Future Development Scenarios for Adaptation to Climate Change in the Ci Kapundung Upper Water Catchment Area, Bandung Basin, Indonesia

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Abstract: Landscape change in the Ci Kapundung upper water catchment area over recent decades has increased the volume of rainfall runoff, increasing the incidence of flooding in the Bandung Basin. At the same time, climate change affects rainfall variability in Indonesia, causing higher frequencies of extreme rainfall and drought in almost all regions of the country. This study develops and assesses four scenarios for the future spatial plan in the catchment area, which is part of a research project on flood risk in the Bandung Basin. The scenarios were created based on recent land use changes within the area, current spatial policies, ecological design principles, and the geodesign framework. All scenarios were simulated using Land Change Modeler (LCM), which applies a combined cellular automata and Markov model (CA-Markov), and a multilayer perceptron (MLP) neural network, to project future landscape forms for 2030. In this simulation, the results were assessed to see the variations of land cover composition. CA-Markov models have been widely used to predict urban growth. Modeling applications for forest cover change simulation have rarely been explored. Results from LCM show that there is no significant difference in the percentages of developed areas, mixed plant communities, and conifers in 2030 in all scenarios. However, the spatial arrangement of land cover varies with each scenario. In the first scenario, for example, the disperse settlement pattern is projected to occur in the watershed in 2030, including in the areas with steep slopes and near the rivers, whereas in other scenarios, specific areas are restricted to be built. The study suggests that further analysis of hydrological impacts of each scenario is needed to ascertain which scenario can effectively reduce flood risk.

Keywords: Climate change, flooding, scenario method, geodesign, land change models

1 Introduction

Recent studies have shown that ongoing emissions of greenhouse gases are driving climate change including inducing higher frequencies of extreme El Niño and La Nina events (CAI et al. 2015). Based on anomalies in sea surface temperature recorded during 1981-2010, QALBI et al. (2017) suggests that rainfall intensity in Indonesia decreased by up to 150 mm/ month during El Niño events and by up to 200 mm/month when El Niño combines with positive IOD (Indian Ocean Dipole) events. Greatest increases in precipitation (200 mm/ month) were recorded during La Nina with negative IOD in 1998 and 2010 occuring in almost all regions in Indonesia. In the future, extreme precipitation in tropical areas is projected to increase, although the specific rainfall patterns affected by climate change at local scales are unpredictable (JHA et al. 2012). Therefore, climate change factors need to be incorporated into flood risk management at the regional scale.

This study is part of a PhD research project assessing flood risk simulation on different scenarios of future land cover in Ci Kapundung upper water catchment area in the northern part

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of Bandung Basin, West Java province, Indonesia. This study specifically assesses the scenario development of spatial planning of the catchment. The watershed encompasses an area of 102.86 sq km with an elevation varying between 760 and 2,206 meters asl.

The land use changes over the period of 1983-2002 resulted in an increasing runoff coefficient for all catchment areas in Bandung Basin (HARYANTO et al. 2010). The study suggests that among all watersheds in Bandung Basin, Ci Kapundung is the catchment that is degrading at the fastest rate and which has the highest runoff coefficient. High rates of overland flow, caused by intense rainfall over long periods of time and saturated soil, results in the major rivers overflowing. BNPB/Indonesian National Board for Disaster Management recorded at least 13 flood events occurring in Bandung Basin in 2014-2015. According to The Directorate of Plant Protection (2000), West Java is the most susceptible province in Indonesia to drought and flood events during El Niño and La Nina (BOER et al. 2012). Figure 1 shows the flooded area in Bandung Basin during a flood event in 2016, which was affected by the increasing magnitudes of the main rivers in the basin during intense rainfall.

