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Geographically Temporally Weighted Regression Model for GIS Mapping of Influence COVID-19 in East Kalimantan

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Abstract. This study is the mapping of Geographic Information System (GIS) based on the Estimation of the Geographically and Temporally Weighted Regression (GWR) model. The mapping focuses on the factors that affect the increase in COVID-19 on the scale of Regency/City in East Kalimantan Province. The purpose of this research was to find the factors affecting COVID-19 and GIS mapping. The data used are secondary data from the Central Bureau of Statistics and the Department of Manpower, from 2020 to August 2021. This study used the analysis of GTWR Spatio-temporal with the geographic weighting of kernel Gaussian and Bisquare functions. GTWR model is a development of the Geographically Weighted Regression (GWR) model and simultaneously considers the elements of location and time simultaneously. GTWR model can handle non-stationary data, both in spatial and temporal, simultaneously. The advantage of the GTWR model is the generated model is local at each location and time, so that the model is representative. The research results indicated that the factors that affect the increase in cumulative cases of positive COVID-19 in the East Kalimantan Province are the number of tuberculosis cases, population density, GDP, the number of hospitals, and the number of villages that have public health centers. Based on the value of the GTWR model parameter estimator, it was obtained the number of tuberculosis cases, population density, and the limited number of hospitals. They have a great influence on Balikpapan city in comparison with other regions. Based on these values, it gave the information to attend to these factors because of the influence of a considerable increase in COVID-19 cases in East Kalimantan.

INTRODUCTION

In Indonesia, the first confirmed Coronavirus disease 2019 (COVID-19) case was a female who had close contact with the 24th confirmed case in Malaysia, and the second case was the mother of the first case [1]. As time goes by, the number of new cases had increased significantly, reaching more than 1.6 million, and more than 44 thousand of them died by April 22, 2021 [2]. From February 26, 2020 to February 28, 2020, there were events identified as clusters of COVID-19 transmission that was *Seminar Sinode Bogor, Seminar Anti Riba Bogor,* and *Seminar Kerohanian Lembang*. These events' participants came from all regions of Indonesia [3]. These events made COVID-19 spread all over Indonesia including Kalimantan. To handle this situation, the government has implemented several policies to deal with Covid-19 which are relatively moderate way through the Large-Scale Social Restrictions Policy and the Policy for Implementation of Restrictions for Community Activities. Moreover, they also implemented an aggressive way through the vaccination program which are very loose through the declaration of a new normal [2]. On March 18-20, 2020, East Kalimantan confirmed nine COVID-19 patients. Most of them was coming from the two main clusters: *Seminar Sinode Bogor, Indonesia* and *Seminar Anti Riba Bogor, Indonesia* [4]. The increasing of COVID-19 in East Kalimantan due to contact with COVID-19 patients. Until February 04, 2021, the total of confirmed

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COVID-19 cases was 43.656 patients, 7.970 patients was treated, 34.641 patients was recovered, and 1045 patients was died [5]. Previous research used the data of COVID-19 in East Kalimantan by using Susceptible Infection Recovered modeling [6].

Based on these descriptions, it is necessary to examine the factors that influence the number of positive COVID-19 cases specifically in the region of East Kalimantan. There was a mapping based on the number of COVID-19 cases in different regions in every COVID-19 website at the provincial level, but there has been no GIS mapping based on the factors affecting COVID-19 on the scale of Regency/City in East Kalimantan. Hereby, this research focused on GIS mapping specifically on factor that affecting it. This research focused on the Geographically Temporally Weighted regression model [7] [8] [9] that will be applied on the data of the number of positive COVID-19 cases and the affecting variables. GTWR research is one of spatial and spatio temporal analysis [10], [11], [12]. Researchers used GTWR model to analyze the data on COVID-19 in different countries [13], [14], [15], [16], [17].

This research aimed to find GIS mapping through GTWR model based on the factors that affect the increasing number of COVID-19 in East Kalimantan. The advantages of this research can provide information related to how much these variables influence and GIS mapping based on the influence of variable. Predictor variables used in the study was population density [18], [19] the Gross Domestic Product [18], [19], the number of hospitals [20], [21] the Number of Villages that have health centers [20], [21] and the number of tuberculosis cases [citation of department of health]. The novelty on this research was using COVID-19 data from 2020 to August 2021.

