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Identifying the driving forces of urban expansion and its environmental impact in Jakarta-Bandung mega urban region

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Abstract. The socio-economic development in Jakarta-Bandung Mega Urban Region (JBMUR) caused the increasing of urban expansion and led to a variety of environmental damage such as uncontrolled land use conversion and raising anthropogenic disaster. The objectives of this study are: (1) to identify the driving forces of urban expansion that occurs on JBMUR and (2) to analyze the environmental quality decline on JBMUR by producing time series spatial distribution map and spatial autocorrelation of floods and landslide as the proxy of anthropogenic disaster. The driving forces of urban expansion in this study were identified by employing Geographically Weighted Regression (GWR) model using 6 (six) independent variables, namely: population density, percentage of agricultural land, distance to the center of capital city/municipality, percentage of household who works in agricultural sector, distance to the provincial road, and distance to the local road. The GWR results showed that local demographic, social and economic factors including distance to the road spatially affect urban expansion in JBMUR. The time series spatial distribution map of floods and landslide event showed the spatial cluster of anthropogenic disaster in some areas. Through Local Moran Index, we found that environmental damage in one location has a significant impact on the condition of its surrounding area.

1. Introduction

Regional development and increasing urban expansion in most developing country including Indonesia affecting a serious problem in environmental condition and decrease carrying capacity of the environment [1]. In Indonesia, two metropolitan areas of Greater Jakarta (Jabodetabek) and Bandung Raya is experiencing the phenomenon of urban expansion. Jabodetabek metropolitan and Bandung Raya became increasingly connected to be a mega-urban area through a corridor called Jakarta-Bandung Mega-Urban Region or JBMUR [2]. The formation of the mega-urban area is caused by a conurbation process that characterized by increased population growth, increased activity in various sectors, and the development of built-up areas such as new city projects and industrial centers which connected through a network of roads or corridors within two metropolitan areas, namely the Bogor-Puncak-Cianjur-Bandung route and the Cipularang Jakarta-Bandung toll road [3]. The conurbation is the process which a metropolitan city experiences an urban physical development that blends with the surrounding cities forming a larger metropolitan area. This larger metropolitan area is an urban area formed by a large city system and its surroundings. Mega urban conurbation process in a globalized world implies in considering it as a complex phenomenon in space and time. It is an extremely large or densely populated urban area which usually consists of several towns merging with the suburbs of a central city. Some important changes introduced in top-down processes of conurbation, mainly through global policies, such as a transportation development, new road or highway construction, new alternative connections among spaces, for instance, that can introduce deep changes in the local structures which need to readapt itself to the new situation and making it possible that emergent processes can arise again but from a different starting point [4].

The increasing population growth of JBMUR especially in urban areas causes the increasing demand for land. Increased demand for such land leads to land conversion, especially the conversion of vegetated lands to built-up area. Uncontrolled land use/land cover changes can cause environmental degradation, which resulting in environmental problems and even anthropogenic disasters such as floods and landslides. The inconsistency between land use and land capacity in relation to environmental carrying capacity may lead to a decrease in environmental quality resulting in anthropogenic disasters [5]. Starting from the beginning of the 1990s, environmental degradation in JBMUR which shown by increasing number of disaster has been a hot issue in the term of sustainable development of mega urban region. The number of floods incidents, landslides and environmental problems that occurred in Indonesia increasingly prompted the importance of the role of disaster risk reduction. According to Yamani et al. [6], land use planning and spatial planning can be used as a tool to reduce disaster risk.

The aims of this study are: (1) identifying the driving forces of urban expansion that occurs in JBMUR; and (2) analyzing distribution patterns of floods and landslides prone areas in JBMUR using time series data and identifying the spatial clustering phenomenon.

Regional development and rapid urban expansion in JBMUR has a significant impact on the local and global environment. Therefore, to prevent uncontrolled rapid urban development in this area which emerging as one of Asian Megacities, must be started from clear understanding of various driving forces that affecting urban expansion [7]. GWR (Geographically Weighted Regression) is an appropriate tool to identify the local spatial dependency of the driving factors which affecting urban expansion. GWR models were used in various studies to identify the spatial variations in the relationship between environmental and socioeconomic indicators, regional development, ecology, natural resourse management and social studies [8-14].

