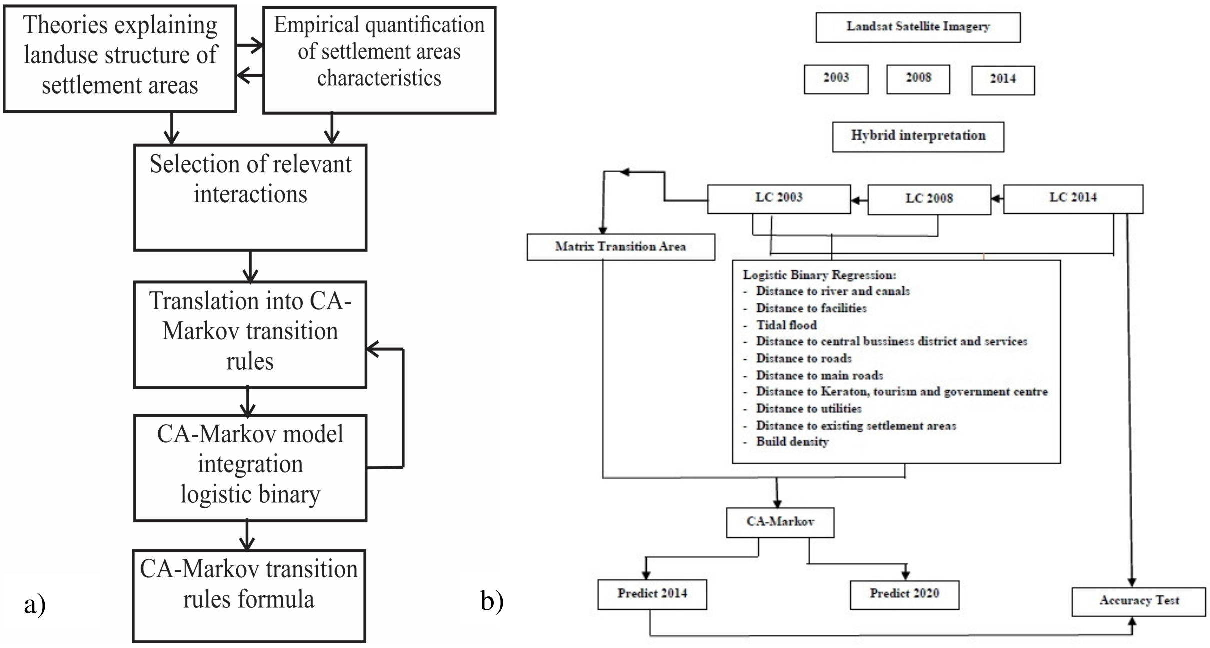

Figure 1. (a) The Procedure Followed for Defining Transition Rules (b)The Framework of Cellular Automata Modeling

3. Result and Discussion

3.1 Settlement Land Use Changes in the Eastern District of Pontianak

Based on the results of the analysis of changes in land use cover changes from 2003-2008, it is concluded that in this period the increasingly of sub-settlement areas (38.49 hectares) in The Eastern district of Pontianak. The settlements areas in the Eastern district of Pontianak (397.35 hectares) in 2008 while previously (358.86 hectares) in 2003.

The results of the analysis using interpolation spatial polynomial order of 3 to the location of land expansion of settlements in 2003 to 2008 in the District of Pontianak East, showing the centre of the development of non-built-up areas located in the central and the eastern part, more precisely in the the eastern part of Kampung Dalam Bugis Village, the southern part of Tanjung Hulu Village and the northern part of Saigon Village (see figure 4).

Analysis of push factors of landuse changes in binary logistic regression between land use changes for non-settlement into settlement areas in 2003-2008 resulted in the regression equation as follows:

$$Y = -3.6640 + 0.000877*X1 - 0.000000*X2 + 0.000358*X3 + 0.000843*X4 - 0.001819*X5 + 0.000382*X6 - 0.000505*X7 + 0.000684*X8 + 0.004674*X9 - 0.264610*X10 \quad (1)$$

Where: Y : Logit of land use change from non-settlement to settlement areas
X1 : Distance to rivers and canals
X2 : Distance to facilities
X3 : Tidal flood
X4 : Distance to central business district and services
X5 : Distance to collector roads
X6 : Distance to main roads
X7 : Distance to Keraton Kadariyah, tourism and government centre
X8 : Distance to utilities
X9 : Distance to existing settlement areas
X10: Buildings density

The equation (1) shows the highest regression coefficients are at distance variable to existing settlements (0.26). A positive coefficient indicates that the greater the coefficient of the independent variable, the greater possibility of land use changes from non-settlement into settlement areas, while a negative coefficient is the opposite which shows that the smaller the coefficient of the independent variable, the greater possibility of land use changes from non-settlements into settlement areas.