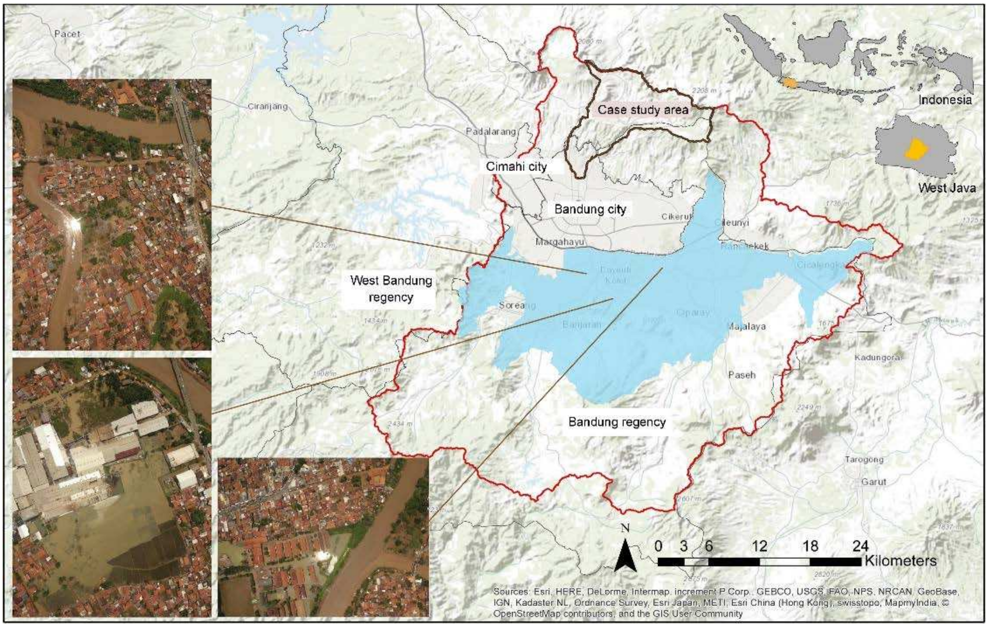


Fig. 1: The flooded area in Bandung basin during 15 March 2016 (658.47 Ha) (The image is redrawn from original image from Pusdantinmas BNPB (2016))

2 Regional Climate Change Adaptation

BMKG/ Indonesian Agency for Meteorology, Climatology and Geophysics predicts changes of rainfall patterns in Indonesia caused by climate change. More intense rainfall with precipitation rates over 50 mm/day will occur in Bandung Basin in the future, while the trend for prolonged periods of precipitation will also increase (BMKG 2017). This suggests that adaptation to climate change is needed to reduce and prevent flooding in the region. More permeable areas and specific vegetation types which are able to absorb runoff water are required. This will help to reduce peak river magnitudes during the rainy season, and add groundwater and baseflow during the dry season.

Based on image classification using SPOT6 satellite images, land cover of Ci Kapundung upper water catchment area in 2015 is composed of developed areas (13.48 %), agriculture (40.09 %), mixed plant communities (16.25 %), conifers (16.02 %), broad-leaved plant communities (14.15 %), and water bodies (0.0001 %). There is no continuous river buffer along the Ci Kapundung River and its tributaries. Development of settlements and infrastructure is not only located in relatively flat terrain, but also on steep slopes. There are regional plans for the three municipalities but there is no specific plan for climate change adaptation. Only one municipality in the watershed has specified that some parts of the area should not be built up due to high soil permeability and thus the capacity to absorb run-off water. However, as yet no particular land cover type is recommended in this area. Characterising future climate scenarios and assessing their impacts on ecological function within the different regions of Indonesia, is a high priority according to the Ministry of Environment and Forestry of Indonesia (2016).

3 Methods

The methodology in this study is shown in figure 2. The 2013, 2015, and 2017 land cover maps of the case study were derived from SPOT 6 satellite images and validated by field surveys. Image calibration and topographic correction using a modified sun-canopy-sensor/SCS+C (SOENEN et al. 2015) were applied before conducting the object-based image classification (RANI et al. 2017).

In this study, four different scenarios of land cover composition in Ci Kapundung watershed have been generated. The development of scenarios was conducted in response to the increasing needs for new settlements and agriculture areas, as well as for climate change adaptation. Scenarios are defined as *"archetypal descriptions of alternative images of the future, created from mental maps or models that reflect different perspective on past, present and future developments"* (ROTMANS 1998, 158).

The first scenario (Status Quo) was made based on the current trend of land cover changes in Ci Kapundung upper water catchment area during 2013-2015. The current trend in land change does not comply with the existing spatial policies. The second scenario (Existing policy-based scenario) was developed according to the existing spatial plans of the area. The last two scenarios aim to optimise flood risk mitigation and the provision of other ecosystem services for Bandung Basin. Ecological design principles were implemented in the third scenario (Ecological design scenario), which include the improvement of ecological functions of riparian zones and the restriction to open new agriculture in protected areas and existing forests. In this scenario, we defined the area where the future building of new settlements and related infrastructure is allowed.