Rapid growth of built-up area as well as uncontrolled land use/land cover change in JBMUR such as converting vegetated lands into built-up area, as well as protected areas into cultivation areas can lead to a decrease in environmental carrying capacity which is the ability of the environment to support human life and other living beings. The decline in environmental carrying capacity can lead to disasters and environmental problems such as floods, landslides, forest fires, land droughts, and increasing critical land. Therefore, it is necessary to conduct such kind of study related to identify the driving forces of land use change especially urban expansion and investigate the distribution patterns of floods and landslides prone areas as the example of environmental impact due to unsustainable patterns of rapid urban development in JBMUR and identify spatial clustering phenomenon on those variables. The results of this study can be used as an evaluation in land use policy and spatial planning (RTRW) and as an effort to prevent and reduce environmental problems such as flood and landslide risk.

2. Method

2.1 Study Area

This study area is Jakarta-Bandung Mega-Urban Region or JBMUR which located in Java Island and generally covers the administrative area of Greater Jakarta (Jabodetabek Metropolitan Area), Bandung Raya Metropolitan Area, and some areas around the mega-urban corridor. Specifically, the administrative areas in JBMUR consist of 20 regencies/municipalities: five (5) municipalities in DKI Jakarta Province (including East Jakarta, South Jakarta, West Jakarta, North Jakarta, and Central Jakarta Municipality), Tangerang Regency, Tangerang Municipality, South Tangerang Municipality, Bekasi Municipality, Bekasi Regency, Depok Municipality, Bogor Regency, Bogor Municipality, Karawang Regency, Cianjur Regency, Purwakarta Regency, Bandung Barat Regency, Cimahi Municipality, Bandung Municipality and Bandung Regency (figure 1).

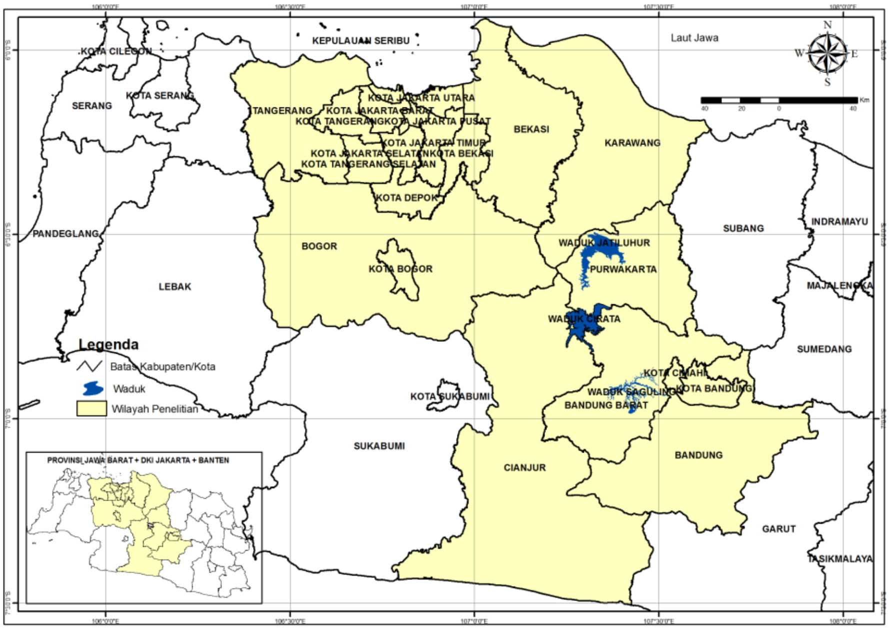

Figure 1. Study Area

2.2 Materials and Methods

The driving forces that affecting urban expansion in JBMUR were identifying using GWR model. GWR is a statistical method to identify local spatial variations. This model works based on the "Tobler's First Law of Geography", which mentioned that everything is usually related with everything else, but those which are near to each other are more related when compared to those that are further away. In GWR model, spatial non-stationarity was assumed and tested. This model addresses the non-stationarity and allows the local spatial variations to vary over space. The result of this analysis is a regression model whose parameter values apply only to each location of observation, and different from other locations. In GWR, we use the weighted matrix element W(i) which the amount depends on the proximity between locations. The weighting function to be used for GWR model in this study is Gaussian Kernel function. The GWR is an expansion of the global regression model. However, unlike global regression that is applied in general at every observation location, GWR produces local model parameter estimators for each observation location using the Weighted Least Square (WLS) method. The formulas and variables used in the model are as follows:

$$\mathrm{Y}_j = C_0(u_j, v_j) + \sum_{i=1}^{p} C_i(u_j, v_j)\mathrm{X}_{ij} + \varepsilon_j \quad (1)$$

where: Y_j = Dependent variable for observation j; X_{ij} = Independent variable Xi at location *j;* u_j, v_j = Coordinate point for location of observation j; $C_0\ (u_j, v_j)$ = Intercept for observation *j;* $C_i\ (u_j, v_j)$ =

Regression coefficient or local parameter estimate for independent variable X*i* at location *j.* The optimal bandwidth of GWR analysis in this study was determined by minimizing the corrected Akaike Information Criterion (AIC's value) with a correction for finite sample sizes, as described in Fotheringham, Brunsdon, and Chalton [15].