The existing settlements variable have the strongly influenced of the land use change in non-settlement into settlements areas which have a negative coefficient, so it can be concluded that the closer the existing settlements, the greater the likelihood that land use changes from non-settlement into settlements.

The smallest regression coefficient is variable of flooding (0). Based on this analysis, flooding variable did not influence at all to land use changes from non-settlement into settlements areas. Flooding that occurred in The Eastern district of Pontianak did not influenced the development of settlement areas, because the level of community's adaptation to the building structure on rumah panggung's settlements was very good, through rumah panggung's foundation have adjusted to the height of tidal flood on the Kapuas river (see figure 2 & 3).

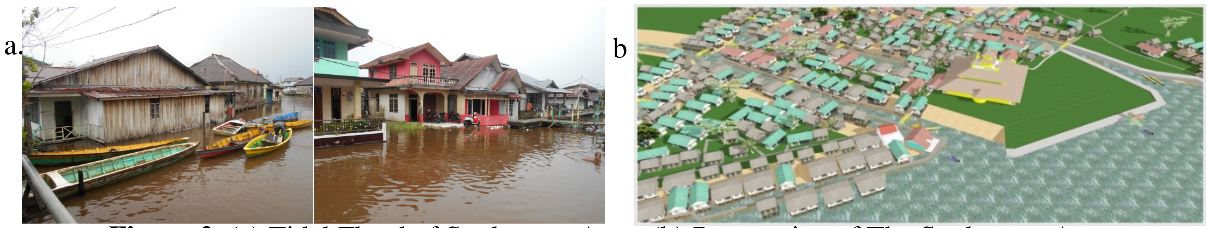

Figure 2. (a) Tidal Flood of Settlement Area; (b) Perspective of The Settlement Area