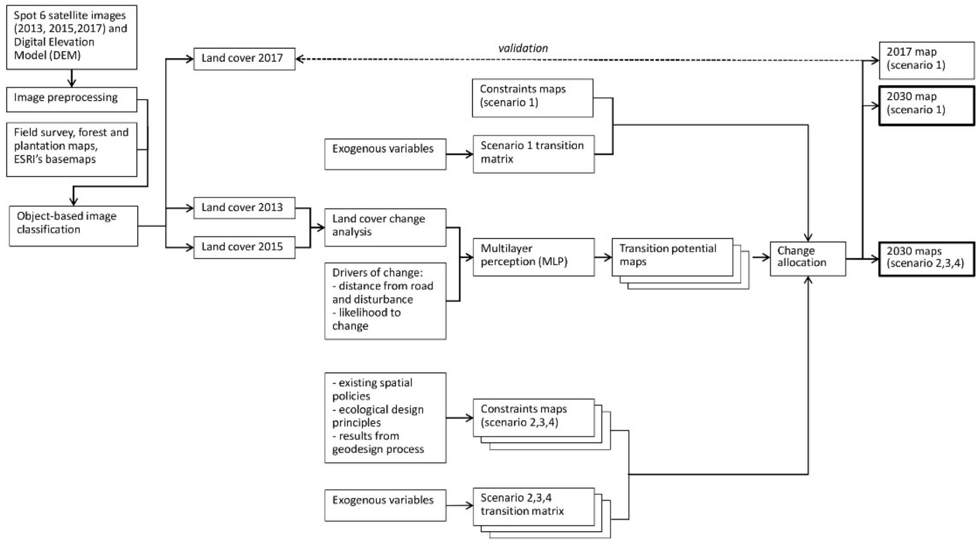


Fig. 2: Methodology used in the study

Geodesign is adopted in this study as an approach to develop the fourth scenario in the case study area. Geodesign is defined as "*a design and planning method which tightly couples the creation of design proposals with impact simulations informed by geographic context, systems thinking, and digital technology*" (FLAXMAN 2010 *cited in* STEINITZ 2012, 12). Collaboration with different stakeholders, systematic understanding of the study area, and evaluation of scenarios are the main components in geodesign (STEINITZ 2012).

We asked three architects and three landscape architects from Indonesia who have knowledge of the case study area to participate in the study. They were asked to define the required allocated area based on the selected criteria. Currently, three of them are living in Bandung city, while the other architects and landscape architects are now living abroad in different countries. So different methods to collect the drawings were implemented in this study. Two drawings were collected directly from the participants in Bandung when we visited the site in September 2017, whereas the collaboration with the other four participants was conducted remotely.

Analyses of the land cover changes from 2013 to 2015 were conducted using the Land Change Modeler (LCM) module of Terrset software. The model applies a combined cellular automata and Markov model (CA-Markov), and a multilayer perceptron (MLP) neural network which create transition potential maps. The transition may include the anthropogenic disturbances, which cause the land cover changes from agriculture to build areas, or dense vegetation cover to agriculture. The CA-Markov model has been widely used to predict urban growth, but application of the model to certain specific scenarios, such as forest cover change simulation, has rarely been explored (GHOSH et al. 2017). Miller (2009) defined CA as *"discrete spatio-temporal dynamic systems based on local rules"* (CLARKE 2014). CA is based on the local interaction between cells to model and simulate complex behaviour (BATTY 2000, *cited in* CLARKE 2014). Markov analysis calculates the transition probabilities of each land cover type. The CA-Markov model in LCM produces a series of probability maps to predict the future land use/land cover. MLP is able to model non-linear relationships between different variables which influence the transition, for example land cover change in relation to proximity to urban centre or roads. Using MLP, all transitions can be empirically modelled at once (EASTMAN 2006).

Based on the land cover changes (2013-2015), transitional maps were developed. The 2017 land cover in the first scenario was simulated and then validated using the actual 2017 map. Kappa statistic was used to assess the accuracy of the predicted land cover map. Changes in the natural and socioeconomic processes in the landscapes cause the transition probabilities among land cover types to change (BOERNER 1996). To estimate this non-stationary Markov model, weighting factors were applied to each transition probability, assuming that the same driver of change in 2013-2017 will occur in 2018-2030. Different weighting factors were applied in the matrix to simulate the land cover maps in the scenario 3 and 4, where there are conservation programs implemented in the area. The results from this land change simulation can be used for a hydrology simulation to estimate flood risk for each scenario.