MATERIAL AND METHOD

Geographically and Temporally Weighted Regression

The Geographically and Temporally Weighted Regression (GTWR) is an effective approach to handle non-stationarity problem of spatial and temporal [7]. GTWR model is the development of GWR models by adding element of time (temporal). The GTWR model is different from the GWR model, GTWR combines temporal and spatial information in a weighting matrix to identify spatial and temporal diversity. GTWR model in Equation (1) for free variable p with response variable y_i on the location (u_i, v_i, t_i) for each observation.

$$y_i = \beta_0(u_i, v_i, t_i) + \sum_{k=1}^{p} \beta_k(u_i, v_i, t_i)\, x_{ik} + \varepsilon_i \quad (1)$$

where y_i is an observation value of response variable for the location of the observation (u_i, v_i) and t_i time, The $\beta_0(u_i, v_i, t_i)$ parameters is a constant of the intercept value, the $\beta_k(u_i, v_i, t_i)$ parameters is the regression coefficient of k-free variables on the location of the observation (u_i, v_i) and t_i time, x_{ik} predictor variable is the observations value of k-descriptors variable on the location of the observation (u_i, v_i) and t_i time and ε_i is the i-observation error which is assumed identical, independent, and $\varepsilon_i \sim N(0, \sigma^2)$.

Estimation of the GTWR Model Parameter

$\hat{\beta}_i(u_i, v_i, t_i)$ regression coefficient at i-point can be obtained with the use of a Weighted Least Square. The estimation of the GTWR model parameters written in Equation (2).

$$\widehat{\boldsymbol{\beta}}(u_i, v_i, t_i) = [\boldsymbol{X}^T \boldsymbol{W}(u_i, v_i, t_i)\boldsymbol{X}]^{-1} \boldsymbol{X}^T \boldsymbol{W}(u_i, v_i, t_i)\boldsymbol{y} \quad (2)$$

where the Weighting $\boldsymbol{W}(u_i, v_i, t_i) = diag(w_{i1}, w_{i2}, \dots, w_{in})$ is the weighting matrix on the location of the observation (u_i, v_i) and t_i time. The diagonal elements $w_{ij}(1 \le j \le n)$ is a function of the spatial-temporal distance at the observation point (u_i, v_i, t_i). At the stage of model preparation, it is assumed that the proximity of the data observation point to i-point in the coordinate system of the spatial-temporal have a greater influence on the $\widehat{\boldsymbol{\beta}}(u_i, v_i, t_i)$ parameters estimator than the data that is located far away from i-point. The proximity has two elements, namely spatial and temporal proximity. Nevertheless, defining and measuring the proximity of spatial-temporal in the coordinate system is a major problem in the preparation of the GTWR model.

Data and Research Data Sources

The data used consisted of the response variable (y), the predictor variables (x), and the location Coordinates of each Regency/City in East Kalimantan Province. The data used was secondary data. Predictor variables consisting of population density and Gross Domestic Product (GDP) was obtained from the Central Statistics Agency (BPS) in East Kalimantan Province of 2020 and 2021 [18], [19]. Predictor variables consisted of the number of hospitals, the number of Villages/District which had public health centers and the number of tuberculosis cases were obtained from the Department of Health in East Kalimantan Province [20], [21]. Data on the number of positive COVID-19 cases were obtained from the official website namely https://covid19.kaltimprov.go.id/ [22]. The research variables described in Table 1.

TABLE 1. Description of Variables and Sources of Research Data

Variables	Symbol	Description Of Variables	Source of Observation Data	Unit	Scale
Response	y	Accumulative of positive Covid-19 cases in Indonesia	The official website of COVID-19 at the provincial level	People	10 Regencies/Cities in East Kalimantan Province
Predictor	x_1	Number of Tuberculosis Cases	Department of Health	Case	10 Regencies/Cities in East Kalimantan Province
	x_2	Population density	The Central Statistics Agency (BPS)	Soul/Km^2	10 Regencies/Cities in East Kalimantan Province
	x_3	Gross Regional Domestic product on the Basis of the Market Price	The Central Statistics Agency (BPS)	Billion Rupiah	10 Regencies/Cities in East Kalimantan Province
	x_4	Number of Hospital	Department of Health	Unit	10 Regencies/Cities in East Kalimantan Province
	x_5	Number of Villages/Districts which have community health center	Department of Health	Unit	10 Regencies/Cities in East Kalimantan Province

The Stage of Data Analysis

Based on the objective of the study, the following stages of data analysis were to find GIS mapping Based Geographically and Temporally Weighted Regression Models for COVID-19 Cumulative Data in East Kalimantan.

