HOW FAR CAN WE PREDICT THE PATTERN OF INFORMAL SETTLEMENTS IN URBAN DEVELOPMENT?

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ABSTRACT: Informal settlements are a common phenomenon in urban development in Indonesia, where societies inhabit a neglected, unused, and unsupervised area, including floodplains. The communities often rely more directly on the provision of ecosystem services derived from urban rivers. Although the physical characteristics are visible, there is still a challenge to map and predict the pattern of informal settlements in urban development. This paper offers a critical review of the use of machine learning in land change modelling as a tool to simulate the existing pattern of informal settlements along the Ci Kapundung River and its surrounding area in Bandung, Indonesia. The model uses an explanatory variable test procedure to assess how significant environmental drivers and urbanization (e.g., slope, elevation, proximity to the river, roads, the distance from existing development, and the likelihood of land cover change) are in the generation process of informal settlements. This study shows that human decisions and the ability of inhabitants to adapt to the new environment have strongly affected the pattern, which cannot be shown from the outcomes but are potentially reflected when using agent-based models.

KEYWORDS: informal settlements, land change modelling, machine learning, urban development.

RESUMEN: Los asentamientos informales son un fenómeno común en el desarrollo urbano en Indonesia, donde las sociedades habitan un área descuidada, sin uso y sin supervisión, incluidas las llanuras aluviales. Las comunidades a menudo dependen más directamente de la provisión de servicios ecosistémicos derivados de los ríos urbanos. Aunque las características físicas son visibles, aún existe el desafío de mapear y predecir el patrón de asentamientos informales en el desarrollo urbano. Este artículo ofrece una revisión crítica del uso del aprendizaje automático en el modelado del cambio de suelo como herramienta para simular el patrón existente de asentamientos informales a lo largo del río Ci Kapundung y sus alrededores en Bandung, Indonesia. El modelo utiliza un procedimiento de prueba de variables explicativas para evaluar qué tan significativos son los impulsores ambientales y la urbanización (p. ej., pendiente, elevación, proximidad al río, carreteras, distancia del desarrollo existente y la probabilidad de cambio de la cobertura del suelo) en el proceso de generación de asentamientos informales. Este estudio muestra que las decisiones humanas y la capacidad de los habitantes para adaptarse al nuevo entorno han afectado fuertemente el patrón, que no se puede mostrar a partir de los resultados, pero que se refleja potencialmente cuando se utilizan modelos basados en agentes.

PALABRAS CLAVES: asentamientos informales, modelado de cambio de suelo, aprendizaje automático, desarrollo urbano.

1. INTRODUCTION

Informal settlements have become an integral part of urban development in Indonesia, where societies inhabit a neglected, unused, and unsupervised area, including floodplains. The communities who inhabit the floodplain often rely more directly on the provision of ecosystem services derived from urban rivers, such as for sanitary use, recreation, and harvesting, to survive in the city, regardless of the high risk of hazards [1]. There is still a challenge to map and predict the pattern of informal settlements in urban development [2] despite the apparent physical characteristics.

Informal settlements in the valley of Ci Kapundung River and its surrounding area at Coblong District, Bandung, Indonesia were chosen as the case study area in this research. The settlements have developed from the original neighborhoods that consisted of two babakans (group of houses) in the early 1900s [3] (Figure 1). Siregar [3] further stated that the dwelling area represents the typical development of Ci Kapundung valley in Bandung that has become a fundamental part of the central urban structure. The area was mostly covered by rice fields with scattered houses until the 1960s. At present, more than 7.000 inhabitants with different backgrounds live in the neighborhood [4]. Many rely on the provision of ecosystem services derived from the river, such as for sanitary use and economic activities [3]. This issue is also common in other Indonesian cities [1].

Various models have been developed to simulate land cover change, including the prediction of urban growth [5] and informal settlement development [2]. Machine learning is one of the modeling approaches [6] that can be combined with other land change models to utilize the ability and overcome the drawbacks of each model [7]. An example of the integrated models is Cellular Automata, Markov, and Multi-layer perceptron (CA-Markov-MLP) model. As one of the Artificial Neural Networks used in machine learning [8], MLP in the model works as a tool to calculate the possibility of land cover alterations based on the drivers that cause the change [8]. This paper offers a critical review of the use of machine learning in the integrated land change modelling as a tool to simulate the existing pattern of informal settlements in the case study area.

