LanduseSim Algorithm: Land use change modelling by means of Cellular Automata and Geographic Information System

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Abstract. The aim of this research is to demonstrate and explain the methods of LanduseSim as land use change modelling software to predict the future of land use. It is a Cellular Automata model for predicting future urban growth and land use change in particularly focusing on future oriented development and scenario planning. The combination between cellular automata and geographic information system will be used to execute the model. In this research, Pekalongan municipal is selected as area study in order to demonstrate the land use change modelling process. Machine benchmark also be taken to explain the relationship between hardware specification and time-elapsed for CA simulation.

Keywords: LanduseSim, Cellular Automata, Land use change

1. Introduction
Land use change is one of the most important aspect in comprehensive spatial planning under planning practice approach [10]. The spatial pattern of land use will be used as a basis in generating zoning policies to ensure sustainable of future urban development. While proposing land use pattern, in general urban planners are limited to the past-present data in particularly of land use change distribution in conjunction with lack of qualitative approach consideration. In result, the process can’t offer comprehensive way in responding with the future development scenario. It means those lack of approach can’t explain the future land use configuration when several spatial entities are projected to be applied such as availability of infrastructure development agenda (e.g. road development, port, terminal, airport etc), facilities development (e.g. education facilities, health facilities, etc), zoning (e.g. protection area), and even new type land use growth (e.g. estimate the future new land use will occupy).

Land use change is a complicated process that is generated by multi-interactions from biophysical factors and human factors at different scales, space and time [4][5][15]. However, the model of urban expansion still lacks of spatially explicit where it can be used to predict the future of possible scenarios where urban planning policies can be evaluated [6]. In the field of land use change studies, cellular automata (CA) has proved as an outstanding method in predicting land use through spatial simulation and modelling process. CA method derives from mathematics works very well in imitating spatially complex process [31], and its development reaches many fields such as in geography modelling [28], modelling the shape of city [2][3], urban physical development [7], land use planning [16], and urban and regional planning [9]. CA model also able to control the spatial pattern change
through rules of change involving configuration of neighbourhood and transition potential map [16][17][27]. Some CA model has been developed by combining scenarios of constraints to be more appropriate for land use planning process, such as was demonstrated by Li and Yeh [16], He et al [13], Mitsova et al [20] and Fuglsang et al [10].

Model CA is a model that is not only used to predict the same phenomenon, more than that it also support spatial simulation interactively by changing the parameters in a model to study the actual real world [18][25]. CA should not only play a role as a framework spatial modelling, but a paradigm for thinking about the complexity of the phenomenon of spatial-temporal including testing for ideas [14] and explore different possibilities in the future [8], including its ability to adopt the theory and practical to resolve the complexities including for testing a bunch of scenarios [1][25]. CA mechanism is essential to be applied on the field of urban and regional planning which has a future orientation, while generally more resemblance to a model search for the observed changes in the nature trend (extracting data and observations were made based on the present to the past).

Several software have been developed based on Cellular Automata algorithm in order to predict the land use/land cover change within Geographic Information System, such as Idrisi by Clark Labs, CLUE-S developed by Peter Verberg [29], Metronamica developed by Risk University and so forth. However, almost all those CA models are used to predict trend oriented-based compare than future scenario-based development. Those are lack of planning act where user can’t control the driving-force and cope with specific target of spatial prediction. In order to fill the gap in terms of urban planning area which is tend to be future scenario-planning basis, a new software has been developed. LanduseSim, is a Cellular Automata model and software for predicting future urban growth and land use change in particularly focusing on future oriented development and scenario planning. LanduseSim is developed by Nursakti Adhi Pratomaoatmojo (Institut Teknologi Sepuluh Nopember) and it have been recognized as a GIS planning tool by worldwide communities. By means of LanduseSim, user will able to test their plan or evaluate the existing plan by considering the impact to spatial plan and the dynamic of land use and environment.

This paper introduces LanduseSim as a planning model [22] includings features, model, frameworks and ability to forecast the future landscape and spatial land use change simulation. Pekalongan municipal is selected as area study in order to demonstrate the LanduseSim implementation under land use change modelling process.

