EurAsian Journal of BioSciences
Eurasia J Biosci 13, 2373-2379 (2019)

Evaluation of forest productivity and governance on the preservation of tropical rain forests in Kalimantan using the NGWR-TS nonparametric geospatial method

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Abstract

Tropical rainforests in Kalimantan are experiencing very rapid degradation, until 2019 the area of forest in Kalimantan has continued to shrink, so it is necessary to evaluate the handling of tropical rainforests by increasing forest conservation in Kalimantan. The purpose of this study is to carry out an experimental investigation about factors that support the preservation of tropical rainforests in 56 Districts/ Cities in Kalimantan. Data that used in this study were secondary data from Forestry Agency Indonesia. The data were 56 Districts/Cities from 5 provinces in Kalimantan. Forest Data in Districts/City were influenced by spatial dependence and spatial heterogeneity. Spatial dependence and spatial heterogeneity could be overcome by using one of the spatial statistical methods, namely the NGWR-TS Nonparametric Geospatial method. The method is the development of a nonparametric spline truncated regression that considers geographical or spatial factors. The results of the study obtained the best NGWR-TS modelling using the Gaussian kernel geographical weighting function with a minimum CV was 25.15. Using NGWR-TS with order m = 2 and point knot 2 with a minimum value of GCV was 1.57. The model had a value of R^2 = 94.12, so variables that significantly affected the preservation of tropical rainforests amounting to 94.12% were the area of Protected Forests, nature reserves and conservation, Production Forests, Area of each Districts/City, Population Density, Rate Economic Growth and Regional Development Index.

Keywords: geospatial, tropical rainforests, kernel gaussian, NGWR-TS, nonparametric

Sifriyani, Ruslan, Susanty FH (2019) Evaluation of forest productivity and governance on the preservation of tropical rain forests in Kalimantan using the NGWR-TS nonparametric geospatial method. Eurasia J Biosci 13: 2373-2379.

INTRODUCTION

Forest on the island of Kalimantan, Indonesia face serious problems, namely deforestation, forest degradation and widespread critical land. Based on Forest Data from the Forestry Agency it is believed that Kalimantan Forests would shrink by 75 percent by 2020 if the deforestation rate is not stopped. Of the approximately 74 million hectares of forests owned by Kalimantan, only 71% were left in 2005. While the number in 2015 shrank to 55%. If the rate of deforestation does not change, Kalimantan is believed to be losing 6 million hectares of forest by 2020, meaning only less than one third of the remaining forest area (BPS Kalimantan Timur 2019).

According to the 2012 East Kalimantan forest area data, around 14.981.978 hectares were then depreciated so that in 2013 the forest area was around 8.563.508 hectares (BPS Indonesia 2017, Dinas Kehutanan 2013). East Kalimantan has lost a forest area of 6.418.470 hectares in one year and this value was not small and could have a negative impact if it continues. Until 2019 the area of forest in East Kalimantan has continued to shrink, so it is necessary to evaluate the handling of tropical rainforests in East Kalimantan.

Indonesia is a country that has the third largest tropical forest after Brazil and Zaire and the functions as the world's lungs. Forest functions include regulating the water system, preventing and limiting flood, erosion, and maintaining soil fertility. Forest products provide the needs of the community in general and specifically for the needs of industrial development and exports so as to support economic development. Protecting the climate atmosphere and giving a good influence,