2. MATERIALS AND METHODS

This study uses Land Change Modeler (LCM) module from Terrset that employs the CA-Markov-MLP model to simulate the land cover change of the case study area from 1905 to 1924 and from 1924 to 2020. The model uses an explanatory variable test procedure to assess the influence of each driver on the land change process [9]. Environmental drivers and urbanization (e.g., slope, elevation, proximity to the river, roads, the distance from existing development, and the likelihood of land cover change) were used as the explanatory variables in the modeling of settlement development in the study area. All GIS datasets were retrieved from BIG/ Indonesian Geospatial Agency. Digital elevation model (DEM) was used to create the slope and elevation maps. Maps showing the proximity to river and roads, the distance from existing development and the possibility of land cover change were generated in Terrset.

Historical maps showing developed areas, a river and existing roads in 1905 and 1924 had been redrawn from [3] and georeferenced using GIS. The two maps were then used as the base maps for the first phase of land change modeling (Figure 1) due to their availability. In addition, the northern section of the case study area was once a part of Kampung Lebak Siliwangi in the early 1900s [3]. The second phase of modeling was conducted using the 1924-2020 base maps. Landsat imagery, which was taken on 8 September 2020, was used to generate the 2020 map using unsupervised classification. The satellite imagery was retrieved from USGS/ United States Geological Survey. All generated maps show two land cover types (e.g., developed and undeveloped areas) (Figure 1).

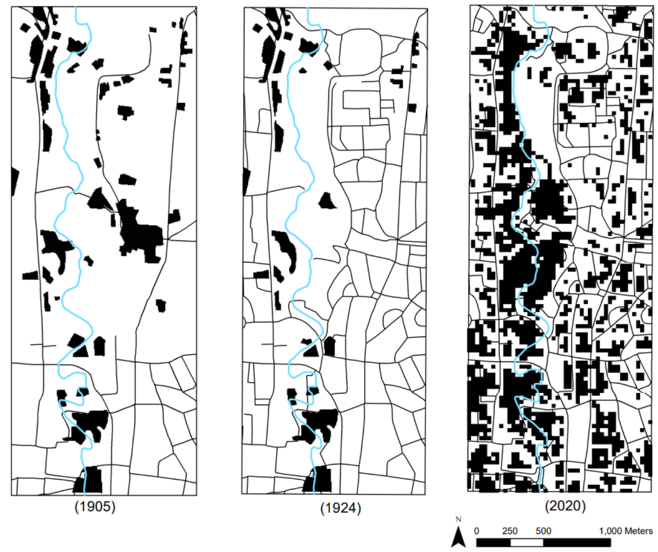

Figure 1 Land cover maps of the case study area (redrawn from Siregar, 1990, and developed from USGS).

3. RESULT AND DISCUSSION

Land cover changes in the case study area from undeveloped to developed areas, and vice versa, are shown in Figure 2. Two phases of modeling have been conducted with accuracy rates of 75.31% and 70.11% for the first and second models, respectively. In this study, MLP was used in the modeling to assess the driver variables that influence the changes. The outcomes from the first phase of modeling (1905-1924) suggest that Ci Kapundung River had become the most influential factor in the early development of the settlement, as more new areas were developed adjacent to the Ci Kapundung River in contrast with other parts of the neighborhoods (Figure 2a). On the other hand, the development was least affected by the location of existing buildings in the area (Table 1). According to [3], one of the major changes that occurred in the neighborhood was the establishment of Techniche Hoogeschool (Institut Teknologi Bandung/ ITB) in 1920. Two groups of houses (babakan), which were regarded as the origin of the kampung, were removed and roads were planned at the current location of ITB in 1924, as indicated in Figure 1.

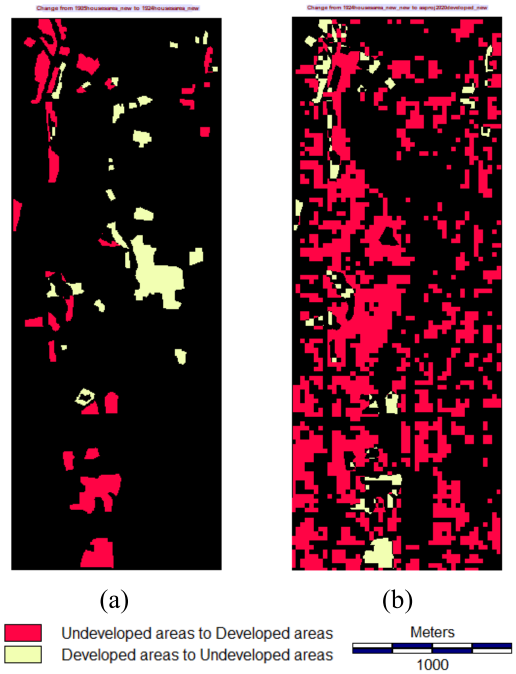

Figure 2 Land cover changes in the study site: (a) 1905-1924; (b) 1924-2020.

Table 1 Driver variables of land cover changes in the case study area.