2. Features and Methods

2.1. LanduseSim Introduction and Features

LanduseSim is a GIS tool for land use/land cover (LULC) modelling and simulation that able to deal with land dynamic simulation. LanduseSim as land use modelling software becomes an appropriate software to do massive spatial simulation for urban sprawl and land use change prediction undergo computer iteration. More advance in utilization, LanduseSim is capable on delivering several critical frameworks for urban and regional planning processes such as explaining the land use changes, generate more planning scenarios, evaluating the developing plans, simulate the plans, and indirectly able to give feed-backs for better decision making. In order to support the main function for planning, LANDUSESIM has several cutting-edge features that can be used for spatial planning approach where its features are able to test scenario planning. The main features are consist scenario of infrastructure development, zoning implementation for protected areas, and generating new type of land use class (Table 1).

Figure 1 shows a illustration concept of initial land use map that will be processed using the main features of LanduseSim. This initial of land use map consist of five type of land use classes i.e. urban area 8 Ha, agriculture land 20 Ha, Forest area 15 Ha, and protected area 6 Ha.
The first feature of LanduseSim is its ability to test scenario of infrastructure plan or development (Figure 2). In this case two alternatives scenarios of additional new road plan are tested to get the expression of landscape change. By simulating both scenarios, scenario 1 and 2, planner will able to choose the less impact on the land use change. The figure 1 shows urban area (8 Ha) was projected to grow as much as 10 Ha and provide the conclusion that scenario 1 is more less conversion of forest compare than scenario 2, while scenario 2 is better choice in considering the agriculture sustainabili ty than scenario 1.

The second feature is its ability to test the zoning such protected area for development (Figure 3). It shows LanduseSim also capable on delivering a robust application towards zoning implementation under land use simulation. The zoning is used to protect some areas from alteration of land use during the simulation process. In addition, the mechanism of zoning could be used to promote the development from certain land use.
The third is LanduseSim able to predict the growth of certain new land use type even on the historical data that never exist (Figure 4). This ability is very special and important, in particularly to deal with spatial planning which dealing with target scenario of development or it can be implemented on fast growth of urbanization.

2.2. LanduseSim Methods
LanduseSim uses a cellular automata algorithm for spatial simulation and it also allow users able to control all factors for spatial simulation procedure [12], such as target growth, the driving-factors, create scenarios of planning involves zoning, infrastructure plan creation, simulation multi-landuse, and even the ability to create new of cell states during the simulation. The CA used in LanduseSim is different compare to Markov-CA which is used to make prediction based on probability or trend basis [23]. LanduseSim model begins through neighbourhood filtering on initial transition potential map where the suitability map each of land use was generated by overlaying the driving-factor as well as the zoning for open space, protected areas and so forth. LUCC Module in LanduseSim, process the CA simulation requires a land use/land cover map, a transition rules, a neighbourhood filter, and time-step simulation. Land use map used as initial base map for simulation procedure and it will be updated regularly based on time-step during simulation. The transition rules are set of land use codes, expected growth cell, suitability maps, dynamic constraints, and conversion elasticity. The transition rules also represented the sequences of land use simulation. The neighbourhood filter executed the suitability
maps as well as the land use conversion elasticity based on selected neighbourhood filter operation.

Figure 5. Framework of Cellular Automata Model using LUCC Module in LanduseSim

Figure 5 describes that cellular automata process in LanduseSim is multi loop iteration based on time-steps. The initial land use map should be prepared at first, while initial transition potential map is the important for growth simulation. Set of transition rules in this application is the key to run on cellular automata simulation. In LanduseSim, transition potential map \( (TP) \) provides direction of simulated land use growth. The value of transition potential map can be generated by following mathematical expression below (Equation 1);

\[
TP_{i,x,y} = \sum_{z=0}^{n} (N_{i(z-n)x,y} \cdot ITP_{i(z-n)x,y})
\]

\( TP_{i,x,y} \) = Transition potential value of land-use \( i \) on certain cell \( (x,y) \) (sum operation of filter)

\( N_{i(z-n)x,y} \) = Neighbourhood filter process by certain filter and its accumulation in to center of the cell \( (x,y) \), while \( n \) is total number of neighbourhood cell with or without cell center.