Received: May 2019
Accepted: October 2019
Printed: December 2019

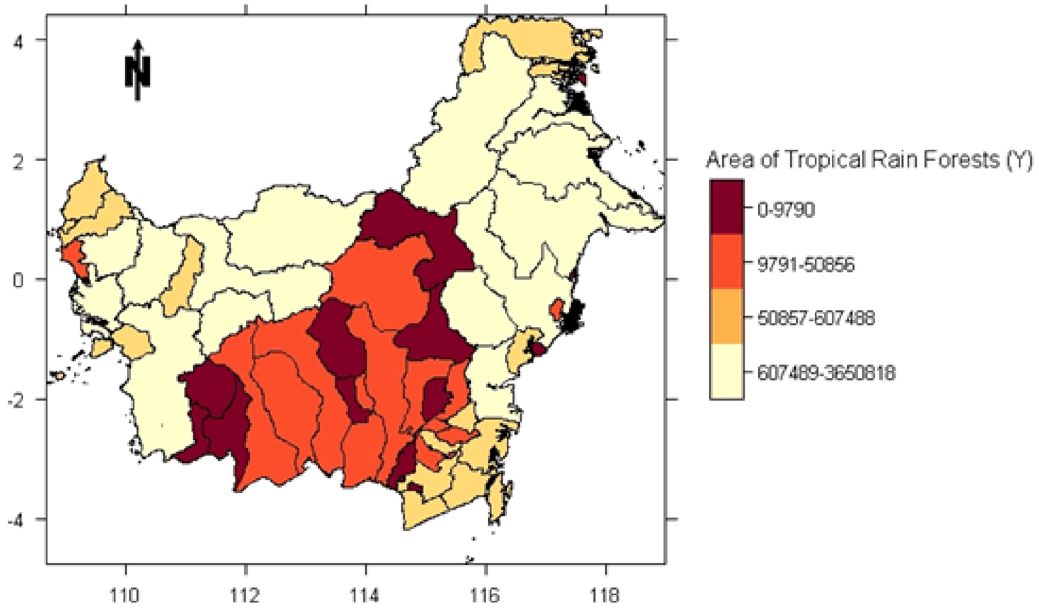

Fig. 1. Map of Distribution of Districts/City Tropical Rain Forests in Kalimantan

providing natural beauty in general and especially in the form of nature reserves, wildlife reserves, hunting parks, and tourist parks, as well as laboratories for science, education and tourism and is one of the elements of the development strategy national.

The purpose of this study is an experimental investigation of what factors support the preservation of tropical rainforests. It also aims to investigate the influence of productivity and forest management on the Preservation of Tropical Rain Forests in 56 Districts/Cities in Kalimantan based on a spatiotemporal perspective. The analysis used NGWR-TS Nonparametric Geospatial.

Based on the description above, this research works on the development of applied spatial regression and statistical methods namely the **Evaluation of Productivity and Forest Management on the Preservation of Tropical Rain Forests in Kalimantan Using the NGWR-TS Nonparametric Geospatial Method**.

DATA AND METHODOLOGY

The data used were secondary data originated from the Forestry Agency (Dinas Kehutanan 2013) in 5 provinces in Kalimantan, namely East Kalimantan, West Kalimantan, Central Kalimantan, North Kalimantan and South Kalimantan. Some other statistical data in this study were obtained from Indonesian Central Bureau of Statistics (BPS Indonesia 2017, BPS Kalimantan Barat 2019, BPS Kalimantan Selatan 2019, BPS Kalimantan Tengah 2019, BPS Kalimantan Timur 2019, BPS Kalimantan Utara 2019).

The number of data used was 56 Districts/Cities in all regions of Kalimantan and forest data in 2019 with the response variable y is the area of tropical rain forests. Predictor variables for forest governance consisted of protected forest area (x_1), nature reserve and conservation (x_2) and total area of each District/City (x_4). Predictor variables for forest productivity factors were Production Forest (x_3) Economic Growth Rate (x_6), Regional Development Index (x_7) and Population Density (x_5).

The statistical method is a development of nonparametric spline truncated regression that considers geographical or spatial factors. Truncated Spline is a function that is built on the basis of polynomial components and truncated components, namely pieces of polynomials that have knots, which could overcome patterns of changes in data behavior. The spline truncated approach is used as a solution to solve the problem of modelling spatial data analysis where the relationship between the response variable and predictor variables does not follow a certain pattern and there are patterns that change at certain sub-intervals. The steps for Nonparametric Geospatial NGWR-TS modelling are described in additional data.

