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The Spatial and Flexible Model for Low-Birth-Weight Prediction

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Abstract— **The case of Low Birth Weight (LBW) in Indonesia is still high. Based on data from the Central Agency on Statistics (BPS), the case of LBW in East Java is still high, with about 20,836 people in 2016 and 14,882 people in 2017. Many factors trigger LBW, especially women's condition and nutritional intake during pregnancy. This study aims to establish a location-based LBW prediction model using a spatial and flexible model. This research was conducted using a Geographically Weighted Regression (GWR) model in East Java and a flexible model with a genetic programming approach. Endogenous variables (Y) portrayed LBW cases in East Java and exogenous variables were the Percentage of Early Marriage (X1), Human Development Index (X2), Number of Midwives (X3), K1 Visit (X4), K4 Visit (X5), Consumption of Fe 30 (X6), and Consumption of Fe 90 (X7). Based on the analysis results using the GWR model, global equation models, and local models 38 models were obtained with R^2 = 82.06%. Meanwhile, based on the results of the analysis with a flexible model with a deep learning approach, the model was obtained with R^2 = 84.8%. From this study, it can be concluded that the GWR model and the flexible model have the same level of accuracy. However, the flexible model can show the non-linear effect of the variables X1 and X3.**

Keywords— **Geographically weighted regression; genetic programming; low birth weight; flexible model.**

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I. INTRODUCTION

Low Birth Weight (LBW) is a health problem that needs special attention in many countries, especially in developing countries or countries with low socioeconomic conditions. LBW is a condition that causes the high Infant Mortality Rate (IMR) [1]–[4]. The Infant Mortality Rate (IMR) is one indicator that determines a country's health status. It is also a part of the goal in the MDG's 4 millennium development which is to reduce the number of infant deaths to 23/1000 live births. According to UNICEF data, Indonesia ranks 78th in the world in cases of LBW, with a percentage of 10% of the birth rate [5].

According to data from the Central Agency on Statistics (BPS), in 2017, there were 14,882 babies born with LBW conditions from a total birth rate of 578,749 in East Java. Moreover, the data also reveals that 50% of the case in IMR occurred in poor families. It is because most poor families cannot fulfill the needs of nutrients for pregnant women [6]. Therefore, the number of IMR increases [7]. The main causes of LBW in three (3) cities with the highest proportion of LBW in East Java indicate the accompanying disease of pregnancy and unbalanced nutrients during the pregnancy [8]. Nutritional fulfillment is certainly necessary for the mother to reduce the case of LBW [9].

Several researchers have conducted a study on LBW's risk factors, but the research's explanation is still limited to tables, diagrams, or graphs. Their study was using cross-sectional study [10], [11], prospective study [12], case-control study [4], [13], and meta-analysis [3], [14], [15]. LBW models that have been created include logistic regression models [16]–[18], multiple linear regression [19], [20], quantile regression model [21], structural model using path analysis [22], comparative study [23], [24], and descriptive spatial analysis [1]. These models are built with an approach to cross-sectional data.

Not many researchers have used a flexible model with genetic programming approach and presented the results of their research in the form of a map using a Geographical Information System (GIS) with Geographically Weighted Regression (GWR) analysis based on locations in cities/regencies in East Java to obtain a prediction model for LBW cases. Therefore, this research was conducted to build a prediction model of LBW in East Java using a flexible model and a spatial model with the Geographically Weighted Regression (GWR) approach.

II. MATERIAL AND METHOD

A. The Determinant Factors of Low-Birth-Weight Infants

WHO states that around 60-80% of the Infant Mortality Rate (IMR) in the world is caused by LBW. LBW has a greater risk of experiencing morbidity and mortality than babies born who have a normal weight [5]. Research on the determinant factors that influence LBW has shown that the upper arm circumference of pregnant women and gestational age are risk factors for LBW [16], [25], [26]. Besides, the study also reveals that the stress conditions of pregnant women [12], sanitation [18], [22], [27], information and education during pregnancy [28], wealth and family income [29], [30], smoke and air pollution [31], [32] are proven to affect the cause of LBW .

B. Research Data Sources

This study utilized secondary data from BPS of East Java [33], East Java Health Office [34], [35], and the Indonesian Midwives Association of East Java [36].

C. Research Variables

This study employed seven independent variables and one dependent variable. The variables studied were Marriage <17 Years (X1), Per Capita Income (X2), Number of Midwives (X3),% K1 Visits (X4), % K4 Visits (X5), % Fe1 (30 Tablets) (X6), % Fe3 (90 Tablets) (X7) and LBW (Y).