\( ITP_{i(z-n)x,y} \) = initial transition potential map value for certain land use \( i \). or it can be represented by suitability map for certain land use to grow.

In this method, a multi-criteria evaluation (MCE) combined with GIS [32] and fuzzy set membership function are used to develop transition potential map (TP) for each of land use using WeightedRaster Module in LanduseSim. Constraint map such as zoning of protected areas, bozem, were defined and combine with its suitability map by multiplying the value of suitability map and constraint map (1 or 0). At the early stage, the value of suitability map will be filtered using neighbourhood operation procedure, by multiplying the neighbourhood suitability value, neighbourhood filter’s weight and land use conversion elasticity. Then, the result will be generated using rank method and it resulted from highest to lowest value of transition potential map. Based on the rank map, the growth cell will be allocated using the rank value on rank map and will stop until reach the determined of cell growth. The next of land use map is generated by overlaying the new
growth cell (certain land use) to the previous state of land use (Land use t) where the new growth cell will replace the cell from previous land use map. This mechanism running on sequences and overlaying to the other different land use process through the time step.

In LanduseSim, the process of Cellular Automata iteration to simulate the growth of certain land use class generated by following mathematical expression below (Equation 2):

\[ LU_{t,x,y}^{t+1} = f \left( LU_{t,x,y}^t, TP_{t,x,y}, G_{i,x,y}, C_{i,x,y}, E_{i,x,y}, Z_{i,x,y}, TS \right) \]  

\( LU_{t,x,y}^{t+1} \) = The new growth (change state) of land-use \( i \) at the time \( t+1 \) on certain cell \( (x,y) \).

\( LU_{t,x,y}^t \) = the state of the previous land use class before simulated on certain cell \( (x,y) \).

\( TP_{t,x,y} \) = Transition potential map of land-use \( i \) on certain cell \( (x,y) \).

\( G_{i,x,y} \) = Number of expected cell growth from land-use/land-cover \( i \) on certain cell \( (x,y) \).

\( E_{i,x,y} \) = Elasticity of change for certain land use to be converted to land use \( (i) \).

\( C_{i,x,y} \) = Land growth constraint that can be represented of certain land use that can’t be converted by land use \( i \) or zoning that need to be conserved or protected. Constraint area usually is used to represent such as certain land use class that not possible to be converted by land use \( i \).

\( Z_{i,x,y} \) = Zoning system such as land use plan, disaster area, growth promotion zone.

\( TS \) = Time-step of cellular automata iteration

### 3. Data Collection

This section discusses about the data, which is used in the modelling process. Land use map on Pekalongan Municipal of 2003 was produced by digitized on scale of 1:5,000 from the geo-referenced of satellite imageries (Google Earth courtesy), and later on the digitized maps were converted into raster format with resolution about 100 meter square (10mx10m) for each of cell. The digitized land use map consists of 11 land use classes. This research uses land use data from Pratomoatmojo [23] and Marfai et al. [19]. This land use map is used as initial map for land use change simulation. On the other hand, the accessibility data which are used as transition map for each of land use growth was produced by Geospatial Agency of Indonesia (In Indonesian: Badan Informasi Geospasial) such as primary roads and secondary roads. In this short brief of modelling, the transition maps include distance to primary road, distance to secondary road, distance to settlement and distance to industry.