The NGWR-TS method consists of estimation of the NGWR-TS model (Sifriyani 2018b), hypothesis testing of Goodness of Fit (Sifriyani et al. 2018a), simultaneous parameter significance test and partial significance test (Sifriyani 2018). Explanation of the method is described in supplementary data.

RESULT AND DISCUSSION

Exploration of Tropical Rainforest Data in Kalimantan

Distribution maps of Districts/City tropical rainforests in Kalimantan can be seen in **Fig. 1**. Districts/Cities that

Table 1. Results of Analysis NGWR-TS Nonparametric Geospatial Method

Category	Methods	Number of knot point	Coefficient of Determination (R^2)	AIC	RMSE
NGWR-TS Model Criteria	NGWR-TS Orde m=1	1	89.115	-36.44	2.99
		2	84.679	-37.25	3.67
		3	87.719	-36.74	3.23
	NGWR-TS Orde m=2	1	91.982	-35.56	2.41
		2	**94.122***	**-34.78**	**1.97**
		3	92.315	-35.45	2.34
Spatial Heterogeneity Test	Breusch-Pagan Test	df	p-Value	Decision	
	108.52	28	2.0181E-11	There is effect of spatial heterogeneity	
CV values for weigthed function	**Weighted Function**	**Optimal Bandwitdth**	**Cross Validation (CV)**	**Generalized CV (GCV)**	
	Kernel Gaussian	3.124	25.153	8.63	
	Kernel Bisquare	0.105	56.996	10.05	

had the largest area of Tropical Rain Forests is Malinau District with 3.650.818 ha of tropical forest. Distribution maps based on area of Tropical rainforests show areas with a forest area of 607.489 hectare with -3.650.818 hectare having the most area.

The NGWR-TS Nonparametric Geospatial Method

The NGWR-TS Nonparametric Geospatial Method was a truncated nonparametric spline regression model in Geographically Weighted Regression. The method was the development of nonparametric regression for spatial data with locally parameter estimators for each observation location (Sifriyani 2018). In the regression model, the assumption used was error with normal distribution mean 0 and variance $\sigma^2(u_i, v_i)$ on every location (u_i, v_i). Coordinat (u_i, v_i) is an important factor in determining the weight used to estimate the parameters of the model. Given data $(x_{1i}, x_{2i}, \dots, x_{li}, y_i)$ and correlation between $(x_{1i}, x_{2i}, \dots, x_{li})$ and y_i are assumed to follow the multivariable nonparametric regression model as follows:

$$y_i = f(x_{1i}, x_{2i}, \dots, x_{li}) + \varepsilon_i, \qquad i = 1,2, \dots, n \quad (1)$$

with y_i is response variable and $f(x_{1i}, x_{2i}, \dots, x_{li})$ is curve with unknown form of assumed additive.

Mathematically the form of the relationship between the response variables y_i and predictor variables $(x_{1i}, x_{2i}, \dots, x_{li})$ at the location *i* for the NGWR-TS Nonparametric Geospatial model could be stated as follows (Sifriyani et al. 2017):

$$\begin{aligned} y_i &= \beta_0(u_i, v_i) + \sum_{p=1}^{l}\sum_{k=1}^{m} \beta_{pk}(u_i, v_i) x_{pi}^k \\ &+ \sum_{p=1}^{l}\sum_{h=1}^{r} \delta_{p,m+h}(u_i, v_i)\left(x_{pi} - K_{ph}\right)_+^m + \varepsilon_i \end{aligned} \quad (2)$$

Equation (2) is a Nonparametric Geospatial Model NGWR-TS degree *m* with *n* area.

Prior to the NGWR-TS nonparametric Geospatial method stage, the first step is to check whether tropical rainforest data has a spatial effect. Testing these spatial effects using the Breusch-Pagan test aims to be used to see the spatial heterogeneity of each location. Based on the results of **Table 1**, data obtained from tropical rainforests had the effect of spatial heterogeneity. This is because each region has different environmental characteristics and diverse geographical conditions.

