SPATIAL MODELING OF TROPICAL DEFORESTATION USING PALSAR DATA

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ABSTRACT: Majority of the tropical nations lack high-resolution spatiotemporal maps of their forests due to persistent cloud cover over their space. Recent advances in radar remote sensing and development of ALOS/PALSAR sensor have provided weather independent data of earth surface at high resolution. In this research, we aim to develop a spatial model to simulate future deforestation in Southeast Asian region utilizing JAXA's Global Forest/Non-forest (GFNF) maps, which were created using PALSAR data. Riau Province, Indonesia is selected as a pilot study site. Two GFNF maps were used for the years 2007 and 2010. A cellular automata model was designed to calibrate the spatial distribution of deforestation patterns across the province. Modeling parameters were customized for each district that allocates deforestation on the basis of its empirical relationships with proximity to roads, rivers, human settlements, altitude, and slope. The modeling result map was validated using fuzzy similarity index. The simulated patterns of deforestation mirror the state of forest in the province for the next two decades.

1. INTRODUCTION

Calculation of actual GHG emissions requires regular monitoring of deforestation. Combining remote sensing techniques with ground based survey is an effective mean of monitoring deforestation and forest degradations. Spatial model of deforestation provides important abstract information of the future to understand complex process of land cover change along with a platform to test different policy implications. Various spatial models have provided valuable insights into forest cover change processes in the Amazon region; however, such models are still rare in Southeast Asian region. This may be due to the fact that the forest area in the region mostly covers with cloud creating a major barrier to generate spatiotemporally consistent land use/cover maps using optical remote sensing in the early decades. But recent advances in spatial resolution of Synthetic Aperture Radar (SAR) have altered this barrier significantly. SAR is particularly useful to monitor deforestation and forests degradation due to its capability to monitor earth surface in all weather and solar illumination conditions. It consists of unique characteristics, i.e., greater penetration of vegetation and weaker reflection from the relatively flat surface in the forest (Shimada and Ohtaki, 2010), that provide important information to interpret and separate different type of forests and other type of land uses. SAR has been providing global coverage of earth surface for civilian use since the early 1990s. The most recent sensor, PALSAR (Phased Array L-band SAR) of ALOS (Advanced Land Observing Satellite) has collected a large amount of data consistently for the last five years. PALSAR data are available from a scene to global mosaics which can be used for generating land use/cover data from local to global scales at various spatial resolutions as high as 10 meters.

In this research, we aim to develop a spatial model to simulate future deforestation patterns in Southeast Asian region utilizing PALSAR derived JAXA's Global Forest/Non-forest (GFNF) time series maps. Riau Province is selected as a pilot study site for the model calibration and validation purpose. Riau Province located in central Sumatra of Indonesia has been facing rapid deforestation threatening to biodiversity, peat drainage, and forest carbon stocks in the region (Uryu et al., 2008).

2. DATABASE AND METHODOLOGY

Geographically, Riau Province is situated within the geographic coordinates 1°7′24″ South latitude to 2°32′36″ North latitude and 100°1′30″ to 103°48′39″ East longitudes. The province consists of 10 administrative districts spanning over 9 million hectares of land. Two land cover maps at 25 meters spatial resolution for the years 2007 and 2010 were prepared. These maps consist of forest and non-forest land cover categories which are a part of GFNF created using ALOS-PALSAR mosaic data. In this paper, local concept was used in the modeling as deforestation process is location specific and differs by local landscape characteristics. In addition, localized coefficients at district level are more robust to address local relationship among the deforestation players than the averaged coefficient at province level. Markov Chain approach was used to calculate landscape transition matrix. This approach analyzes two land cover maps (2007 and 2010) and produces a quantitative transition probability matrix from forest to non-forest. This matrix was used for the model calibration and prediction of the future spatial patterns. The spatial distribution of deforestation across the province was calibrated with a cellular automata model. Model calibration parameters were customized for each district that allocates deforestation on the basis of its empirical relationships with proximity to roads, rivers including coastlines, settlements including urban centers, altitude, and slope. Spatial integrity across the districts was attained by employing distance to non-forested lands that was updated annually over the entire study area.

Weight of Evidence (WofE) as a probability function was used in the modeling. WofE, entirely based on the Bayesian approach of conditional probability, combines spatial data from variety of sources to describe and analyze interactions, provides evidences for decision making, and makes predictive models (Thapa and Murayama, 2011). This method concerns the favorability to detect change from forest to non-forest area in relation to potential evidences (i.e., proximity to roads, rivers, etc.). Spatial modeling architecture shown in Figure 1 is programmed in DINAMICA software. In this paper, prediction of future spatial patterns of deforestation was limited to the BAU (business as usual scenario) only.