The dependent variable (Y) used in this model is percentage of built-up area (2015); Six (6) independent variables (X) included in this model are: X_1 = population density (person/km^2); X_2 = percentage of agricultural land, excluding ricefield (%); X_3 = distance to the CBD/capital regency (km); X_4 = percentage of household working in agricultural sectors (%); X_5 = distance to the provincial road (km); X_6 = distance to the local road (km).

In this study, we employed Global Moran and Local moran Index (LISA statistics) to analyze distribution patterns of floods and landslides prone areas in JBMUR using time series data and identifying the spatial clustering phenomenon. The formula of Global Moran's Index (I) and Local Moran's Index (I_i) or LISA statistic can be seen as follows:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(Z_i - \bar{Z})(Z_j - \bar{Z})}{S_Z{}^2 \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \quad (2)$$

$$I_i = \frac{\sum_{j=1}^{n} W_{ij}(Z_i - \bar{Z})(Z_j - \bar{Z})}{S_Z{}^2 \sum_{j=1}^{n} W_{ij}} \quad (3)$$

Where: I= Global Moran's Index; I_i= Local Moran's Index or LISA statistics; Z_i = representing the value of variable Z for point/location i; Z_j= representing the value of variable Z for point/location j (the neighbour); Z = the average value (mean) of Z; W_{ij} = spatial association between i and j (contiquity matrix); representing the proximity of i-th village (*desa*) i's and village (*desa*) j's locations; n = the total number of villages (*desa*); S_z^2= the variance of the observed values. Unit of analysis used in this model is village (desa). There are 2955 villages/desa in JBMUR.

3. Results and Discussions

3.1 Identifying Driving Forces which Affecting Urban Expansion in JBMUR

The development of the Jakarta-Bandung corridor has resulted in a massive urban expansion. Rapid urban development in two biggest metropolitan areas (Jabodetabek and Bandung Raya) mainly contributes to urban sprawl and increases population density, as well as encourage urban activities and economic growth in the region and its surrounding area [2]. Based on our previous research, in the period of 1972-2010, urban land area in Jabodetabek increased by about 2,096 km2 because of urbanization and suburbanization's impact [5]. Land use/land cover change continues to increase in JBMUR from 1996 to 2015, especially from vegetated lands such as rice fields and mixed gardens to built-up area. The rapid expansion of built-up area is largely driven by the existence of road networks (especially toll roads) that connect the two metropolitan areas. Areas that have experienced the most widespread land are Bandung, Bogor, Bekasi and Tangerang Regencies. One type of land use that undergoes many changes or conversions into built-up area is rice field.

Based on GWR analysis, the spatial distribution pattern of built-up area of observation and prediction of the model are almost the same (figure 2). From figure 2, it can be seen that the largest percentage of built-up areas which has red colour are mostly located in the center of Jakarta and Bandung metropolitan areas with built-up percentages of over 80%. In the area covered by green colour which closer to the periphery, the percentage of built-up area were lower.

The important analysis results from GWR model can also be known from the value of local R^2. R square (R^2) or coefficient of determination is usually used to calculate the suitability of the model. There is only 1 single value of R^2 in OLS (Ordinary Least Square) model, but in GWR model, each location has their own value of R^2, or often called local R^2. One of the reason using GWR is because local analysis intends to show spatial variability between locations and understand the spatial data more detail. High local R^2 indicates that the local regression model more fits the observations. In figure 3, the value of local R^2 varies for each location with a range between 0.698 and 0.910. The highest local R^2 value is located in the south-eastern part of the study area (especially located in Bandung metropolitan area and some parts of Purwakarta and Cianjur Regencies). Area with a higher local R^2 value is more potential to get the impact of urban expansion, so those areas will easily converted into built-up area compare with the other area with smaller value of local R^2.