Furthermore, it determines the coordinates of the observation location. From the two weighting functions, gaussian kernel and bisquare kernel, the best model is a weighting Kernel Gaussian function with a smaller CV value than the CV value from the Kernel Bisquare function. The analysis is summarized in **Table 1**.

The best model was obtained from the Nonparametric Geospatial Model NGWR-TS with order m = 2 and the number of vertices 2, according to the R^2 value of 94,122. This value explained the area of protected forest (x_1), nature reserve and conservation (x_2), production forest (x_3), Area of each District/City (x_4), population density (x_5), economic growth rate (x_6), and Regional Development Index (x_7) is 94,122% which could explain as factors that influenced the preservation of Tropical Rain Forests in Kalimantan.Nonparametric Geospatial Model NGWR-TS model, order m = 2 and knot point h = 2 given by.

$$\begin{aligned} y_i &= \beta_0(u_i, v_i) + \sum_{p=1}^{7}\sum_{k=1}^{2} \beta_{pk}(u_i, v_i) x_{pi}^k \\ &+ \sum_{p=1}^{7}\sum_{h=1}^{3} \delta_{p,m+h}(u_i, v_i)\left(x_{pi} - K_{ph}\right)_+^m + \varepsilon_i \end{aligned} \quad (3)$$

with number of predictor variables $p = 7$ yaitu $x_1, x_2, x_3, x_4, x_5, x_6$ and x_7. Next step is to complete the model (3), the optimum K_{ph} knot point selection was determined based on the smallest Generalized Cross Validation (GCV) value.

The next step for the Nonparametric Geospatial Model NGWR-TS (3) is to determine the points of knots K_{ph}. This modelling K_{ph} is the point where sub-intervals change in the regression curve. Selecting knot points K_{ph} used GCV method. The smaller the GCV value, the more optimum the knots selected. GCV values for the Nonparametric Geospatial Model NGWR-TS with order m=2 and the number of K_{ph}=2 are shown in Supplementary Data. The smallest GCV value obtained was 1.5749 with optimum knot points.

K_{11}=4.42 ; K_{12}= 4.58; K_{21}=6.96; K_{22}=7.21; K_{31}=1.10; K_{32}=1.14; K_{41}=23900; K_{42}=24751; K_{51}=5339.3; K_{52}=5529; K_{61}=4.77; K_{62}=4.92; K_{71}=71.695; K_{72}=72.059.

It could be concluded that general NGWR-TS Nonparametric Geospatial model model is as follows.

$$y_i = (\beta_0(u_i,v_i) + \beta_{11}(u_i,v_i)\, x_{1i} + \beta_{12}(u_i,v_i)x_{1i}^2 + \cdots + \\ +\beta_{71}(u_i,v_i)x_{7i} + \beta_{72}(u_i,v_i)x_{7i}^2 + \delta_{13}(u_i,v_i)(x_{1i} - K_{11})_+^m \\ +\delta_{14}(u_i,v_i)(x_{1i} - K_{12})_+^2 \ldots + \delta_{73}(u_i,v_i)(x_{7i} - K_{72})_+^2 + \varepsilon_i \quad (4)$$

The equation (4) for tropical rainforest data for 56 Districts/Cities could be expressed in the equation as follows:

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_{56} \end{bmatrix} = \begin{bmatrix} \beta_0(u_1,v_1) + \sum_{p=1}^{7}\sum_{k=1}^{2} \beta_{pk}(u_1,v_1)\, x_{pn}^k \\ \beta_0(u_2,v_2) + \sum_{p=1}^{7}\sum_{k=1}^{2} \beta_{pk}(u_2,v_2) x_{pn}^k \\ \vdots \\ \beta_0(u_{56},v_{56}) + \sum_{p=1}^{7}\sum_{k=1}^{2} \beta_{pk}(u_{56},v_{56}) x_{pn}^k \end{bmatrix} + \begin{bmatrix} \sum_{p=1}^{7}\sum_{h=1}^{2} \delta_{p,m+h}(u_1,v_1)\big(x_{pn} - K_{ph}\big)_+^m \\ \sum_{p=1}^{7}\sum_{h=1}^{2} \delta_{p,m+h}(u_2,v_2)\big(x_{pn} - K_{ph}\big)_+^m \\ \vdots \\ \sum_{p=1}^{7}\sum_{h=1}^{2} \delta_{p,m+h}(u_{56},v_{56})\big(x_{pn} - K_{ph}\big)_+^m \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_{56} \end{bmatrix} \quad (5)$$