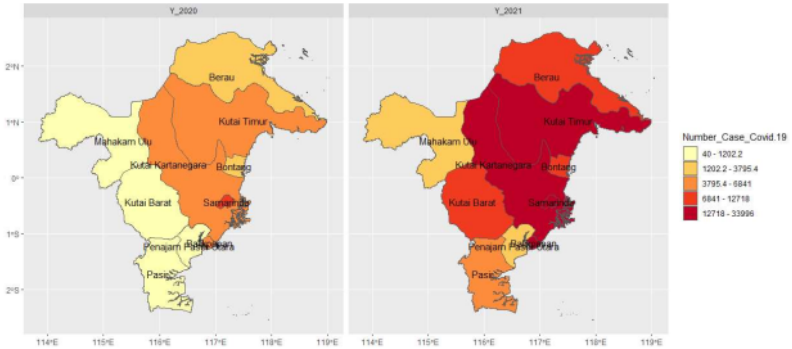
1. The exploration of the distribution on the response variable and the predictor variables in the period of 2020 to 2021 were using the spatial distribution mapping.
2. Description of the COVID-19 accumulative data and the predictor variables
3. Estimation of the GTWR model

4. Mapping the spread of COVID-19 based on the GTWR model estimation.

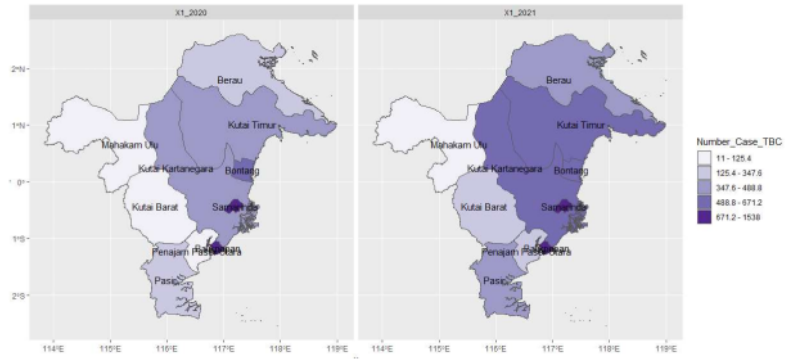
RESULTS AND DISCUSSION

Results and discussion are begun by providing information about the spatial distribution mapping, the description of the number of positive COVID-19 cases data and the variables that effect. The next analysis was Estimators of the GTWR model parameters and GIS Mapping Based GTWR Models Estimation For COVID-19 Cumulative Data in East Kalimantan.