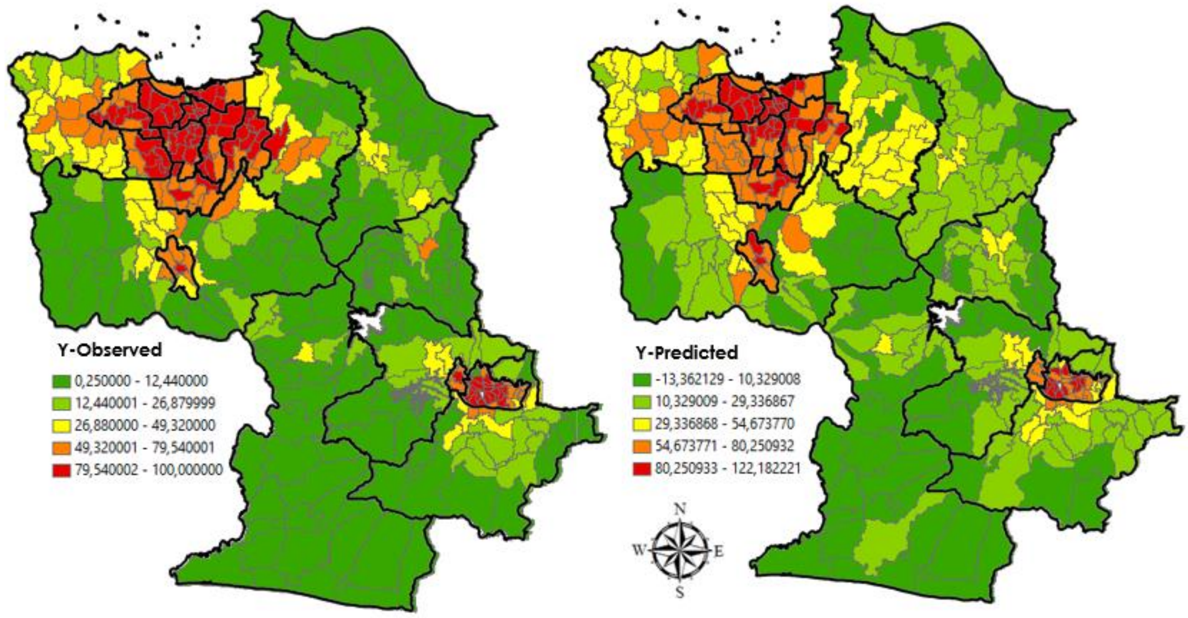

Figure 2. Percentage of built-up area in (1) Observed and (2) Predicted based on GWR Model

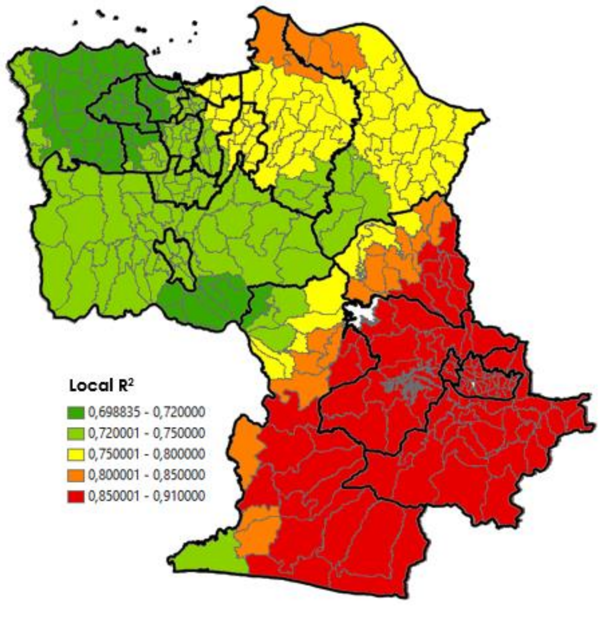

Figure 3. The local R^2 values based on GWR analysis

GWR employs a spatial weighting function with the assumption that everything which located in the near places are more similar than others in distant places (First Law of Geography). figure 4 showed the local variations of parameter estimates (C coefficient) for each independent variable based on GWR results. From figure 4, it can be known the value of local parameter estimates (C) for each independent

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variable (X) used in the model. Based on the results, it seem that the most dominant influence on urban expansion is agricultural activities.

Population density is considered as having relationships with urban expansion [16]. Spatial distribution pattern of the coefficient or parameter estimate (C) for X1 [POPDENS] or population density can be seen in figure 4 (a). POPDENS (X1) has a positive correlation on urban expansion in the whole areas (although the value index are relatively low), which means that increasing population density will increase the percentage of built-up area in that location. An increasing populated region will also potentially lead to increase construction of new settlement location as well as other built-up areas such as new towns, new industrial land, etc [17, 18]. The red colour area in fgure 4 (a) is the location with the biggest influence of population density factor on the increasing of built-up area.