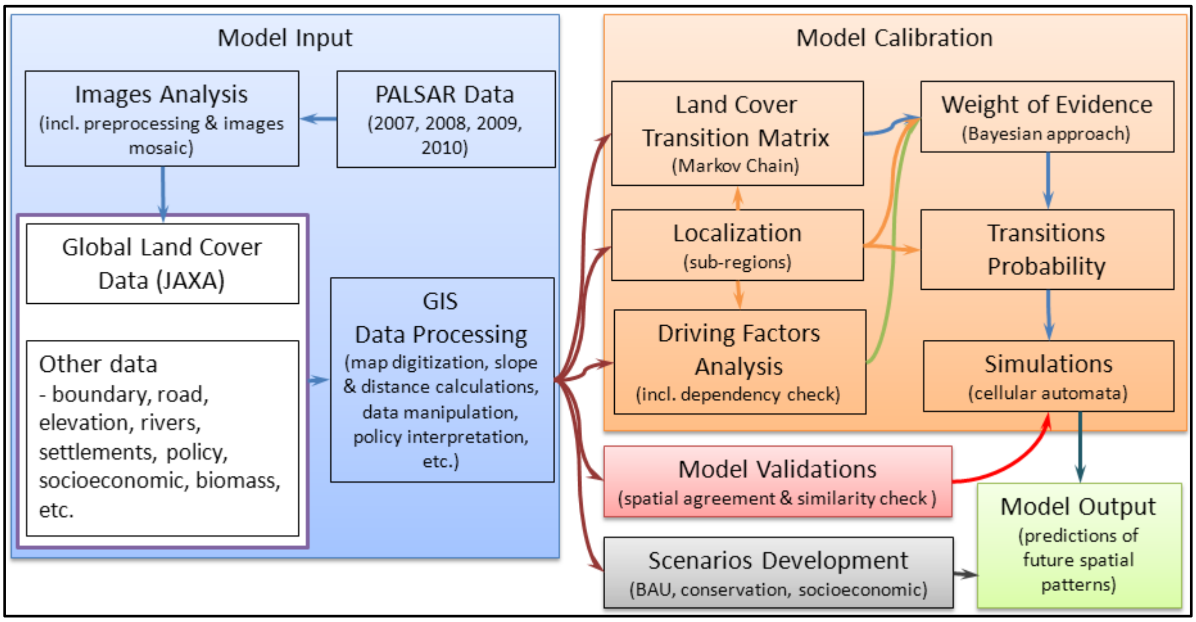

Figure 1. Conceptual framework of deforestation modeling.

Model validation was conducted by comparing the simulated map of 2010 with reference map of 2010. A neighborhood context was considered for validating the simulation results because even maps that do not match exactly cell by cell could still present similar spatial patterns and likewise spatial agreement within certain pixels vicinity. We used fuzzy similarity method (Hagen, 2003) with exponential decay function that accounts the fuzziness of location and category within a cell neighborhood. The fuzzy similarity test is based on the concept of fuzziness of location, in which a representation of a cell is influenced by the cell itself and, to a lesser extent, by the cells in its neighborhood. A reciprocal two-way fuzzy similarity index, from the reference map (2010) to the simulated map (2010) and vice versa, was adopted at multiple window sizes, i.e., 1×1, 3×3, 5×5, 7×7, 9×9, and 11×11 pixels. The fuzzy similarity index produces the measure of similarity associated with each window size from 0 to 1 which indicates validation fits from distinct patterns to identical, respectively.

3. RESULTS AND DISCUSSION

The Figure 2 shows PALSAR based GFNF maps of the study area in 2007 and 2010, simulated map in 2010 and fuzzy similarity index map as validation results. The spatial patterns of forest to non-forest changes are easily discernible in the reference maps (Figs 2.a-b) where a large area of the natural forest is converted to non-forest in the north-west part of the province in 2010. Quantitatively, the forest landscape in the province decreased from total 4.76 million hectares in 2007 to 4.28 million hectares in 2010, a gross reduction of 160 thousand hectares per year. The net rate of forest transition from forest to non-forest, calculated based on Markov approach, varies by administrative districts ranging from 6 to 21% per year. Pekanbaru, Rokanhilir, Dumai, and Rokanhulu are facing rapid deforestation compared to the other 6 districts in the province.