4 Results and Discussion

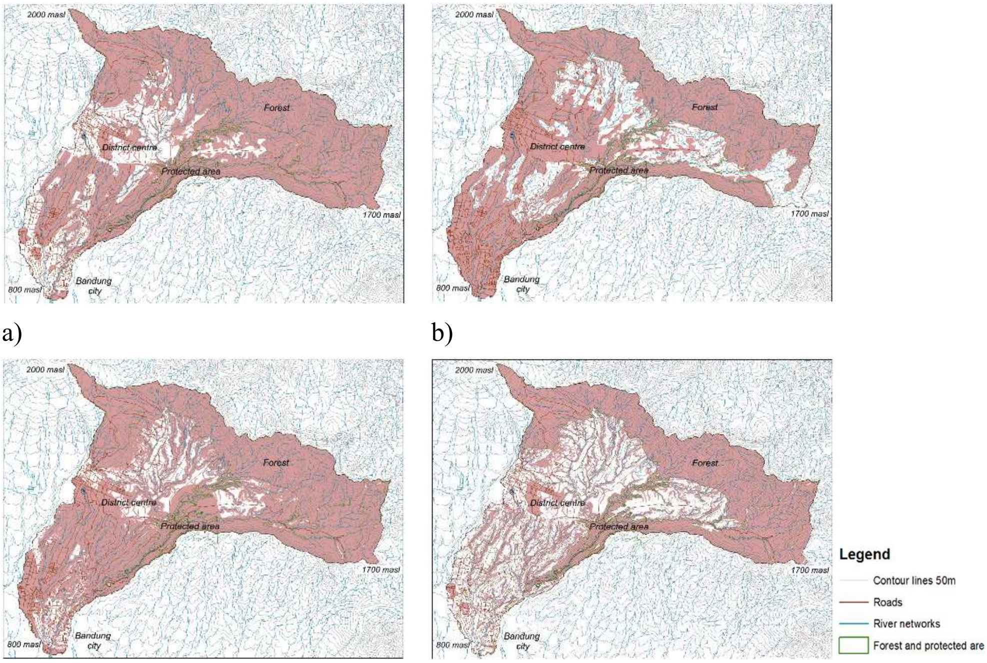
Using the combined CA-Markov model and MLP in LCM, the future land cover in 2030 was simulated based on the images of projected potential for transition under the four scenarios. In the land change simulation, water bodies were excluded in the process due to the small and constant area coverage in 2013-2015, to avoid unbalanced numbers of samples taken from each land cover type.

The model validation showed a low value of the Kappa statistic between the predicted result and the actual 2017 land cover. This result might be caused by the relatively low accuracy of the MLP process (52.86 %) or the exogenous variables which have not been yet calculated in the land change simulation. Natural and socioeconomic processes in the case study area influence the land cover change, so the transition probabilities are not stationary.

In the first scenario, there is no specific area allocated for future development, because LCM simulated the land cover in 2030 based on current trends in land cover change (2013-2015). In the second scenario, two constraints maps, which show areas restricted to the development of new settlements and agriculture, were created based on the existing spatial policies (e. g. land use zoning, minimum distance for river buffer, maximum slope percent rise to build new houses which differs among the three municipalities). Maps illustrating the constraints in the third scenario were developed using ideal development criteria (e. g. only areas with slopes less than 15 % and located in an area with low soil permeability is allowed to be built and no agriculture practices inside the river buffer) (Figure 3).

In the development of the fourth scenario, evaluation maps, which include the information on physical, hydrological, and ecological characteristics, were prepared as part of the geo-design process. These evaluation maps were used to analyse and evaluate the existing condition of the case study, using four evaluation criteria; site, location, administrative criteria (area of municipalities and zoning of the protected area, forests, and agriculture areas owned by government), and existing land cover in 2015. Based on these evaluation maps, six participants' zoned areas were selected, where new development may take place in 2030 (Figure 4).