### 4. Result and Discussion

#### 4.1. Expected Growth

The process of cellular automata in LanduseSim requires transition map for each of land use growth. In this case, two class of land use have been selected to be expected to grow i.e. settlement and industry (see Table 1). The growth cell for those classes are just hypothetical data that is used as instrument to process growth prediction in this study. However, in trend prediction the number of growth cell can be generated from two-years land use map comparison. Meanwhile, it also possible generated form certain regulation, planning or decision from local government as targeted number of growth. Each of land use class has its own land use constraint to develop, which means the land use will never expand to their land use constraints (see Table 1).
### Table 1. Transition rules of Settlement and Industry

| Land use | LU Code | Expected to Grow | Growth in cell (10mx10m) | Land use constraints |
|----------|---------|-----------------|--------------------------|----------------------|
| Industry | 1       | 50 Ha ~ 500,000 m² | 5,000 cells              | River (11), Transportation Terminal (2), Settlement (3), Urban open space (4) |
| Settlement | 3       | 700 Ha ~ 7,000,000 m² | 70,000 cells             | River (11), Transportation Terminal (2), Industry (1), Urban open space (4) |

#### 4.2. Initial Transition Potential Map

Initial transition potential map in land use change modelling is the important map as basis growth of certain land use. In this study, accessibility factors were used as driving-forces of settlement and industrial growth. The standardization process of distance map using *Fuzzy Set: Decreasing* (Equation 3) module in LanduseSim, to generate real values between 0 (zero) until 1 (one).

\[
S_{std,x,y} = \frac{S_{i,x,y}}{\max_i S_i}
\]  
\[
S_{std,x,y} = -\left( \frac{S_{i,x,y}}{\max_i S_i} - 1 \right)
\]

- \( S_{std,x,y} \) = the standardized value on certain cell \((x,y)\).  
- \( S_{i,x,y} \) = the suitability score/distance value on certain cell \((x,y)\).  
- \( \max_i S_i \) = maximum value of suitability score/distance value

In this research, transition maps for land use growth (e.g. settlement and industry) are generated by overlaying each of distance map and its relevant weight. The score defined by qualitative approach of area observation and general perspective. However, in order to ensure a scientific approach in weighting process, another high-trust method or stakeholder perspective can be used as alternative, such as AHP (*Analytical Hierarchical Process*) [26]. In order to create transition potential map for each land use, *WeightedRaster* module in LanduseSim to operate the weighting process for each set of driving-factors. The driving-factors also can be gathered by several ways in land use change modelling, such as literature based, focus group discussions, Delphi analysis, confirmatory factor analysis, logistic regression, neural networks analysis and so forth. Here, settlement driving-force consists of distance to primary roads (0.20), distance to secondary roads (0.4), and distance to settlement area (0.40). Meanwhile, the growth of industry will be influenced by distance to existing industry (0.45), distance to primary roads (0.35) and distance to secondary roads (0.20).

![Figure 6. Standardized value of distance for each driving-factor](image-url)
4.3. **Land use change prediction**

The process of cellular automata iteration in this research uses neighbourhood filter 3x3 of sum operation and it uses 10 time-steps to generate 10 years map-series starts from 2003 to 2013 (Figure 7).

Figure 7. Time-series map generated using LanduseSim
Figure 7 shows the result of land use change simulation by means of LanduseSim-Cellular Automata and its transition rules (Table 2). The settlement area tend to growth in several parts from west, north, east to south, while industry area spreads to several spots near to existing industry. The result of simulation is described in more detail as quantitative calculation of land use change matrices in Table 2.

Table 2. Land use change matrices analysis of Pekalongan 2003 – 2013 (in cells)