	Influence order	
	Phase 1 (1905-1924)	Phase 2 (1924-2020)
Slope	4	6 (least influential)
Elevation	2	4
Proximity to river	1 (most influential)	2
Proximity to road	3	1 (most influential)
Distance from existing development	6 (least influential)	3
Likelihood of land cover change	5	5

The explanatory variable test procedure has also been performed in the second phase of modeling (1924-2020). The results show how the development of new roads in the 1920s (Figure 1) initiated further growth of settlements and public facilities along the roads. The kampung adjacent to the river has been spreading despite the difficulty to build houses on such steep slopes. Terrain slope as the least significant driver of settlement development (Table 1) also indicates the ability of inhabitants to adapt to the new environment, including the steep river valley.

The change in the order of influence between five driver variables in 1905-1924 and 1924-2020 (e.g., slope, elevation, the proximity to the river and roads, and the distance from existing development) shows how human decisions, in the form of spatial policies applied and choices made by inhabitants, have contributed to the fluctuated development in the area (Table 1). For example, the location of buildings in 1924 was scattered outside the river valley (Figure 1), indicating that the development in 1905-1924 was least affected by the distance from the existing buildings at the beginning of the period. However, such driver had more impact on the recent development of the case study area. There is a possibility that new buildings were constructed near certain existing land uses in correspond with the economic issues. Visual presentation of the possibility of land cover change from undeveloped to developed areas in 1905-1924 and 1924-2020 is shown in Figure 3. The black color represents areas with unchanged land cover, whereas other colors ranging from blue to red represent areas that have possibility to change, with red that has the highest chance.

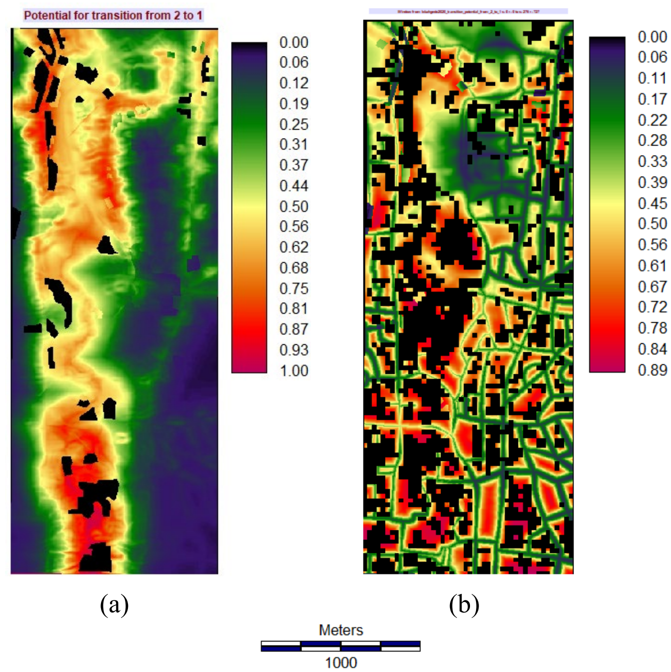

Figure 3 Potential for land cover change from undeveloped to developed areas: (a) in 1905-1924; (b) in 1924-2020.

Every model has its strengths and shortcomings [10]. MLP can predict the spatial variables that affect the land cover changes within specific periods provided that analysts have the complete set of data. However, it is argued that each dweller or local business's motives and plans for new development cannot be integrated into the model and reflected in the outcomes. Agent-based models, in particular, can be used to simulate the land cover alteration planned by each dweller or landowner, as well as the development guided by spatial policies [6]. One example of agent-based models is Envision [11] which applies multiple development policies and scenarios from agents (e.g., landowner, government, etc.). However, natural drivers which also influence the land cover changes are not covered in the modeling process.

4. CONCLUSIONS

This study assesses how machine learning in the hybrid CA-Markov-MLP land change modeling can simulate the development pattern of settlements in the valley of Ci Kapundung River at Coblong District, Bandung in 1905-1924 and 1924-2020. The modeling results show that there is a change in the order of influence between five driver variables in both periods. The proximity to the river has become the most influential driver of change in the first phase of modeling, whereas the proximity to roads was the main factor of land cover alteration in the second phase. It is argued that the change is due to the human decisions (e.g., spatial policies applied, and choices made by inhabitants and other stakeholders to build settlements and other facilities in the area) that cannot be directly modelled by MLP. However, MLP is still capable of evaluating the spatial variables that influence the land cover changes. Agent-based models are potentially be used to simulate the land cover change based on the decisions made by each dweller or landowner and the spatial policies. However, it should be noted that all models have their drawbacks. Therefore, further assessment of model accuracy should be performed. The modeling outcomes, then, are required to be interpreted based on the evaluations.

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