Spatial Distribution Map and Description of Research Variables



(a) Mapping of the number of Positive COVID-19 Cases Confirmed in 2020 to 2021

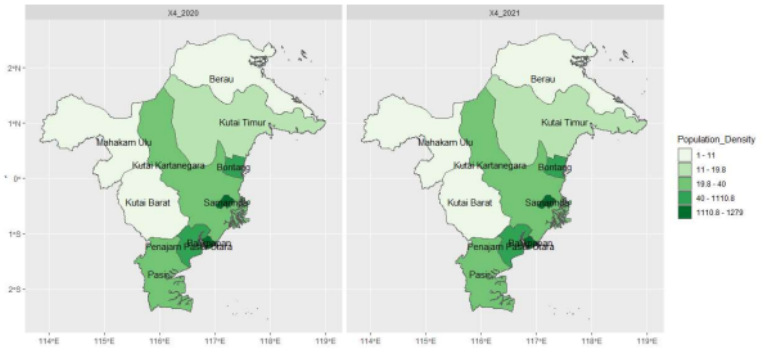


(b) Mapping of the Number of Tuberculosis Cases in 2020 to 2021

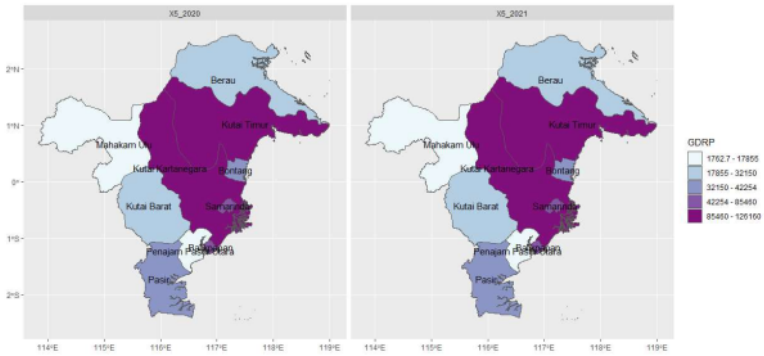
FIGURE 1. Spatial Distribution Mapping of (a) Positive COVID-19 Cases and (b) the Number of Tuberculosis Cases in 2020 to 2021

In figure 1(a), it shows that COVID-19 case in 2020 was in the interval 40–6.880 cases, meanwhile, on August 10, 2021, it has reached the interval of 1.418–33.996 cases. Figure 1(a) shows that the highest positive cases number of COVID-19 in 2020 was occurred in Samarinda of 6.880 cases with the lowest cases occurred in Mahakam Ulu Regency of 40 cases. The data confirmed up to August 10, 2021 indicated that the highest number of positive cases is Balikpapan with 33.996 cases and is followed by Kutai Kartanegara Regency with 21.946 cases. Regions with the highest cases are Balikpapan, Samarinda, and Kutai Kartanegara, as seen by the darker color of the map. Figure 1(b) shows data mapping for tuberculosis cases in 2020 and August 10, 2021. In general, there is no increase in the number of tuberculosis cases in each region/city in East Kalimantan. The number of tuberculosis cases in 2021 has decreased compared to cases that occurred in 2020. It can be seen from the color that was initially dark turned into a lighter

color. Based on figure 1(b), the regions that have the highest number of tuberculosis cases in 2020 was Balikpapan with 1538 cases. Afterward, it continues with the highest cases in 2021 of 816 cases. Meanwhile, the lowest case occurred in Mahakam Ulu Regency.



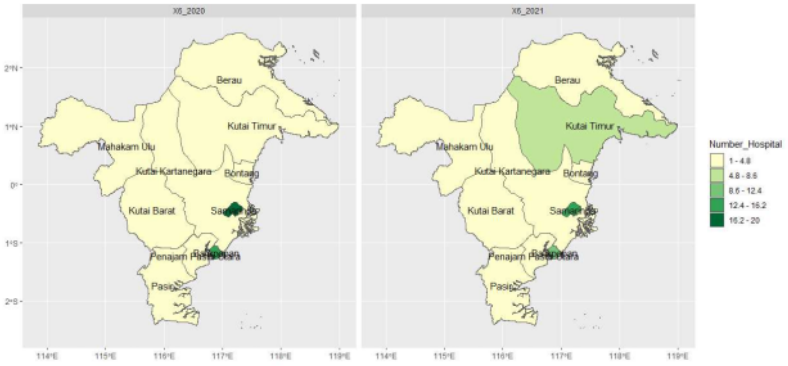
(a) Mapping of Population Density in 2020-2021



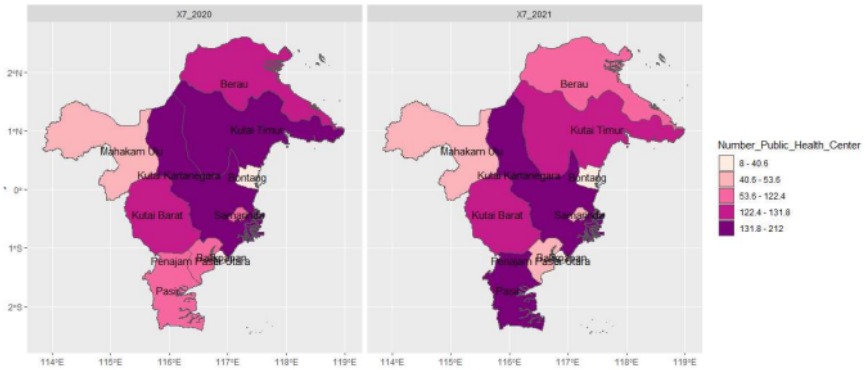
(b) Mapping of Gross Regional Domestic Product in 2020-2021