All conceptual designs created by the participants were compared and overlaid, and based on the synthesis of the different site designation, the final plan for the fourth scenario was constructed. In this plan, zones, where new development will be permitted in the future, are mainly located near the existing developed area with relatively gentle slopes.



a) b) c) d)

Fig. 3: (a-b) Constraints maps which delineate areas restricted to new development of settlements and agriculture in scenario 2; (c-d) Constraints maps which delineate areas restricted to new development of settlements and agriculture in scenario 3

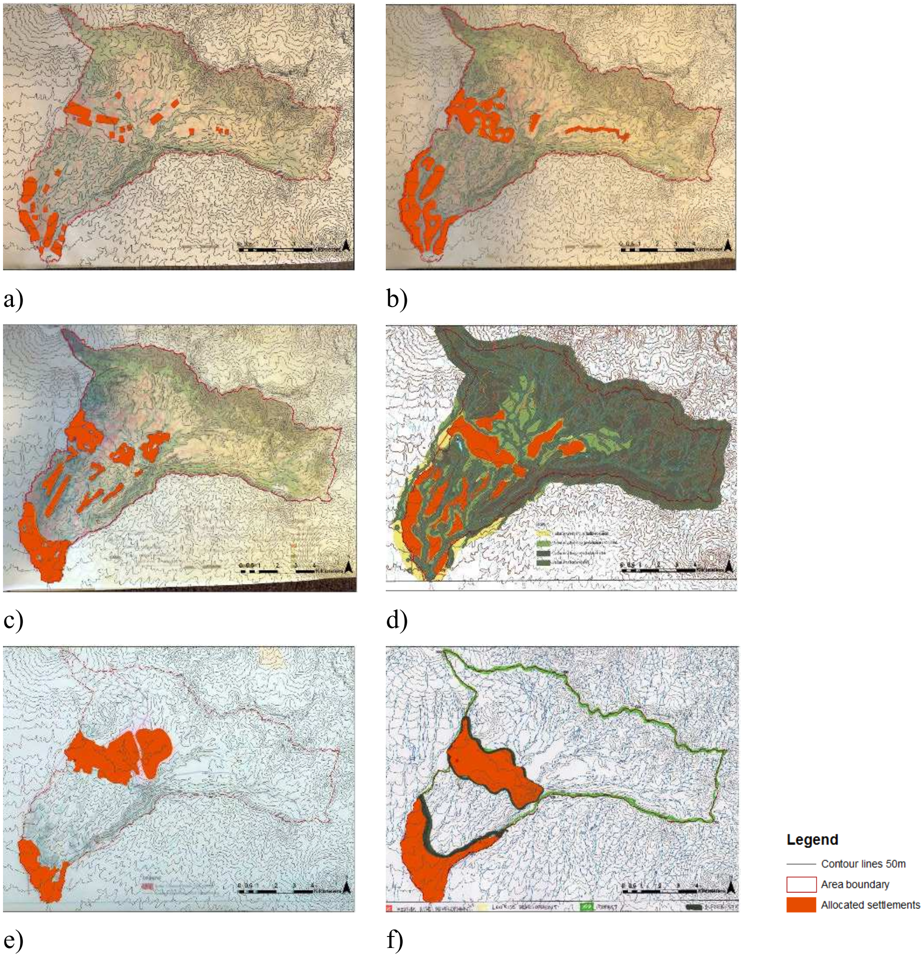


Fig. 4: (a-f) Comparison of zoning created by all participants (change model)

The simulation results show that in the first scenario, the disperse settlement pattern is projected to occur in the watershed in 2030, including in the areas with steep slopes inside the forests and near the rivers, as shown in the black circles number 1 and 2 in figure 5b respectively. In the second scenario, different policies from each municipality affects the development of new settlements in the area. As illustrated in the black circle number 3 in figure 5c, new settlements are projected to occur on areas with steep slopes in the western part of the case study area, because there is no restriction to develop such areas. Although the requirement of minimum distance for river buffer has been stated in the existing policies, no allocation for specific types of vegetation in the riparian has been mentioned.