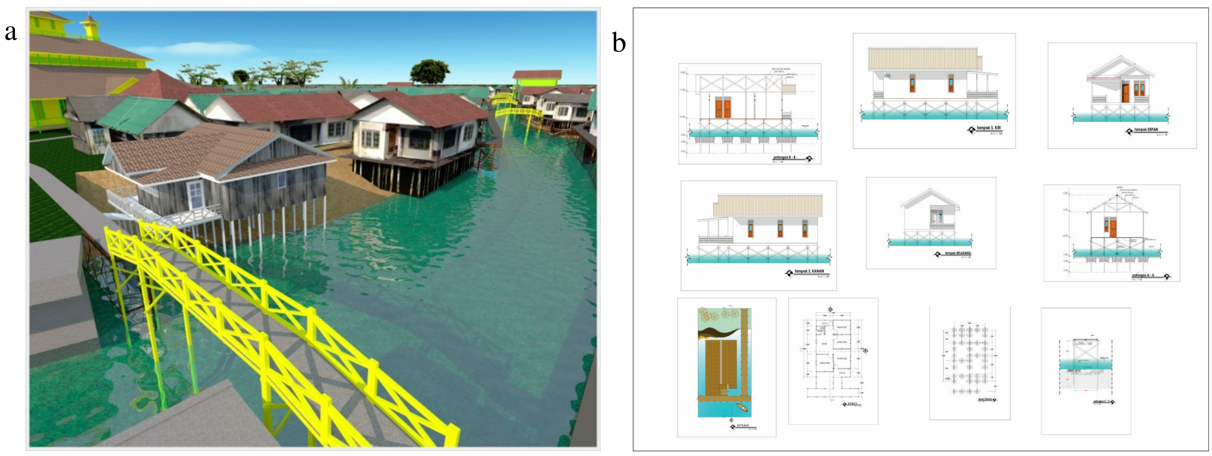

Figure 3. (a) Settlement Area of Rumah Panggung; (b) Sketch of Rumah Panggung

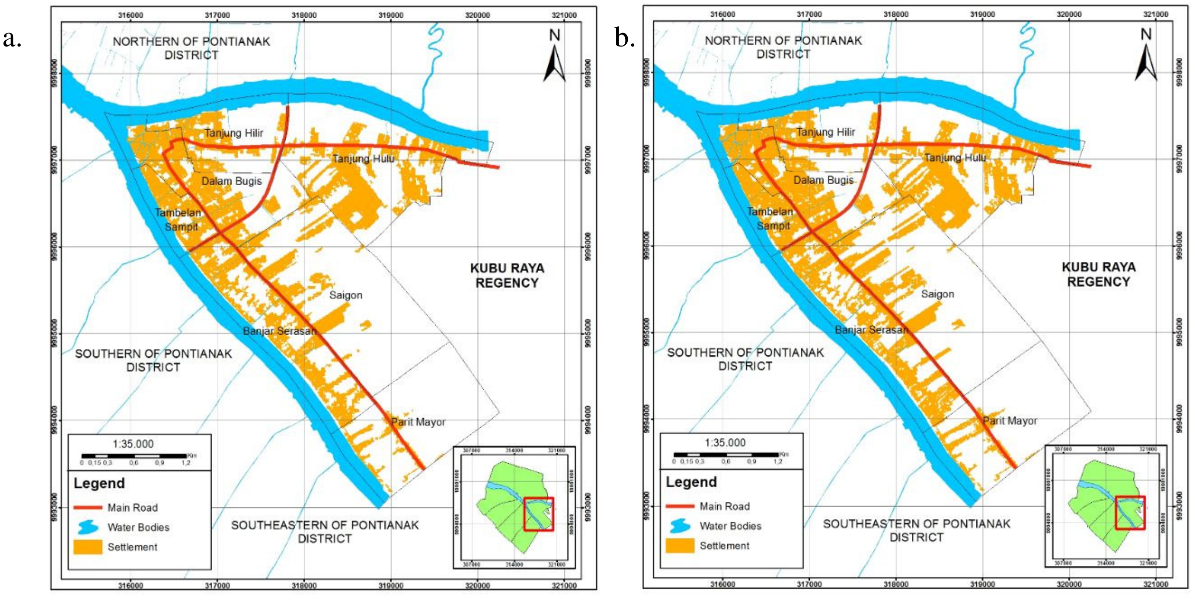

Figure 4. (a) Map of Existing Settlement Areas in 2003; (b) Map of Existing Settlement Areas in 2008