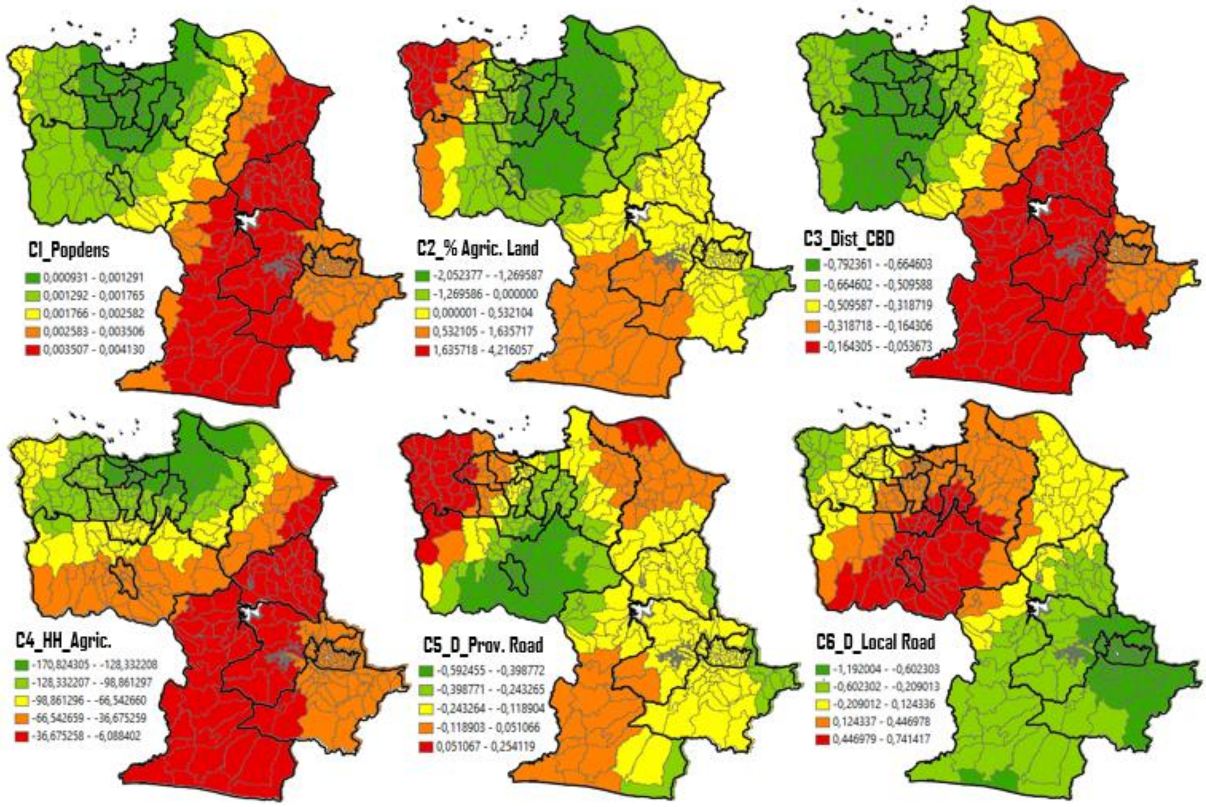

Figure 4. Parameter Estimates (C) for Each Independent Variable

The second and forth independent variables used in the model (X2 and X4) are the percentage of agricultural land area (non-paddy field) [%_AGRIC.LAND] and percentage of the household works in agricultural sector [HH_AGRIC]. Based on the literature review, variable related to agricultural activities were considered as having relationship with urban expansion [19, 20, 21]. The spatial distribution pattern of local parameter estimate values for X2 [%_AGRIC.LAND] can be seen in figure 4 (b). Considering GWR results, the coefficient or local parameter estimate for X2 has a positive to negative value in different location. A positive value of the local parameter estimates means that the effect of X2 is directly proportional to the dependent variable (Y). On the other hand, negative value of local parameter estimates indicating negative relationship between the dependent variable (Y) and X2 [%_AGRIC.LAND]. Locations with negative local parameter estimates values (in figure 4 (b) are light green and dark green colour areas - located in the center of the study area) indicating that at those locations, the reduced percentage of agricultural land (excluding paddy field) will have a significant effect on the increasing of built-up areas. Thus, it can be predicted that the increasing of built-up area in the light green and dark green areas which covering the area of Jakarta, Bogor, Depok, Bekasi and a small area of Tangerang, is the result of land conversion from agricultural land (non-paddy field).