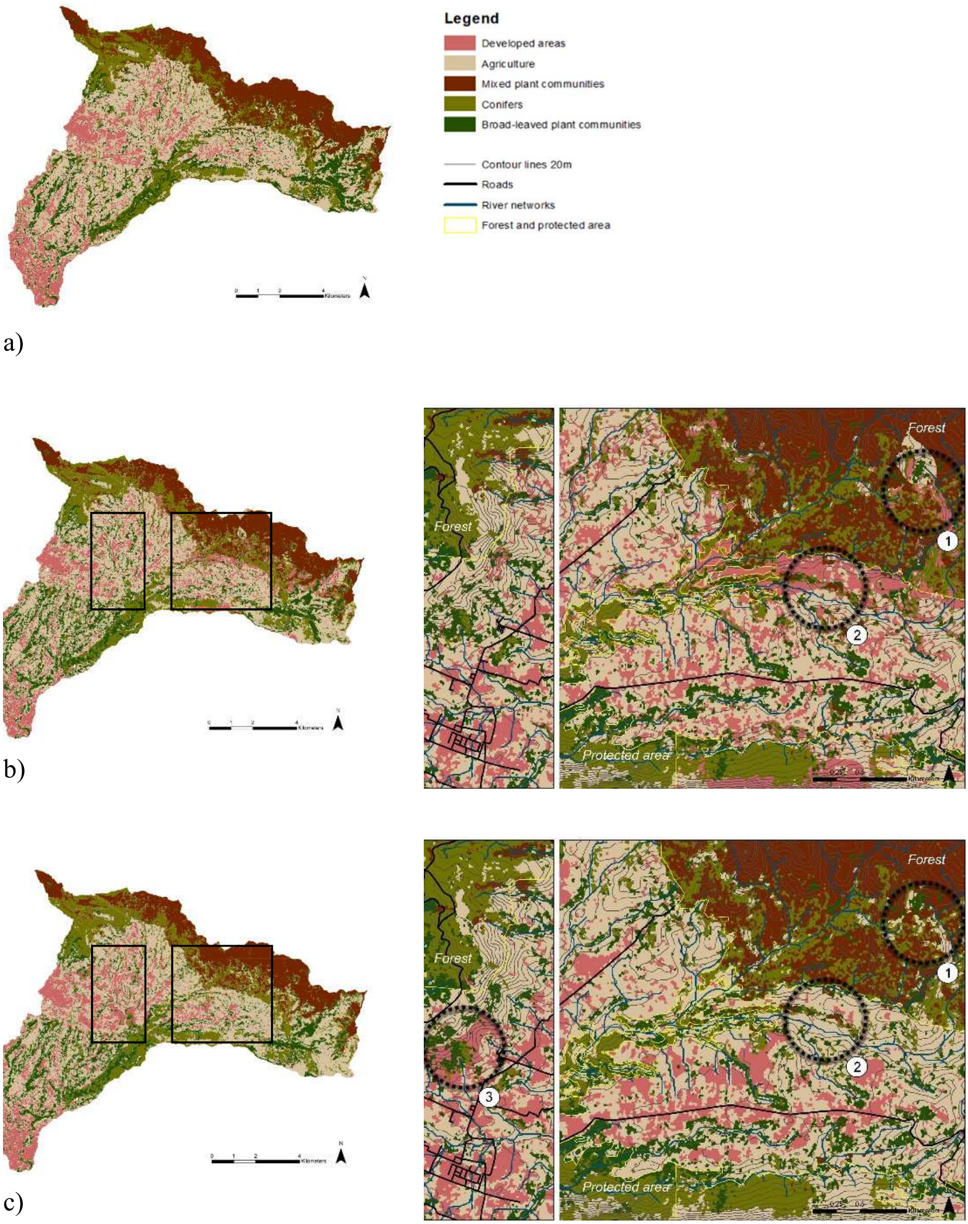
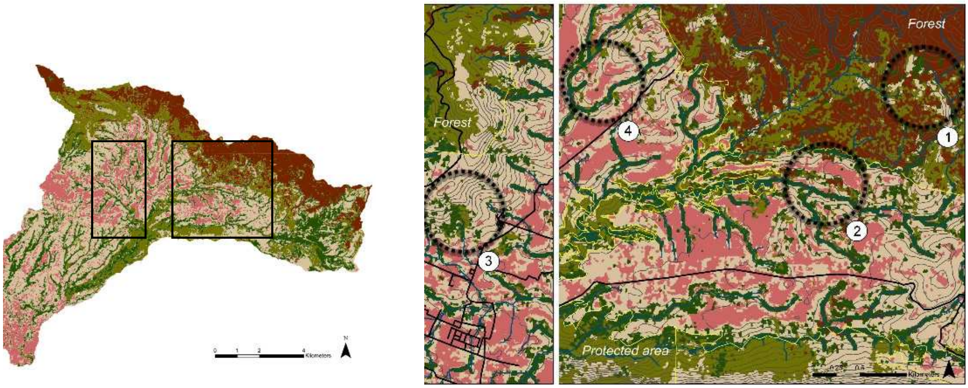
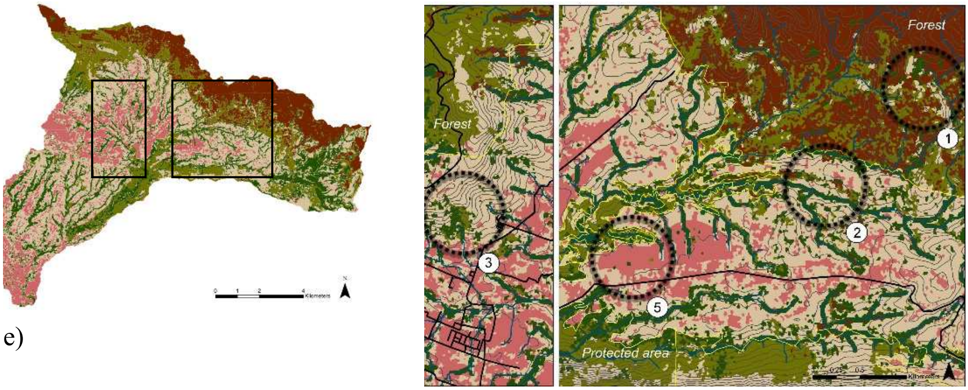