FIGURE 2. Spatial Distribution Mapping of (a) Population Density and (b) Gross Regional Domestic Product in 2020-2021

Figure 2(a) shows the distribution of population density in 2020-2021. In general, there is no increase in tuberculosis cases number in each regency/city in East Kalimantan. It can be seen from the similar pattern of colors from 2020 to 2021. Some regencies/cities have higher population density in Balikpapan with 1,279 population/Km^2, Samarinda with 1,218 population/Km^2, and Kutai Kartanegara with 1,089 population/Km^2. It is also seen from the color map that increasingly dark in the region. Figure 2(a) shows the distribution of GDP in 2020-2021. GDP shows the economic condition of a region. In general, there is no increase in GDP in each regency/city in East Kalimantan. This can be seen from the pattern of colors which is almost the same from 2020 to 2021. However, most of the region has a higher value of GDP.



(a) Mapping the Number of Hospital in 2020-2021



(b) Mapping the Number of Public Health Center in 2020-2021

FIGURE 3. Mapping Spatial Distribution (a) Mapping the Number of Hospitals and (b) the Number of Public Health Center in 2020 – 2021

Figure 3(a) shows the distribution of the number of hospitals in 2020-2021. In general, there is no increase in the number of hospitals in each regency/city in East Kalimantan. It can be seen from the pattern of colors which is almost the same and evenly in each region. However, East Kutai Regency is experiencing an increasing number of hospitals in 2021 compared to another region/city, as can be noticed from the color which turns to be darker. Figure 3(a) shows the distribution of the number of public health center in 2020-2021. In general, there is no increase in the number of public health center in each regency/city in East Kalimantan. This can be seen from similar colors pattern from 2020 to 2021. However, for some regions, such as East Kutai and Berau, the number of Public Health Centers has decreased. This can be seen from the colors which turn brighter from 2020 to 2021.

TABLE 1. Descriptive Statistics of Response Variables and Predictor Variables

Descriptive Statistics	Positive case of COVID-19 (y)	Number of Tuberculosis Cases (x_1)	Population Density (x_2)	GDP (x_3)	Number of Hospital (x_4)	Number of Public Health Centers (x_5)
Minimum	40	11	1	1762.69	1	8
Maximum	33996	1538	1279	126160.2	20	212
Range	33956	1527	1278	124397.5	19	204
Sum	160901	9669	7403	956789.3	101	1826

TABLE 1. Descriptive Statistics of Response Variables and Predictor Variables

Descriptive Statistics	Positive case of COVID-19 (y)	Number of Tuberculosis Cases (x_1)	Population Density (x_2)	GDP (x_3)	Number of Hospital (x_4)	Number of Public Health Centers (x_5)
Median	5443.5	395	28	37518.26	3	88
Mean	8045.05	483.45	370.15	47839.47	5.05	91.3
SE Mean	1983.691	95.30724	122.9133	8672.878	1.170863	13.46537
Variance	78700590	181669.4	302153.6	1504376000	27.41842	3626.326
Standard Deviation	8871.335	426.227	549.685	38786.29	5.23626	60.21899

Data description on the number of COVID-19 cases and the influence variables or predictor variables is presented in Table 1.

Parameter Estimator of GTWR Model on COVID-19 Data in East Kalimantan

GTWR model estimation on i location and at t time is as follows:

$$\hat{y}_{it} = \hat{\beta}_0(u_i, v_i, t_i) + \hat{\beta}_1(u_i, v_i, t_i)x_{it1} + \hat{\beta}_2(u_i, v_i, t_i)x_{it2} + \hat{\beta}_3(u_i, v_i, t_i)x_{it3} + \hat{\beta}_4(u_i, v_i, t_i)x_{it4} + \hat{\beta}_5(u_i, v_i, t_i)x_{it5} \quad , i = 1,2, \dots ,10 \; ; t = 1,2 \tag{3}$$