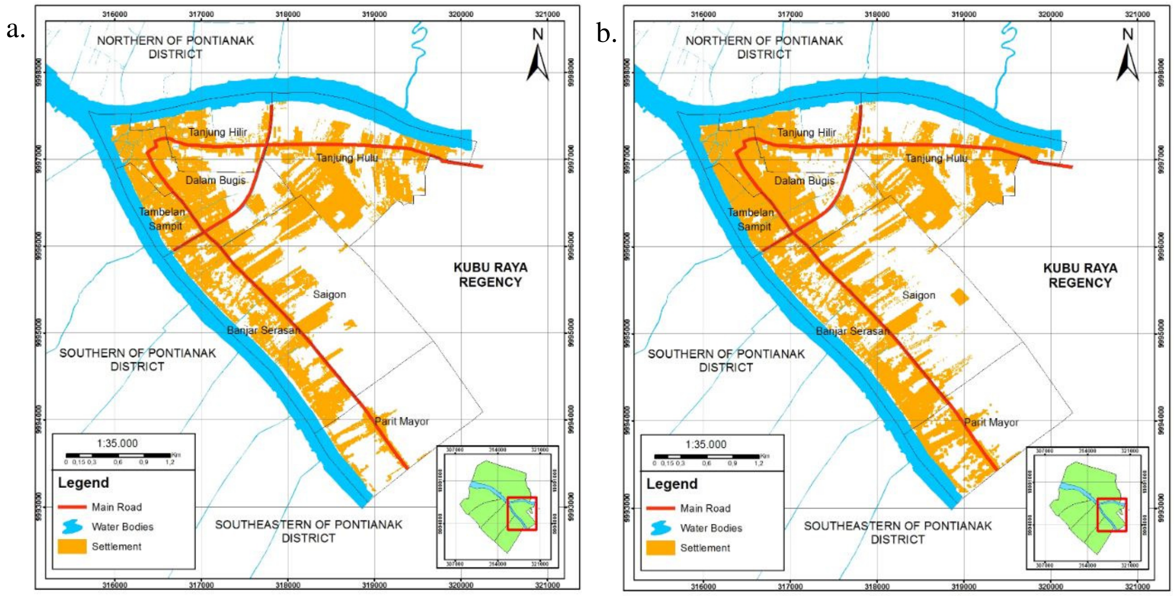

Figure 5. (a) Map of Existing Settlement Areas in 2014; (b) Map of Existing Settlement Areas in 2020

3.2 Prediction of Settlement Areas in the Eastern District of Pontianak

The settlement areas prediction results in 2014 (440.82 hectares), the predicted outcome is smaller (0.35 hectares) than the area of Pontianak urban settlements (441.17 hectares). The results show the accuracy in predicting settlements land use change in The Eastern district of Pontianak have been able to get the overall accuracy (79.74%) and the highest kappa index (0.55). Based on this analysis, the prediction of settlement areas using Cellular Automata-Markov modeling has been accurate and will be used to predict the development of settlements areas in 2020.

The prediction results show that in 2020 (481.98 hectares) of settlement areas. During a period of 6 years from 2014 to 2020 there was an increase of settlement areas (40.81 hectares) or 6.80 hectares/year. Based on the analysis using spatial interpolation polynomial order of 3 to the location of land expansion of settlements in 2020 in the eastern district of Pontianak, showing settlement areas are developing fairly evenly in Saigon Village, Tanjung Hulu Village, Banjar Serasan Village and the highest develops is in Parit Mayor Village (see figure 5).

Analysis of push factors of land use changes in binary logistic regression between land use changes for non-settlement into settlement areas in 2014 to 2020 resulted in the regression equation as follows:

$$Y = 4.4328 - 0.001154*X1 + 0.002352*X2 + 0.000000*X3 - 0.001400*X4 + 0.005696*X5 - 0.001250*X6 + 0.002758*X7 - 0.002166*X8 - 0.754588*X9 + 0.003258*X10 \quad (2)$$

Where: Y : Logit of land use change from non-settlement to settlement areas
X1 : Distance to rivers and canals
X2 : Distance to facilities
X3 : Tidal flood
X4 : Distance to central business district and services
X5 : Distance to collector roads
X6 : Distance to main roads
X7 : Distance to Keraton Kadariyah, tourism and government centre
X8 : Distance to utilities
X9 : Distance to existing settlement areas
X10: Buildings density

The equation (2) shows the most significant regression coefficient is the distances to existing settlements variable (0.75). The distance to existing settlements have the most significant effect of changing in non-settlement into settlement areas which have a negative coefficient, so it can be concluded that the closer the existing settlements the greater the likelihood that land use change from non-settlement into settlement areas. Besides that, the distance to the main road and the density of the buildings are also highly enough to influence the land use changes from non-settlement to settlement areas. Just as logit changes in settlement areas in 2003-2008, the smallest regression coefficient is flooding variable (0). Based on this analysis, flooding variable did not influence at all to land use changes from non-settlement into settlement areas, it is similar to the percentage of flood exposure in a very small number (see figure 6). Based on the prediction results, Parit Mayor Village will be the centre of the highest development of settlements areas in the eastern district of Pontianak in 2020, because the Parit Mayor Village still has space of non-built-up areas, so that it can be developed into settlement areas (see figure 7). Moreover, in terms of accessibility factors in Parit Mayor Village has by passed the main roads to get crossing the Trans Kalimantan bridge.

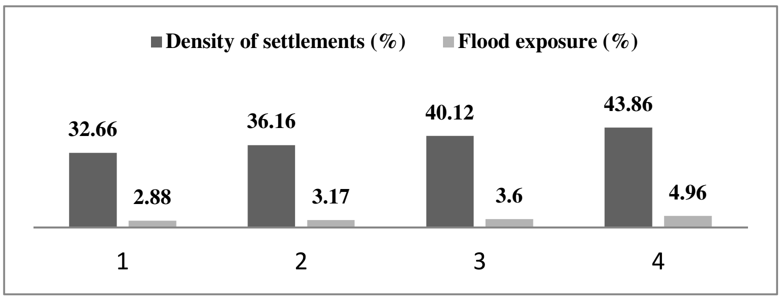

Figure 6. Chart of Density and Flood Exposures in Settlement Areas.