| LAND USE CHANGE | Class    | 2003   | 2004   | 2005   | 2006   | 2007   | 2008   | 2009   | 2010   | 2011   | 2012   | 2013   |
|-----------------|----------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Industry        | 10618    | 11118  | 11618  | 12118  | 12618  | 13118  | 13618  | 14118  | 14618  | 15118  | 15618  |
| 2 Transportatio | 1343     | 1343   | 1343   | 1343   | 1343   | 1343   | 1343   | 1343   | 1343   | 1343   | 1343   |
| 3 Settlement    | 195312   | 202312 | 209312 | 216312 | 223312 | 230312 | 237312 | 244312 | 251312 | 258312 | 265312 |
| 4 Urban open    | 3408     | 3408   | 3408   | 3408   | 3408   | 3408   | 3408   | 3408   | 3408   | 3408   | 3408   |
| 5 Openland      | 3812     | 3429   | 3186   | 2993   | 2881   | 2767   | 2637   | 2487   | 2359   | 2205   | 1989   |
| 6 Plantation    | 22740    | 21563  | 20352  | 18960  | 17496  | 15966  | 14225  | 12552  | 11098  | 9787   | 8523   |
| 7 Dryland       | 15434    | 13863  | 12658  | 11700  | 10675  | 10035  | 9564   | 9196   | 8747   | 8396   | 8051   |
| 8 Fishpond      | 35752    | 35263  | 34707  | 34132  | 33590  | 33016  | 32464  | 31979  | 31525  | 31086  | 30667  |
| 9 Swamp         | 15059    | 14897  | 14763  | 14642  | 14532  | 14414  | 14291  | 14192  | 14086  | 13906  | 13614  |
| 10 Paddy Field  | 155844   | 152142 | 148007 | 143762 | 139539 | 135077 | 130553 | 125835 | 120948 | 115836 | 110722 |
| 11 River        | 7300     | 7360   | 7300   | 7360   | 7360   | 7360   | 7360   | 7360   | 7360   | 7360   | 7360   |

Figure 8. The graph of changing area of non-built up land use from 2003 to 2013

The results of simulation (Table 2 and Figure 8) are essential for urban and regional planning process that offers a better perspective towards future condition. In terms of spatial evaluation, spatial metrics can be used as one of the methodology to measure the spatial configuration [24][30]. In this research, actually the final output of land use change prediction can be evaluated using spatial metrics calculation to provide detail measurement about urban sprawl phenomenon. However, this research not attempting the spatial metrics measurement.

4.4. Machine Benchmark

In conjunction with demonstration of land use modelling using LanduseSim, this study also do benchmarking about LanduseSim process due to different specification of computation power under
the similar condition of simulation. All process will use 10 years iteration per year of time-step. Table 3 shows the speed of computation process while using LanduseSim to simulate the land use change using the same data. Based on Figure 9, it gives a conclusion that speed of processor means a lot for simulation process using LanduseSim. The more power of processor specification will result faster of iteration.

![Figure 9. Iteration performance of several CPU’s using LanduseSim](image)

### Table 3. LanduseSim benchmark simulation process

| CPU, Memory, HDD, OS | CPU Released | Core/Threads | Run at speed | (Resolution) Number of Cells | Num of LU Growth / Time (Per year Growth simulation) | Elapsed Time |
|----------------------|--------------|--------------|--------------|------------------------------|------------------------------------------------------|--------------|
| Intel Core i7 4720HQ @ 2.6GHz OS : Windows 10 64Bit | Q1’ 2015 | 4 Cores 8 Threads | 3.4 Ghz | (798 * 915) 730,170 cells | 2 Land use classes 10 Years | 19 Minutes |
| Intel Core i5-4200M @ 2.5 Ghz Mem : 4GB RAM DDR3 OS : Windows 7 SP1 64Bit | Q4’ 2013 | 2 Cores 4 Threads | 3.0 Ghz | (798 * 915) 730,170 cells | 2 Land use classes 10 Years | 22 Minutes |
| Intel Core i3 2310 M @ 2.1 Ghz Mem : 2GB RAM DDR3 OS : Windows 7 32Bit | Q1’ 2011 | 2 Cores 4 Threads | 2.1 Ghz | (798 * 915) 730,170 cells | 2 Land use classes 10 Years | 41 Minutes |
| AMD A8-4500M APU @ 1.9 Ghz (run default on 1.4 Ghz) Mem : 4GB RAM DDR3 OS : Windows 7 SP1 64Bit | Q2’ 2012 | 4 Cores 4 Threads | 2.3 Ghz | (798 * 915) 730,170 cells | 2 Land use classes 10 Years | 62 Minutes |
| Intel Celeron N2840 @ 2.58 Ghz Mem : 2GB RAM DDR3 OS : Windows 7 32Bit | Q3’ 2013 | 2 Cores 2 Threads | 2.58 Ghz | (798 * 915) 730,170 cells | 2 Land use classes 10 Years | 92 Minutes |