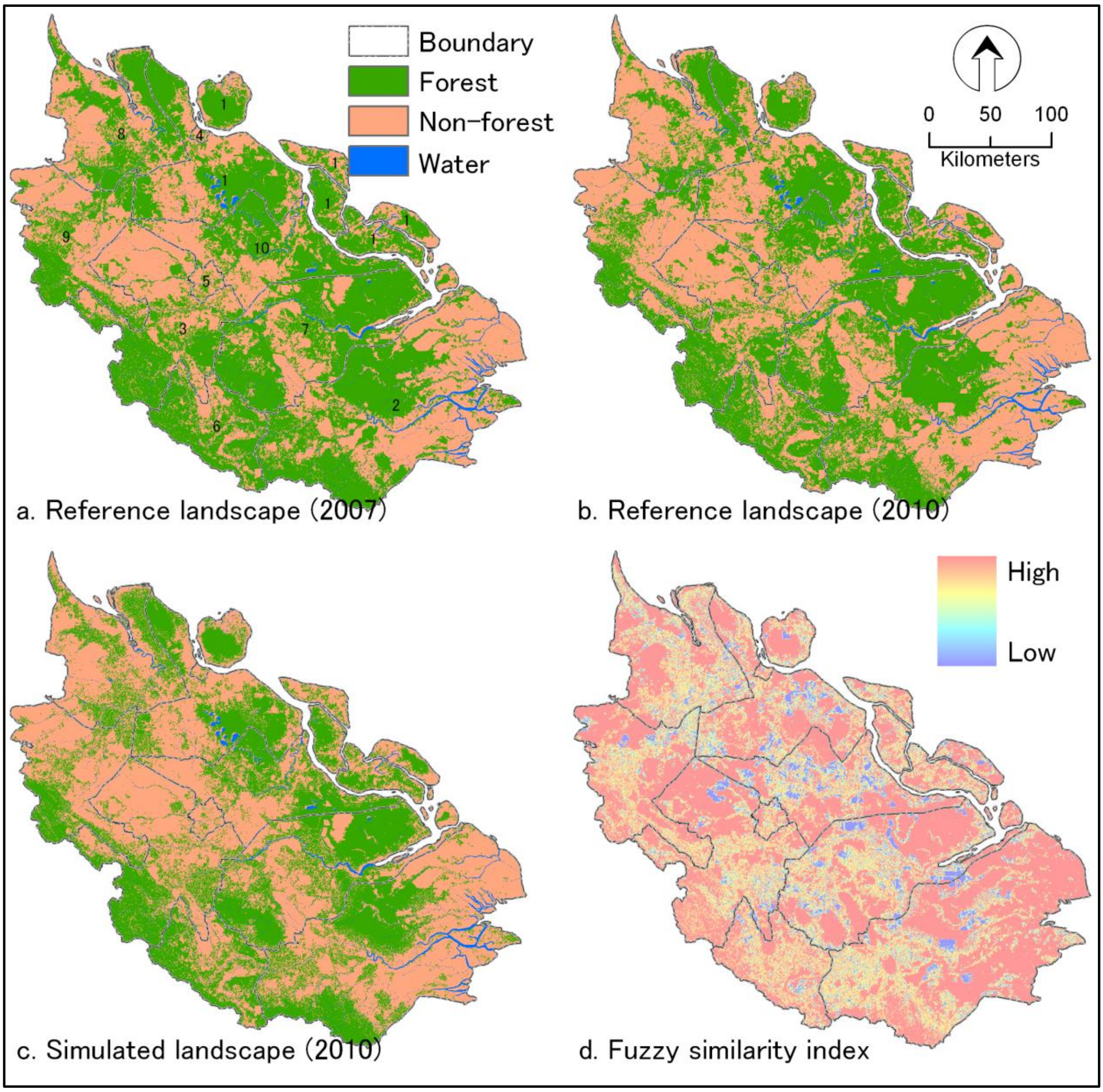

Figure 2. JAXA's Global Land Cover maps (a & b) for Riau Province, simulated map (c), and validation map (d). Note: The numbers in the map 2.a. refer to administrative district, i.e., 1: Bengkalis, 2: Indragiri Hilir, 3: Kampar, 4: Dumai, 5: Pekanbaru, 6: Singingi, 7: Pelalawan, 8: Rokanhilir, 9: Rokanhulu, and 10: Siak.

The landscape patterns in the simulated map (Fig 2.c) are observed almost similar to the reference map (Fig 2.b).The degree of similarity and spatial distribution of the model fitness between the reference and simulated maps can be confirmed by the validation map (Fig 2.d). The bluish color indicates poor fitness of the model while yellow and red colors show higher fitness. Further quantification of model accuracies may be needed for policy or forestry related MRV (Measureable, Reportable, and Verifiable) discussions. Overall spatial agreements between the reference map (2010) and the simulated map (2010) varied in different window sizes, i.e., 1×1 (78.59%), 3×3 (81.89%), 5×5 (84.01%), 7×7 (84.82%), 9×9 (85.18%), and 11×11 (85.36%). Achievement of 78.59% accuracy at pixel level with the given deforestation drivers reflects relatively good results. However, a tiny improvement in modeling accuracies is noticed in the window size of greater than 5×5.