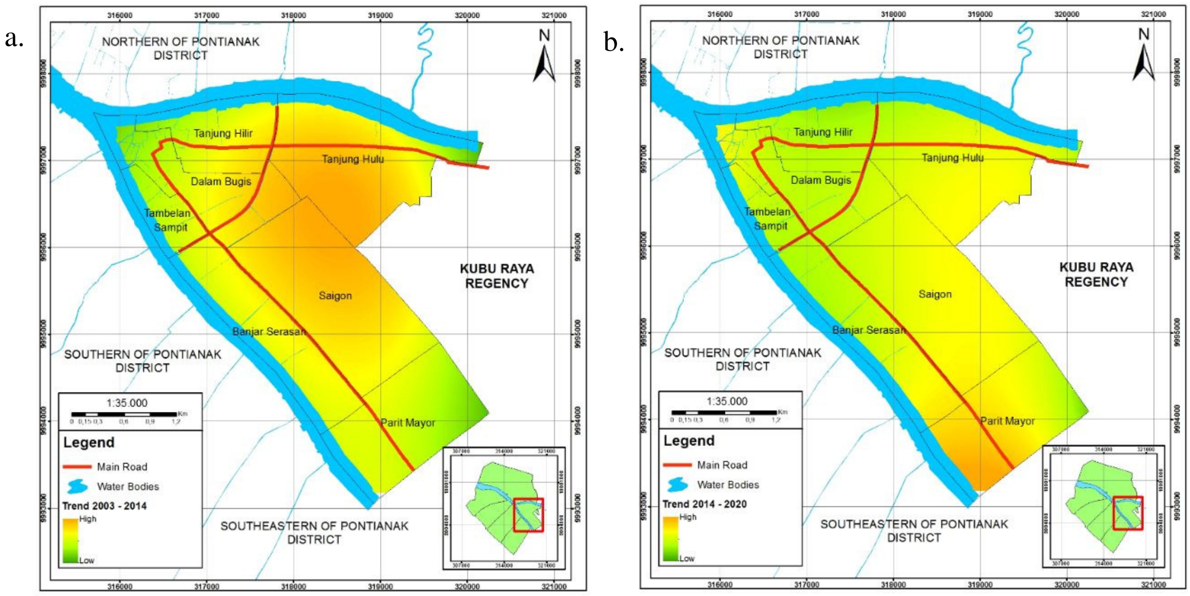

Figure 7. (a) Map of Trend Settlement Areas in 2003-2014; (b) Map of Trend Settlement Areas in 2014-2020

4. Conclusion

The settlement land use changes in the eastern district of Pontianak in 2003-2008 increased (38.49 Ha). The results of land expansion of settlements show the centre of the development of non-built-up areas located in the central and the eastern part, more precisely in the eastern part of Kampung Dalam Bugis Village, the southern part of Tanjung Hulu Village and the northern part of Saigon Village. Analysis of binary logistic regression resulted the strongly influenced is distance variable to existing settlements (0.26). Flooding variable did not influence to the development of settlement areas, because the community's adaptation to the building structure on rumah panggung's settlements was very good, through rumah panggung's foundation have adjusted to the height of tidal flood on the Kapuas river.

The prediction results of settlement areas in the eastern district of Pontianak in 2014-2020 increased (40.81 Ha). The results show the settlements land use change in the eastern district of Pontianak is overall accuracy (79.74%) and the highest kappa index (0.55). The prediction results show of settlement areas in 2020 (481.98 Ha) and 2014 (440.82 Ha). The increasingly of settlement areas (40.81 Ha). The results of land expansion of settlements show the settlement areas are developing fairly in Saigon Village, Tanjung Hulu Village, Banjar Serasan Village and the highest develops in Parit Mayor Village. Analysis of binary logistic regression resulted the most influential is distances to existing settlements variable (0.75). Flooding variable did not influence to land use changes from non-settlement into settlement areas, it is similar to the very small number of flood exposure percentage.

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