*Notes: the length of time in simulation process is determined by the type and speed of CPU*

### 5. Conclusion

LanduseSim is spatial modelling software that able to do massive simulation such as predict of urban sprawl and land-use change prediction undergo computer iteration. In urban planning perspective, LanduseSim able to assist crucial framework in planning process to provide information about the future of landscape which is very important for zoning and decision about the development-phase.
LanduseSim is developed to be robust application of land use change modelling for planning oriented and great to deal with planning practices. LanduseSim is also capable on deal with trend oriented prediction and its showing high accuracy on spatial assessment. Nugroho [21] have measured it and get the result of accuracy about 89% while Gharbia et al [11] is about 87-89%. LanduseSim is also appropriate to assess several works related to urban planning, such as urban and regional planning review by evaluating simulation result towards spatial plan, spatial planning revision, and assist planner to re-adjust development program based on simulation process for optimal urban development. In order to improve the quality of spatial planning, urban planner needs a tool to predict dynamic of land use in the future to get better and precision information about the dynamic of landscape. This will lead better development planning and increase planner confident when creating short-term or long-term period of spatial planning document. It also drive urban planner to arrange the time-frame of infrastructure development.

6. References
[1] Adhvaryu, B. 2010. Enhancing urban planning using simplified models: SIMPLAN for Ahmedabad, India. Progress in Planning, 73, 113-207.
[2] Batty, M. 1997. Cellular automata and urban form: a primer. Journal of the American Planning Association, 63(2), 266-274.
[3] Batty, M., Xie, Y., Sun, Z. 1999. Modeling urban dynamics through GIS-based cellular automata. Computers, Environments and Urban Systems, 23, 205-233.
[4] Barredo, J., Kasanko, M., McCormick, M., Lavalle, C. 2003. Modelling dynamic spatial processes: Simulation of urban future scenarios through cellular automata. Landscape and Urban Planning, 64, 145-160.
[5] Barredo, J.I., Demicheli, L., Lavalle, C., Kasanko, M., McCormick, N. 2004. Modelling future urban scenarios in developing countries: An application case study in Lagos, Nigeria. Environment and Planning B, 31, 65-84.
[6] Chen, J., Gong, P., He, C., Luo, W., Tamura, M., Shi, P. 2002. Assessment of the urban development plan Beijing by using a CA-based urban growth model. Photogrammetric Engineering & Remote Sensing, 68, 1063-1071.
[7] Clarke, K.C., Hoppen, C. Gaydos, L. 1997. A self-modifying cellular automaton model of historical urbanisation in the San Francisco Bay Area, Environment and Planning B, 24, 247-261.
[8] Engelen, G., 1988. The theory of self-organization and modeling complex urban system. Eur. J. Oper. Res, 37, 42-57.
[9] Engelen, G., Geertman, S., Smits, P., Wessels, C. 1999. Dynamic GIS and strategic physical planning support: a practical application, Chapter 5 in Stillwell, J.C.H., Geertman, S. and Openshaw, S. (eds) Geographical Information and Planning, Springer, Berlin, 87-111.
[10] Fuglsang, M., Munier, B., Hansen, HS. 2013. Modelling land-use effects of future urbanization using cellular automata: An Eastern Danish case. Environmental Modelling & Software, 50, 1-11.
[11] Gharbia, S.S., Alfatah, S.A., Gill, L. et al. 2016. Land use scenarios and projections simulation using an integrated GIS cellular automata algorithms. Model. Earth Syst. Environ. (2016) 2: 151. https://doi.org/10.1007/s40808-016-0210-y