It is given modeling for a particular area, an area that has an area of the largest tropical rainforest in Kalimantan, Malinau district. The modeling would use a parameter estimator $\hat{\beta}$ and $\hat{\delta}$ NGWR-TS and the optimal knots shown in Supplementary Data.

$$y_{malinau} = 2.93 - 0.343x_1 - 2.41\, x_1^2 + 2.44x_2 + 0.029x_2^2 \\ -0.00019x_3 - 8.90x_3^2 + 0.00024x_4 + 1.57\, x_4^2 + 4.14x_5 \\ +2.91x_5^2 - 0.003x_6 - 0.0016\, x_6^2 + 2.33\, x_7 + 0.019\, x_7^2$$

and Truncated function is

$$y_{malinau} = -0.005(x_1 - 4.43) - 0.0061(x_1 - 4.58) \\ +0.0004(x_2 - 6.96) + 0.0004(x_2 - 7.21) \\ -0.0003(x_3 - 1.10) - 0.0003(x_3 - 1.40) \\ +0.94(x_4 - 239) + 102.165(x_4 - 247) \\ +0.00065(x_5 - 5339.3) + 0.0006(x_5 - 5529.9) \\ -7.29(x_6 - 4.77) - 5.75(x_6 - 4.92) \\ +3.40(x_7 - 7.69) + 2.38(x_7 - 72.059) \quad (6)$$

Model (6) shows that there were estimators of NGWR Geospatial regression parameters that had a positive contribution and negative contribution to the preservation of tropical rainforests. Equation (6) shown the factors that contributed positively to tropical forests in Malinau district were nature reserves and conservation (x_2), Area of each District/City (x_4), population density (x_5), Regional Development Index (x_7). Positive contributions had an explanation that with increasing x_2, x_4, x_5 and x_7 will increase the preservation of tropical rainforests in Malinau district. The value of the contribution was in accordance with the parameter estimator coefficient $\hat{\beta}$ and $\hat{\delta}$ NGWR-TS.

The negative contribution for tropical forests in Malinau district based on equation (6) was Area of Protected Forest (x_1), Production forest (x_3), Economic growth rate (x_6). The height of protected forests and production forests will threaten the preservation of tropical rainforests in Kalimantan. The rate of economic growth increases will reduce the preservation of tropical rainforests. Predictor variables that have a large influence on tropical rainforests in Districts Malinau were protected forest area, population density and regional development index.

NGWR-TS nonparametric geospatial regression modeling produced a different parameter estimator $\hat{\beta}$ and $\hat{\delta}$ for each District/City. This shows that each predictor variable had a different relationship between one District/City and another District/City so that it was difficult to interpret. Therefore, each predictor variable was grouped into three regional groups based on the regression coefficient or parameter estimator $\hat{\beta}$ and $\hat{\delta}$ to facilitate interpretation. NGWR-TS modeling for 56 districts/cities in Kalimantan was described in supplementary data.

Mapping NGWR-TS Results for Factors that Affect Tropical Rain Forests in each District/City in Kalimantan

Estimator Parameter of NGWR-TS Geospatial Regression for each District/City had a different value from other Districts/Cities so that each region will have different modelling and different estimator results. The following was a spatial mapping based on the diversity of NGWR-TS Geospatial regression coefficient estimators.