The spatial distribution pattern of local parameter estimate values for X4 [HH_AGRIC] can be seen in figure 4 (d). Considering GWR results, the coefficient or local parameter estimate for X4 has a negative value for the whole areas. This indicates that X4 [HH.AGRIC] has negative relationship with the dependent variable (Y). Similar to the explanation for the variable X2 above, if the area of agricultural land decreases, number of household who works in agricultural sectors will also decrease because of the shrinking of farmland. This shrinking of farmland is caused by land use change or landuse conversion from agricultural to built-up areas.

The third independent variable used in the GWR model (X3) is distance to the CBD (central business district). Distance to the CBD or city center is also considered as one of the driving factors that influence urban expansion [5]. The spatial distribution pattern of local parameter estimate values for X3 [DIST_CBD] can be seen in figure 4 (c). Considering GWR results, the coefficient or local parameter estimate for X3 also has a negative value for the whole areas. This indicates that X3 [DIST_CBD] has negative relationship with the urban expansion. The lands that have been converted to urban expansion are lands which have good accessibility and located close to the central city/CBD. Parameter estimate values for X3 [DIST_CBD] are all negative and range from -0.792 to -0.053. The negative coefficient value indicates that X3 is inversely proportional to the dependent variable [Y]. The lands located close to the CBD will tend to be converted to built-up area.

The last two variables included in GWR model (X5 and X6) are the distance to the provincial road (X5/D_PROV.ROAD) and the distance to the local road (X6/D_LOCAL ROAD). Based on Tuloli [22], Prasetyo, Koestoer, & Waryono [23], and Susanti [24], infrastructure development and accessibility to the roads or highways were considered as driving factors which caused the outspreading of urban expansion. For the distance variable to provincial road (X5), the parameter estimate value ranges from -0.592 to 0.254. As for the distance variable to the local road (X6) the coefficient value ranges from -1.192 to 0.741. Accessibility is a important factor to the development of built-up areas, so [D_PROV.ROAD] and [D_LOCAL ROAD] are included in the GWR model. However, from the GWR results, it can be seen that the magnitude of the influence of the distance variables vary for each location.

3.2 Spatio-temporal distribution patterns and spatial clustering of floods and landslides prone areas in JBMUR

The relationship between urban expansion and environmental deterioration occured in JBMUR was investigated in this study by choosing floods and landslides as representative examples of anthropogenic disaster. Spatial distribution patterns of floods and landslides in JBMUR in the years of 2000, 2006 and 2014 are shown in figure 5 and figure 6. Based on figure 5, number of villages experiencing floods are tend to increase. Blue area shows the location which inundated by floods. Flood incident occurred mostly in the northern part of DKI Jakarta, the northern part of Bekasi Regency, and the northern part of Karawang Regency since the area has a flat topography condition. Floods also tend to occur in the area of Bandung Municipality and the northern part of Bandung Regency because the area has rapid development especially the increasing number of built-up area.

Similar to condition that occurred in flood disaster, landslides in JBMUR also tend to increase from year to year while the spread of landslide events occurred in the southern part of Bogor Regency, Cianjur Regency, West Bandung Regency, and Bandung Regency since those regions have a predominantly steep and hilly topography condition (figure 6). Brown area shows the location which have landslide occurrence. The region has a dominant slope of 41% -60% so vulnerable to the occurrence of landslide disaster.