TABLE 2. Summary of Parameter Estimator Value on GTWR Model

Estimasi Parameter	Minimum	Q_1	Median	Q_3	Maximum
$\hat{\beta}_0$	-5392.300	-5067.800	-4798.200	-4638.800	-4463.556
$\hat{\beta}_1$	-39.634	-39.287	-38.379	-36.986	-36.741
$\hat{\beta}_2$	21.770	22.144	23.383	24.638	25.076
$\hat{\beta}_3$	0.084	0.092	0.099	0.104	0.111
$\hat{\beta}_4$	1600.100	1633.700	1698.700	1728.600	1802.590
$\hat{\beta}_5$	93.679	96.681	101.950	109.210	114.508

Table 2 shows a summary of GTWR model parameter estimator value using a geographic weighting of Gaussian Kernel Function with Fixed Bandwidth on the spatial and temporal weighting functions. Variable $x_1$of tuberculosis cases number has a coefficient value of -39.634 to -36.741. Variable x_2 of population density has a coefficient value of 21.770 to 25.076. Variable x_3 of GDP has a coefficient value of 0.084 to 0.111. Variable x_4 of the number of hospitals have a coefficient value of 1600.100 to 1802.590. Variable x_5 of the number of Public Health Centers has a coefficient value of 93.679 to 114.508. Coefficient values of each variable are spread across the regions/cities in East Kalimantan.

Based on the estimation results of GTWR model parameters, the factors that affect the increase of positive cases of COVID-19 are variable x_1 of the number of tuberculosis cases, variable x_2 of population density, variable x_3 of GDP, variable x_4 of the number of hospitals, and variable x_5 of the number of Public Health Centers. The $\boldsymbol{\beta}$ estimator value for each region/city in East Kalimantan Province is presented in Table 3.

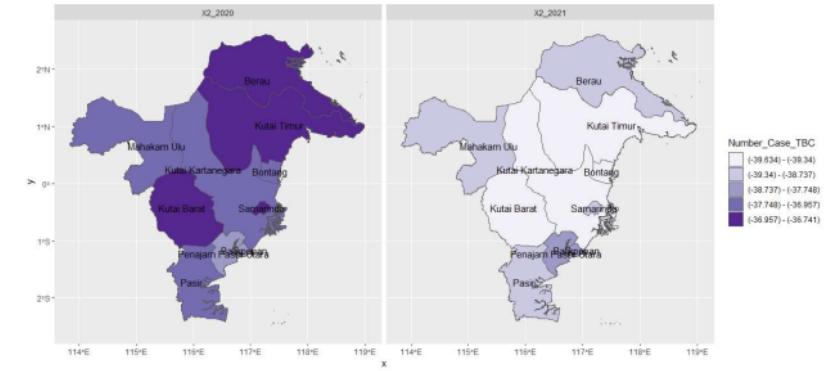
TABLE 3. Parameter Estimation Value in Each Region/City

Regency/ City	Year	$\widehat{\beta}_0$	$\widehat{\beta}_1$	$\widehat{\beta}_2$	$\widehat{\beta}_3$	$\widehat{\beta}_4$	$\widehat{\beta}_5$
Paser	2020	-4513.9	37.4717	22.11889	0.093188	1766.074	94.78808
Kutai Barat	2020	-4718.13	36.8695	22.22856	0.085986	1719.689	**99.03135***
Kutai Kartanegara	2020	-4647.22	37.3494	22.1058	0.094903	1741.614	96.03751
Kutai Timur	2020	-4714.64	36.8296	22.20377	0.086311	1717.84	98.70959
Berau	2020	-4620.77	36.7411	22.03453	0.083836	1726.511	98.87277
Penajam Paser Utara	2020	-4463.56	37.9321	22.24499	0.09656	1784.473	93.92686
Mahakam Ulu	2020	-4720.08	36.9591	22.15258	0.089175	1727.921	97.57374
Balikpapan	2020	-4502.67	**38.3446***	**22.45355***	**0.09838***	**1802.59***	94.14268
Samarinda	2020	-4486.95	36.9508	21.76994	0.095088	1727.66	93.67854
Bontang	2020	-4644.83	36.9949	22.06702	0.089883	1730.563	96.89514
Paser	2021	-4995.67	38.8372	24.61254	**0.110633***	1600.88	106.6003
Kutai Barat	2021	-5373.09	39.3661	25.04413	0.100758	1634.428	114.3627
Kutai Kartanegara	2021	-4960.65	39.4717	24.61647	0.104879	1657.227	108.031
Kutai Timur	2021	-5392.27	39.4502	**25.07546***	0.100567	1639.72	114.5075
Berau	2021	-5294.02	39.0448	24.9926	0.102173	1605.773	114.0006
Penajam Paser Utara	2021	-4941.25	38.6527	24.45479	0.109744	1605.645	105.9662
Mahakam Ulu	2021	-5261.04	39.2722	24.87998	0.103744	1631.572	**111.9169***
Balikpapan	2021	-4876.36	38.4133	24.31303	0.110108	1600.129	104.8747
Samarinda	2021	-5003.42	39.3332	24.62651	0.10624	1638.662	108.3011
Bontang	2021	-5334.4	**39.6338***	24.67394	0.102815	**1679.627***	112.5987