The largest regression coefficient estimator value gave explanation that the predictor variable x also had a large influence on Tropical Rain Forests. **Fig. 2** shows that the Districts /City had the largest regression coefficient estimator value for the Extent of Protection Forest (x_1) were Districts of Citywaringin Barat, Sukamara, Lamandau, Bengkayang, Kayong Utara, Ketapang, Pontianak, Singkawang, Kubu raya, Landak, Melawi, Mempawah, Sambas Sanggau dan Sintang. The highest estimator value was held by Mempawah district, which means that the Protected Forest Area of Mempawah district has a strong relationship affecting Tropical Rain Forests in Kalimantan compared to 55 other Districts / Cities.

The largest regression coefficient estimator value on natural reserve and conservation variables (x_2) were Districts of Malinau, Bulungan, Tana Tidung, Nunukan, Tarakan city, Kutai Kartanegara, Kutai Timur, Berau, Penajam Paser Utara, Balikpapan City, Samarinda City and Bontang City. The highest estimator value was held by Nunukan district which means nature sanctuary and conservation (x_2) Nunukan district has a strong relationship affecting Tropical Rain Forests in Kalimantan compared to 55 other Districts/Cities. The largest regression coefficient estimator values in the Production Forest (x_3) were Malinau, Bulungan, Tana Tidung, Nunukan, Tarakan, Bengkayang, Pontianak,