[12] Hall, P. 2002. Urban and Regional Planning Fourth Edition, Routledge.
[13] He, C., Okada, N., Zhang, Q., Shi, P., Li, J. 2008. Modelling dynamic urban expansion processes incorporating a potential model with cellular automata. Landscape and Urban Planning, 86, 79-91.
[14] Itami, R.M. 1994. Simulating spatial dynamics: cellular automata theory. Landscape and Urban Planning, 30, 24-47.
[15] Lambin, E.F., Geisth, H. 2001. Global land use and land cover change: What have learn so far?. Global Change News Letter, 46, 27-30.
[16] Li, X. and Yeh, A.G.O. 2000. Modelling sustainable urban development by the integration of constrained cellular automata and GIS, International Journal of Geographical Information Science, 14(2), 131-152.
[17] Li, X. and Yeh, A.G.O. 2004. Data mining of cellular automata’s transition rules. International Journal Geographical Information Science, 18, 723-744.
[18] MacGill, S.M. 1986. Evaluating a heritage of modelling styles. Environmental and Planning A, 18, 1423-1446.
[19] Marfai, M.A., Pratomoatmojo, N.A., Hidayatullah, T., Nirwansyah, A.W., & Gomaeruzzaman, M. 2011. Model Kerentanan Wilayah Pesisir Berdasarkan Perubahan Garis Pantai dan Banjir Pasang (Studi Kasus: Wilayah Pesisir Pekalongan). RedCarpet Studio. Yogyakarta
[20] Mitsova, D., Shuster, W., Wang, X. 2011. A cellular automata model of land cover change to integrate urban growth with open space conservation. Landscape and Urban Planning, 99, 141-153.
[21] Nugroho, A.A. 2013. Model Perubahan Landuse akibat kenaikan muka air laut dan pasang maksimum di pantai utara teluk lamong (PUTL) bagian surabaya. Master Tesis Teknik Manajemen Pantai ITS. Indonesia
[22] Pratomoatmojo, N.A. 2014. LanduseSim sebagai aplikasi pemodelan dan simulasi spasial perubahan penggunaan lahan berbasis Sistem Informasi Geografis dalam konteks perencanaan wilayah dan kota. Seminar Nasional CITIES 2014. ISBN : 978-602-71612-0-7
[23] Pratomoatmojo, N.A. 2012. Land use change modelling under tidal flood scenario by means of Markov-Cellular Automata in Pekalongan Municipal. Universitas Gadjah Mada, Yogyakarta.
[24] Rutledge, D. 2003. Landscape indices as Measures of the Effect of Fragmentation: Can Pattern Reflect Process?. DOC Sci. Intern. Ser. 98, pp. 1-27, 2003.
[25] Sante I., Garcia, A.M., Miranda, D., Crecente, R. 2010. Cellular automata models for the simulation of real-world urban processes: A review and analysis. Landscape and Urban Planning, 96, 108-122.
[26] Satty, T.L. 1980. The analytic hierarchy process. McGraw-Hill, New York.
[27] Thomas, H., Laurence, H.M. 2006. Modelling and projecting land-use and land-cover changes with a cellular automaton in considering landscape trajectories: an improvement for simulation of plausible future states. EARSeL eProceedings 5, 63-76.
[28] Tobler, W. R. 1979. Cellular geography, in Gale, S. and Olsson, G. (eds) Philosophy in Geography, Reidel, Dordrecht, 379-386.
[29] Verburg, P.H., Veldkamp, W.S.A., Espaldon, R.L.V., Mastura, S.S.A. 2002. Modeling the spatial dynamics of regional land use: The CLUE-S Model. Environmental Management, 30, 391-405.
[30] Wijaya, A., Susetyo, C., Diny, A.Q., Nabila, D.H., Pamungkas, R.P., Hadikunnua, M., and Pratomoatmojo, N.A. 2017. Spatial Pattern Dynamics Analysis at Coastal Area Using Spatial Metric in Pekalongan, Indonesia. doi:10.20944/preprints201705.0145.v1
[31] Wolfram, S. 1984. Cellular automata as models of complexity, Nature, 311, 419–424.
[32] Xue, F. and Bian, Z. 2008. GIS combined with MCE to evaluate land quality. Agriculture, IFIP International Federation for Information Processing, Volume 258; Computer And Computing Technologies, 1, 215-222.