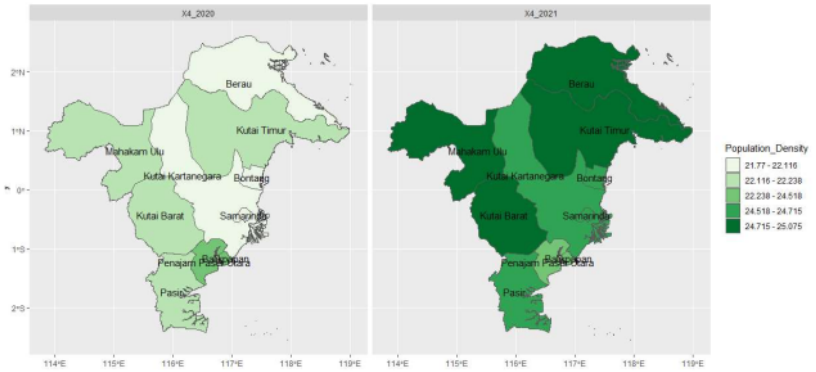
Based on the parameter estimator value of GTWR model, Balikpapan has the highest number of tuberculosis cases which also affects the high positive case numbers of COVID-19 in 2020. It is also shown in figure 1(a) that Balikpapan City has darker color with high case of COVID-19. Meanwhile, Bontang city has the highest number of tuberculosis cases which affecting COVID-19 cases in 2021. Based on these values, it provides information to the reviewers to focus more on tuberculosis cases due to the considerable influence on the increasing of COVID-19 cases in East Kalimantan. An increase in COVID-19 cases in Balikpapan is also affected by the high population density and the limited number of hospitals, as seen by the highest parameter estimator amongst other regional estimators. GIS mapping based on the model of GTWR will be described in the next sub-chapter.

GIS Mapping Based on GTWR Models Estimated For COVID-19 Cumulative Data in East Kalimantan

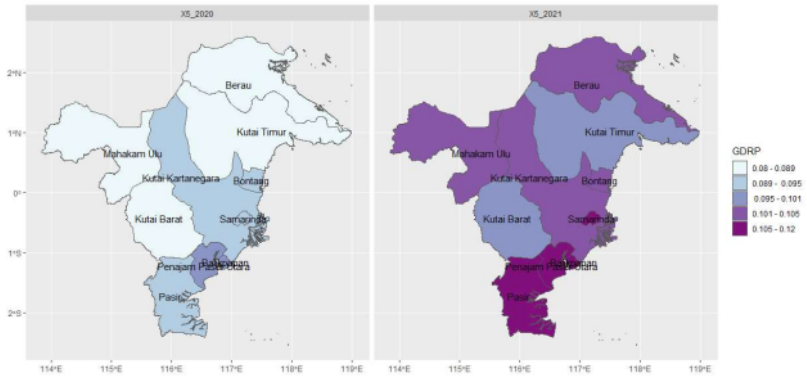
Mapping based on the estimation results of GTWR model is presented in figure 4. Model estimation value is aimed to obtain how much the influence of variable on the number of COVID-19 cases.