Fig. 5: (a) Existing land cover in 2015; (b-e) Alternative future land cover of Ci Kapundung upper catchment area in all scenarios



d)



e)

Fig. 5 (continued)

In the third and fourth scenarios, no development is allowed inside the forest, protected area, and the river buffer. Broad-leaved vegetation will be planted in the buffer to reduce run off flowing into the river (circle 2 in figure 5d and 5e). New settlements will be built in the northern part of the catchment outside the forest in the third scenario, because the area has relatively gentle slopes (circle 4 in figure 5d), whereas in the last scenario, new settlements will occur near existing settlements in West Bandung regency and Bandung city, as suggested by all geodesign participants (circle 5 in figure 5e).

Although all scenarios have different spatial arrangements, there is no significant difference in the percentages of developed areas, mixed plant communities, and conifers in 2030 (Table 1). The similar percentages of the three land cover types reflect the same weighting factors which were applied to the transitions in the Markov matrices. The developed areas, for example, have the same compositions in all scenarios in 2030 (17.58 %), despite the varieties of spatial distribution in the area, as shown in the constraints map of each scenario. In the scenario 3 and 4, existing developed and agriculture areas inside the river buffer were converted into dense broad-leaved plant communities. A higher weighting factor was used to simulate the transition in the two scenarios. As a result, areas with broad-leaved plant communities in the third and fourth scenarios have higher percentages than the same land cover type in the first and second scenarios.

Table 1: Allocation of land cover changes for each scenario

Land cover	Developed areas	Agricul-ture	Mixed plant communities	Conifers	Broad-leaved plant communities
Existing in 2015	13.481 %	40.091 %	16.255 %	16.019 %	14.154 %
Scenario 1	17.586 %	33.950 %	16.008 %	16.012 %	16.444 %
Scenario 2	17.586 %	33.950 %	16.008 %	16.012 %	16.444 %
Scenario 3	17.583 %	31.407 %	16.256 %	16.009 %	18.744 %
Scenario 4	17.586 %	31.412 %	16.251 %	16.012 %	18.740 %

5 Conclusion

CA and Markov analysis simulate the spatial arrangement and the transition probabilities of each land cover type respectively. A Bayesian approach is suggested to be used to accurately estimate the non-stationary Markov model for the land change simulation. Constraints maps were created based on the allocation criteria for each land cover in the four scenarios. Therefore, the spatial arrangement of land cover varies with different scenarios.

In the development of scenarios using the geodesign approach, it is suggested that participants from different backgrounds (e. g. local government, local consultants, developers, academics) should participate in the process, to give a broader perspective on land use planning in the study area. In this study, the participants have specified one important urban design principle, which was not included in the development of other scenarios. New settlements are likely to be built near the existing developed areas, such as the district centre, for the reason of accessibility to public facilities, which have already been built in the area. Geodesign connects remote people to collaborate, and gives a medium for implementing principles from different fields of study for the land use planning.

Further analysis of hydrological impacts of each scenario is needed to ascertain which scenario can effectively reduce flood risk. This should be supported through the simulation of future climatic conditions based on climate change models. We conclude that the geodesign approach in this study can be transferred to other regions in Indonesia, especially if there is no specific spatial planning for catchment areas with regards to climate change adaptation.

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