Using the same calibration coefficients and reference map of 2010 as input, we performed a simulation to estimate the spatial patterns of deforestation for the years 2020 and 2030. Figure 3 shows state of the forest, observed and predicted spatial patterns of deforestation up to 2030. If the observed deforestation process (i.e., deforestation by 2010) continues, most of the remaining forest by 2030 is likely cleared in many districts of the province. Very few forest patches will remain intact in south-western border and mid-eastern parts in the province. However, these deforestation patterns may be altered while incorporating with other deforestation drivers such as socioeconomic and various environmental and land use policies of the government.

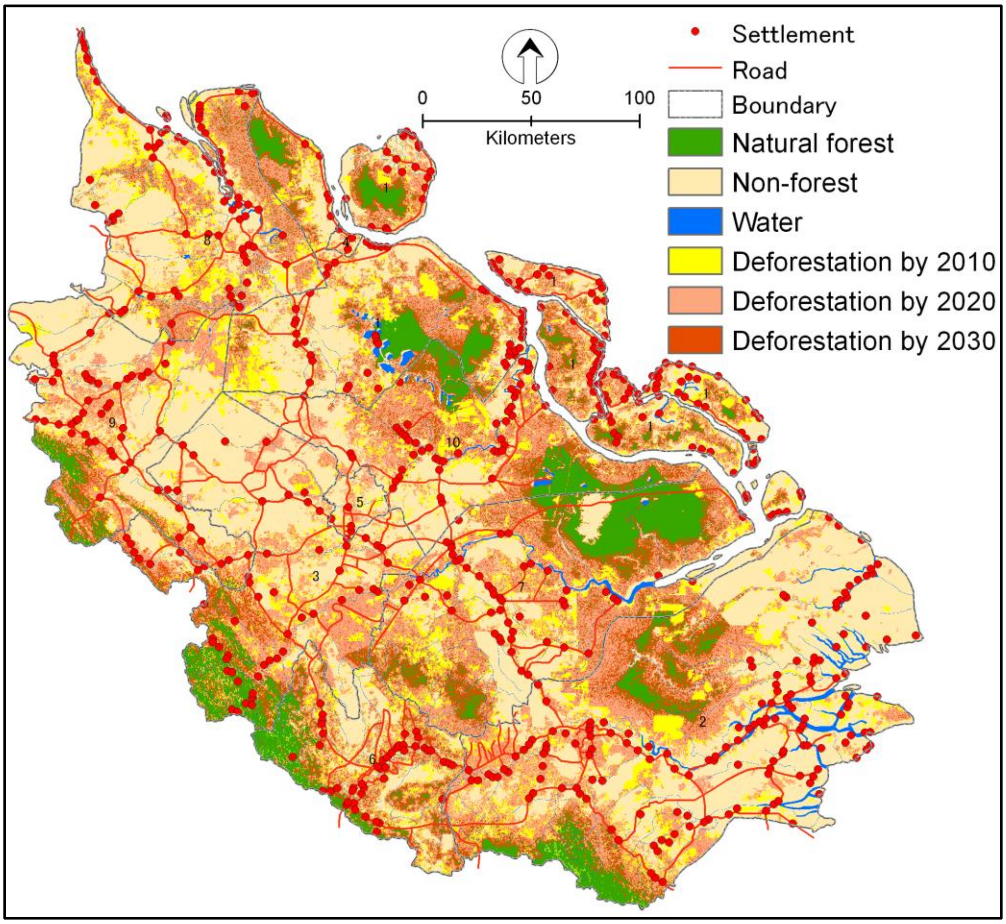

Figure 3. Spatial patterns of deforestation in Riau Province.

4. CONCLUSION

PALSAR images are unaffected by cloud cover and provided an excellent data for measuring forest change and estimation of deforestation patterns in Riau Province. The simulation model features the concept of sub-region, empirical cellular automata modeling, and robust validation method. The multi resolutions validation technique has captured neighborhood similarities in spatial patterns between the maps compared and provided the information on which scale the model can produce high accuracies. This is an important mean for forest planners to understand performance and predictability of a model by spatial scales. The simulation result provides effective visual and quantitative information to be useful to inform stakeholders on how ongoing business as usual process can affect deforestation patterns over a certain period of time. However, further improvement of the model is necessary incorporating with other deforestation drivers and testing of multiple what-if scenarios. As negotiations within the international community advance toward agreement on policy mechanism to maintain tropical forest intact, further advancement of this method is expected to provide efficient means for building reliable reference level and forest MRV systems in Southeast Asian region.

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