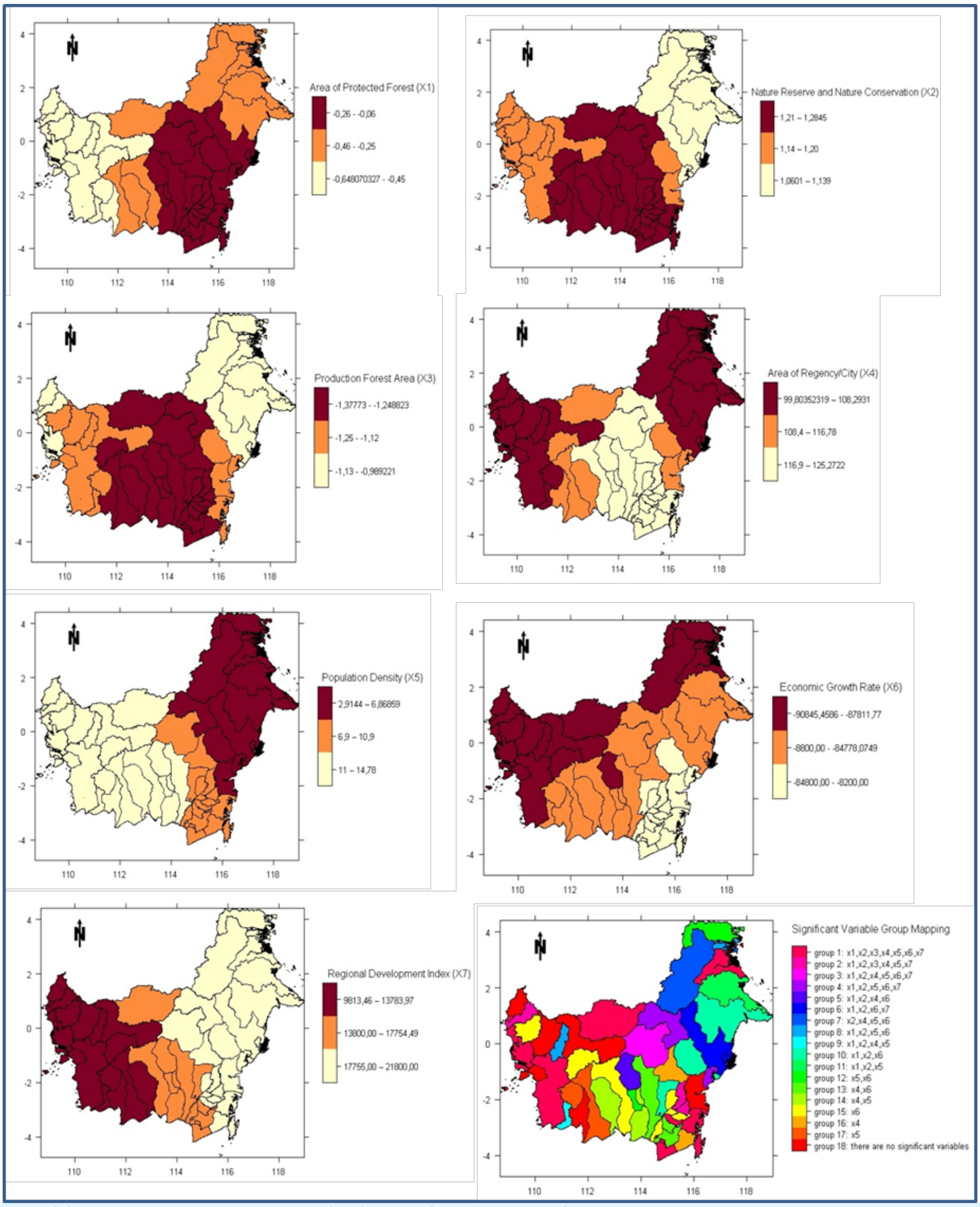

Fig. 2. Map of Spatial Diversity Estimator of NGWR-TS Parameters for Variable Tropical Rain Forests in Kalimantan

Singkawang, Kubu Raya, Mempawah, Sambah, Kutai Kartanegara, Kutai Timur, Berau, Balikpapan, Samarinda and Bontang. The highest estimator value was held by Nunukan, which means production forest (x_3) Nunukan has a strong relationship affecting Tropical Rain Forests in Kalimantan compared to 55 other Districts / Cities.

Regression coefficient estimator value in district (x_4) variables were Tanah Laut, Kotabaru, Banjar, Barito Kuala, Tapin, Hulu sungai selatan, Hulu sungai tengah, Hulu sungai utara, Tabalong, Tanah bumbu, Belangan, Banjarmasin, Banjar baru, and Kapuas. The highest estimator value was held by Barito Selatan, which means area of each district (x_4) Districts of Barito Selatan has a strong relationship affecting Tropical Rain Forests in Kalimantan compared to 55 other Districts/Cities.

Districts/City which has the largest regression coefficient estimator value for population density variable (x_5) were Districts Banjarmasin, Citywaringin Barat, Citywaringin Timur, Kapuas, Sukamara, Lamandau, Seruyan, Katingan, Pulau Pisau, Gunung Mas, City Palangka Raya, Bengkayang, Kapuas Hulu, Kayong Utara, Ketapang, Pontianak City, Singkawang

Table 2. Test results for partial parameter significance

Groups Area	Districts/Cities	Factors affecting Tropical Rain Forests in each Districts / City
1	Bulungan district	protected forest area (x_1), nature reserve and conservation (x_2) and total area of each District / city (x_4) Predictor variables for forest productivity factors are Production Forest (x_3) Economic Growth Rate (x_6), Regional Development Index (x_7) and Population Density (x_5).
	Tanah Laut district	
	Kotabaru district	
	Hulu Sungai Selatan district	
	Banjarmasin city	
	Banjarbaru city	
	Kapuas Hulu district	
	Ketapang district	
	Pontianak city	
	Singkawang city	
	Kubu Raya district	
2	Tabalong district	$x_1, x_2, x_3, x_4, x_5, x_7$
	Balangan district	
	Bengkayang district	
3	Murung Raya district	$x_1, x_2, x_4, x_5, x_6, x_7$
4	Penajam Paser Utara district	x_1, x_2, x_5, x_6, x_7
	Mahakam Ulu district	
5	Gunung Mas district	x_1, x_2, x_4, x_6
6	Kutai Kartanegara district	x_1, x_2, x_6, x_7
	Samarinda city	
7	Malinau district	x_2, x_4, x_5, x_6
	Tarakan city	
8	Tana Tidung district	x_1, x_2, x_5, x_6
	Bontang city	
	Sekadau district	
9	Sukamara district	x_1, x_2, x_4, x_5
10	Barito Selatan district	x_1, x_2, x_6
	Kutai Barat district	
	Kutai Timur district	
	Balikpapan city	
11	Berau district	x_1, x_2, x_5
12	Nunukan district	x_5, x_6
	Palangka Raya city	
13	Banjar district	x_4, x_6
	Tapin district	
	Kapuas district	
14	kotawaringin Timur district	x_4, x_5
	Pulang Pisau district	
15	Barito Kuala district	x_6
	Hulu Sungai Tengah district	
	Hulu Sungai Utara district	
	Katingan district	
	Landak district	
	Melawi district	
	Mempawah district	
	Barito Timur district	
16	Barito Utara district	x_4
	Tanah Bumbu district	
17	Lamandau district	x_5
	Seruyan district	
18	City waringin Barat district	Not significant
	Kayong Utara district	
	Sambas district	
	Sanggau district	
	Sintang district	
	Paser district	