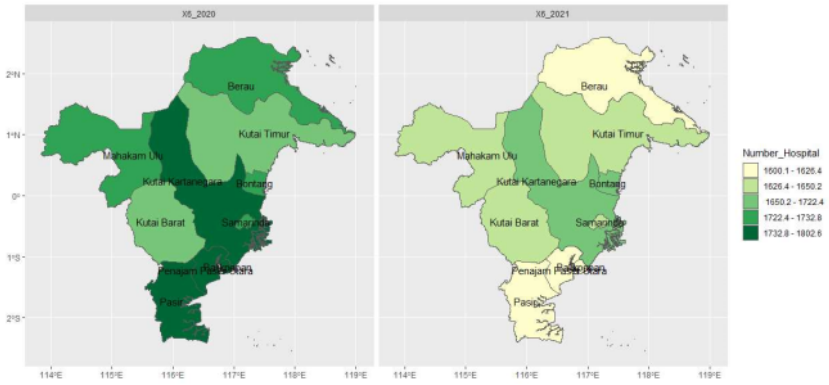
(a) Mapping Based on Estimator Value of Tuberculosis Cases Number



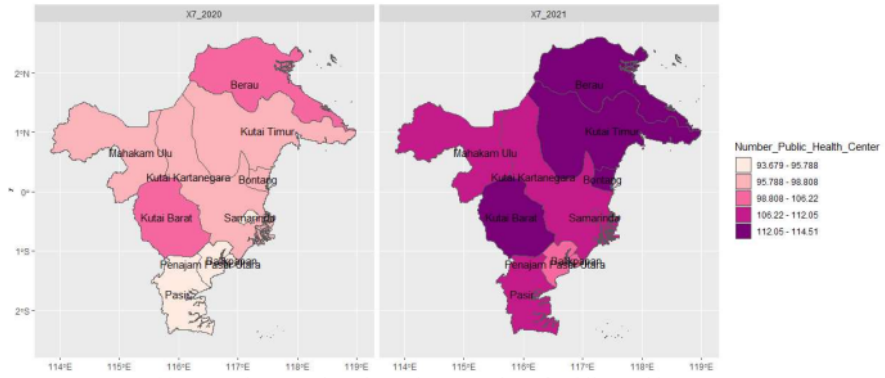
(b) Mapping Based on the Estimator Value of Population Density



(c) Mapping Based on the Estimator Value of GDP



(d) Mapping Based on the Estimator Value of Number of Hospital



(e) Mapping Based on the Estimator Value of Public Health Center

FIGURE 4. Mapping Based on Estimator Value of (a) Tuberculosis Cases Number (b) Population Density (c) GDP (d) Number of Hospital, and (e) Number of Public Health Centers in 2020 – 2021

Figure 4 shows the distribution of the estimator model or coefficient value of tuberculosis cases variable and population density in 2020-2021. These estimation number aims to determine the large and small influence of the variable on the data of positive cases number of COVID-19. In figure 4(a), the number of Tuberculosis cases in 2020 in all regencies/cities of East Kalimantan tends to have a high influence on the number of positive cases of COVID-19. It can be seen from the dark colors which are evenly distributed in the whole region. Meanwhile, in 2021, it has a low influence on the positive cases number of Covid-19. It can be seen from the light colors in the region. Figure 4(b) shows that population density in all regencies/cities in East Kalimantan tends to have a low influence on the number of positive cases of COVID-19. It can be seen from the light colors which are evenly distributed in the whole region. Meanwhile, in 2021, population density in all regencies/cities in East Kalimantan has a high influence on the number of positive cases of COVID-19. It can be seen from the dark colors in the region.

CONCLUSION

Geographically Temporally Weighted Regression (GTWR) model can provide solutions non-stationary data simultaneously both spatially and temporally. The advantage of GTWR is that the model is localized at each location and time, therefore the model is more representative. The results showed that the factors that influenced the cumulative increase in positive COVID-19 cases in East Kalimantan Province were the number of tuberculosis cases, population density, GDP, number of hospitals, and the number of sub-districts/villages that had public health centers. Based on the value of the parameter estimator of the GTWR model, Balikpapan has the highest number of tuberculosis cases in

2020. Meanwhile, in 2021, Bontang has the highest number of tuberculosis cases that affect COVID-19 cases. An increase in COVID-19 cases in Balikpapan is also affected by the high population density and the limited number of hospitals, as seen by the highest parameter estimator amongst other regional estimators. Based on these values, it provides information to the reviewers to focus more on tuberculosis cases in society due to the considerable influence on the increasing of COVID-19 cases in East Kalimantan.

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