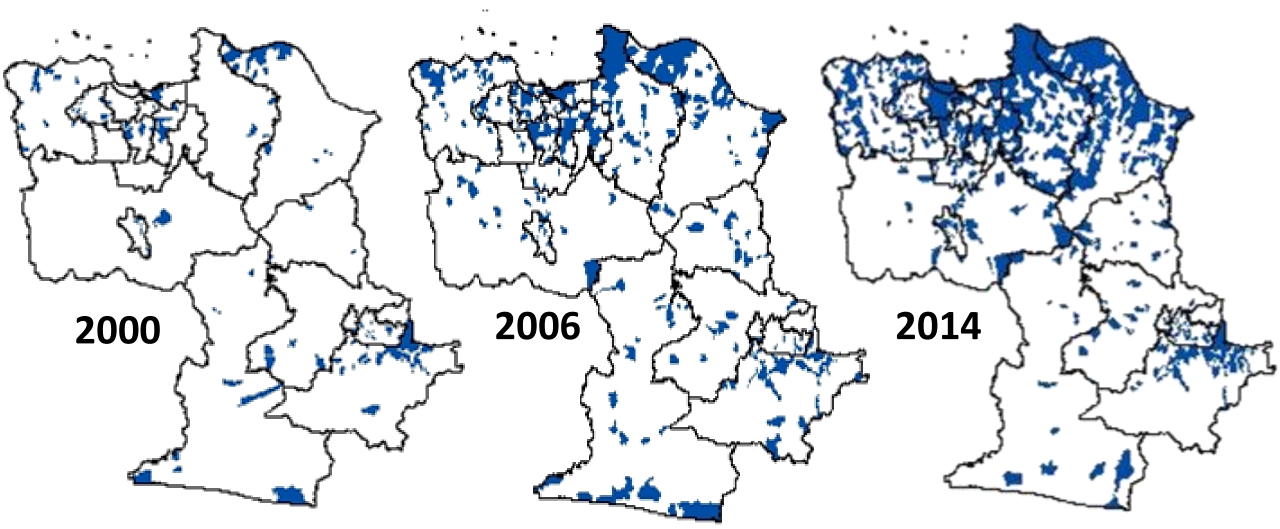

Figure 5. Spatio-temporal distribution patterns of floods in JBMUR

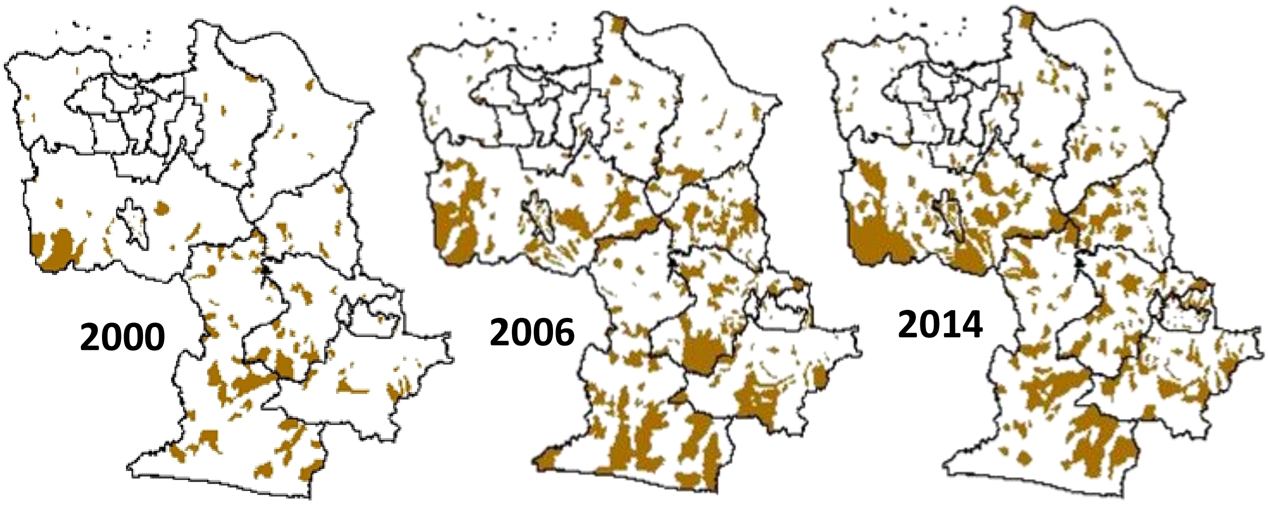

Figure 6. Spatio-temporal distribution patterns of landslides in JBMUR

In this study, we employed spatial autocorrelation analysis using Global Moran Index and Local Moran Index/LISA to identify spatial clusters of flood and landslide prone areas in JBMUR. Flood and landslide's spatial clusters were detected since the spatial autocorrelation or Global Moran Index (Moran's I Index) has a positive value (figure 7). Moran's I Index values for floods and landslides are 0.3 and 0.2, respectively. Those values indicates the spatial clustering phenomenon and through figure 7 it can be seen that the spatial association of floods (based on the number of floods evidence) is higher than landslides, so that the spatial distribution pattern of floods is more clustered than landslide.