City, Kubu Raya, Landak, Melawi, Mempah, Sambas, Sanggau, Sekadau and Sintang. The highest estimator value was held by Citywaringin Barat district, which means population density (x_5) in Citywaringin Barat district has a strong relationship affecting Tropical Rain Forests in Kalimantan compared to 55 other Districts / Cities. The Districts/City with the largest regression coefficient estimator value on the Economic Growth Rate variable (x_6) were Districts of Tanah laut, Kotabaru, Banjar, Barito Kuala, Tapin, Hulu sungai selatan, Hulu sungai tengah, Hulu sungai utara, Tabalong, Tanah bumbu, Balangan, Barito Selatan, Barito Timur, Paser, Kutai Barat, Penajam paser utara, Banjarmasin City, Banjarbaru City and Balikpapan City. The highest estimator value was held by Kotabaru district, which means Economic growth rate (x_6) in Kotabaru district has a strong relationship affecting Tropical Rain Forests in Kalimantan compared to 55 other Districts/Cities.

Districts/City which has the largest regression coefficient estimator value in the Regional Development Index variable (x_7) in **Fig. 2** were Districts of Malinau, Bulungan, Tana Tidung, Nunukan, Kotabaru, Hulu sungai selatan, Hulu sungai tengah, Hulu sungai utara, Tabalong, Tanah bumbu, Balangan, Barito utara, Barito timur, Murung raya, Paser, Kutai barat, Kutai kartanegara, Kutai timur, Berau, Penajam Paser Utara, Mahakam Ulu, Balikpapan, Tarakan, Samarinda dan Bontang. The highest estimator value was held by Malinau district, which means Regional Development Index (x_7) in Malinau district has a strong relationship affecting Tropical Rain Forests in Kalimantan compared to 55 other Districts/Cities.

The purpose of the NGWR-TS parameter significance test is to determine the factors that have a significant effect on the preservation of tropical rainforests in each District/City in Kalimantan. Statistical Test (Fotheringham et al. 1997a, 1997b) for partial testing of NGWR-TS.

Partial test using significance level α = 0.05 obtained results of 56 regencies / Cities which were divided into 18 regional groups based on predictor variables related to tropical rainforests of each District / city. The 18 groups were shown in **Table 2** and the results obtained were then mapped on the predictor variable spatial diversity map in **Fig. 2**.

CONCLUSION

The Nonparametric Geospatial Regression Model NGWR-TS with a Gaussian kernel weighting produces an R^2 value of 94.12. This value explained that 94, 12% of the variables of Protected Forests, nature reserves and nature conservation, Production Forests, Area of each Districts/City, Population Density, Economic Growth Rate and Regional Development Index affected the preservation of Tropical Rain Forests in Kalimantan.

ACKNOWLEDGEMENTS

The authors acknowledge The Research Center of Medicine and cosmetic from Tropical Rainforest Resources for generously supporting this project.

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