Through the LISA cluster map (shown by figure 7), there are 4 categories of spatial association, i.e: (1) high-high/HH (high values surrounding by high values); (2) low-low /LL (low values surrounding by low values); (3) high-low/HL (high values surrounding by low values); or (4) low-high/LH (low values surrounding by high values). The red areas (HH type of spatial association) shows spatial cluster of high vulnerability on floods and landslide prone area while the blue areas (LL type) shows spatial cluster of low vulnerability on floods and landslide prone area. Based on the LISA statistic's result shown in the figure 7, the northern part of Jakarta, Bekasi, Tangerang and Karawang have high vulnerability of floods, while the southern part of Bogor, Cianjur and Purwakarta have high vulnerability of landslides.

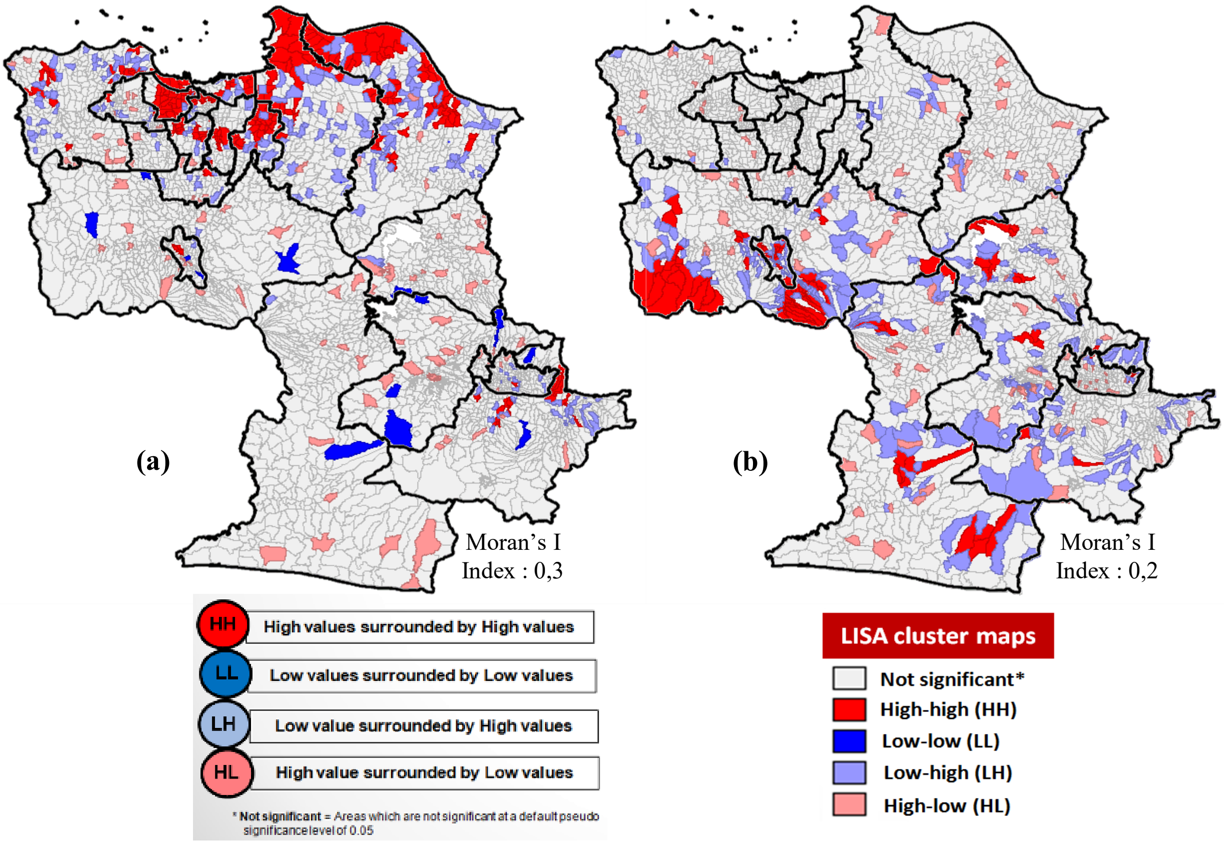

Figure 7. LISA Cluster Map of (a) Floods and (b) Landslides Prone Areas

4. Conclusion

Several kinds of driving forces, namely: local demographic, social, and economic factors including distance to the CBD, provincial and local road spatially affect urban expansion in JBMUR. The timeseries spatial distribution map of floods and landslides showed the spatial cluster of anthropogenic disaster in some areas. Through Local Moran Index, we found that environmental damage such as floods and landslides in one location has spatial association with its surrounding areas. The LISA cluster map from this study could be used as preliminary result to be developed for making floods and landslides zoning map and disaster risk management which useful to minimize environmental deterioration impacts of urban sprawl and uncontrolled urban expansion in megacities/mega urban region.

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