D. Data Analysis Method

The influence of determinant factors on LBW cases in East Java was estimated with a spatial approach, namely the Geographically Weighted Regression (GWR) model. As a comparison, modeling was also carried out with a flexible model with a deep learning approach. The best model for predicting LBW cases in East Java was determined based on the R2 value. The analysis process was carried out using GWR4, ArcGIS 10.3, and Eureqa 1.24.

III. RESULT AND DISCUSSION

A. Descriptive Statistics

In general, LBW incidents in East Java Province in 2018 occurred mostly in Jember Regency with 1887 cases and Malang Regency with 1261 cases. Descriptive statistics of each research variable are presented in table 1 below:

TABLE I
DESCRIPTIVE STATISTICS OF VARIABLES.

Variables	Min.	Mean	Max.
Marriage <17 years (X1) (%)	5.21	20.36	50.2
Income Per Capita (X2)	59.9	70.35	81.07
Number of Midwives (X3)	87	542.68	1281
% Visit K1 (X4)	88.1	97.74	105.2
% Visit K4 (X5)	77.6	89.34	99.6
% Fe1 (30 Tablets) (X6)	81.16	95.69	103.86
% Fe3 (90 Tablets) (X7)	76.32	88.37	100.06
LBW (Y)	73	566.9	1887

Before further testing using GWR, the spatial heterogeneity test was first carried out. The spatial heterogeneity test was conducted to determine whether the data contained variations between locations. The GWR model is appropriate if the data varies between locations. The hypotheses to be tested were:

$H_0: \sigma^2_{(u_1,v_1)} = \sigma^2_{(u_2,v_2)} = \cdots = \sigma^2_{(u_7,v_7)} = \sigma^2$ vs

$H_1: \mathit{there\ are\ at\ least\ a\ pair}\ \sigma^2_{(u_i,v_i)} \neq \sigma^2$

Test using the *Breusch Pagan* obtained the following results

Statistics Test of *Breusch Pagan* = 19.182

$\chi^2_{(0.05,7)} = 14.067$

Statistics Test of *Breusch Pagan* > $\chi^2_{(0.05,7)}$ (14.067) so that there was enough evidence to reject H_0. It was concluded that there were spatial variations in LBW cases in East Java Province. Therefore, the LBW case data in East Java could be modeled with the Geographically Weighted Regression model.

B. Global Model Testing

Global model testing was done using a regression model; the partial test results for each variable are as follows:

TABLE II
GLOBAL MODEL TEST

Parameter	Coefficient	t-statistics	p-value
β_1	-953.114	-0.893	0.3789
β_2	3.746	0.655	0.5175
β_3	-1.922	-0.176	0.8614
β_4	18.525	7.248	0.0000
β_5	38.428	1.835	0.0764
β_6	-30.720	-2.206	0.0352
β_7	-6.024	-0.389	0.6997
β_0	7.626	0.613	0.5443

Based on the results of global model testing, an equation is obtained

$$Y = -953.114 + 3.746X_1 - 1.922X_2 + 18.525X_3 + 38.428\,X_4 - 30.720X_5 - 6.024X_6 + 7.626X_7 \quad (1)$$

It is shown in Table 2 that two parameters have a p-value less than 0.05 (p <0.05), namely β_4 and β_6. From this test, it was proven that the variable K1 Visit (X4) and Fe Consumption (X6) had a significant effect on LBW in East Java province in all districts/cities.

C. Local Model Testing

Local model testing was conducted to determine the effect of the independent variables at each research location. The result parameters and statistics of the local model test results are shown in Table III.

Based on the results of local model testing of the GWR in table 3, it is shown that the variable K1 visit (X4) and Fe consumption (X6) significantly affected LBW in East Java in all districts/cities. While the K4 Visit variable (X5) only had a significant effect in Pacitan, Ponorogo, Kediri, Jombang, Nganjuk, Madiun, Magetan, Ngawi, Kediri, and Madiun districts. Based on these results, further detection was carried out with a partial test of the results of the Geographically Weighted Regression model with the seven predictor variables. From the partial test results, the following results are obtained:

TABLE III

PARAMETER AND T-STATISTICS OF LOCAL MODEL

Location	Intercept	X1	X2	X3	X4	X5	X6	X7
Pacitan	26.538 (1.17)	-735.955 (-0.711)	5.422 (0.952)	-3.825 (-0.352)	18.063 7.354)	35.305 (1.492)	-34.390 (-1.879)	-14.332 (-0.727)
Ponorogo	28.939 (1.187)	-789.767 (-0.769)	5.036 (0.892)	-3.971 (-0.367)	18.2 (7.441)	38.265 (1.635)	-36.062 (-1.987)	-16.623 (-0.85)
Trenggalek	28.836 (1.118)	-817.284 (-0.796)	4.888 (0.867)	-4.219 (-0.388)	18.355 (7.504)	39.895 (1.706)	-36.842 (-2.025)	-18.378 (-0.934)
Tulungagung	28.525 (1.064)	-824.974 (-0.803)	4.871 (0.864)	-4.418 (-0.403)	18.458 (7.531)	40.743 (1.738)	-37.097 (-2.03)	-19.722 (-0.993)
Blitar	27.41 (0.955)	-829.999 (-0.804)	4.819 (0.852)	-4.958 (-0.444)	18.65 (7.573)	42.522 (1.803)	-37.511 (-2.03)	-22.445 (-1.107)
Kediri	28.034 (1.04)	-765.5 (-0.741)	5.313 (0.933)	-4.57 (-0.41)	18.435 (7.463)	39.002 (1.647)	-35.552 (-1.919)	-20.091 (-0.99)
Malang	25.902 (0.762)	-1001.62 (-0.948)	3.239 (0.578)	-6.198 (-0.55)	19.131 (7.782)	55.31 (2.321)	-43.515 (-2.35)	-31.782 (-1.549)
Lumajang	27.293 (0.805)	-1288.792 (-1.229)	1.537 (0.276)	-4.97 (-0.456)	19.158 (7.851)	64.281 (2.69)	-49.58 (-2.704)	-32.81 (-1.608)
Jember	25.973 (0.765)	-1414.951 (-1.34)	0.749 (0.134)	-4.676 (-0.43)	19.188 (7.834)	68.913 (2.844)	-52.167 (-2.828)	-33.958 (-1.641)
Banyuwangi	25.956 (0.798)	-1422.331 (-1.363)	0.68 (0.122)	-4.379 (-0.406)	19.033 (7.787)	67.252 (2.818)	-51.954 (-2.842)	-31.234 (-1.544)
Bondowoso	26.499 (0.788)	-1423.164 (-1.349)	0.847 (0.152)	-4.409 (-0.406)	19.11 (7.81)	68.201 (2.824)	-51.985 (-2.824)	-33.217 (-1.611)
Situbondo	26.709 (0.806)	-1422.79 (-1.352)	0.936 (0.168)	-4.198 (-0.388)	19.032 (7.789)	67.222 (2.798)	-51.702 (-2.818)	-32.207 (-1.574)
Probolinggo	27.619 (0.811)	-1286.144 (-1.217)	1.796 (0.323)	-4.75 (-0.434)	19.083 (7.816)	63.708 (2.656)	-49.137 (-2.675)	-33.018 (-1.609)
Pasuruan	26.068 (1.163)	-863.862 (-0.845)	4.102 (0.736)	-3.727 (-0.351)	17.969 (7.391)	41.231 (1.783)	-38.601 (-2.158)	-14.656 (-0.766)
Sidoarjo	25.66 (0.775)	-969.528 (-0.902)	3.822 (0.677)	-5.669 (-0.5)	18.823 (7.599)	53.071 (2.205)	-41.914 (-2.247)	-31.003 (-1.495)
Mojokerto	27.618 (0.925)	-859.938 (-0.823)	4.597 (0.813)	-4.997 (-0.445)	18.595 (7.527)	45.375 (1.917)	-38.608 (-2.086)	-24.99 (-1.226)
Jombang	26.462 (0.97)	-679.323 (-0.649)	5.723 (0.989)	-5.141 (-0.45)	18.396 (7.355)	37.773 (1.57)	-33.751 (-1.785)	-21.342 (-1.022)
Nganjuk	27.88 (1.095)	-720.962 (-0.698)	5.645 (0.986)	-4.229 (-0.38)	18.267 (7.381)	36.448 (1.534)	-34.175 (-1.842)	-18.16 (-0.897)
Madiun	28.591 (1.193)	-755.071 (-0.734)	5.325 (0.938)	-3.862 (-0.355)	18.139 (7.391)	36.75 (1.563)	-35.033 (-1.921)	-16.137 (-0.82)
Magetan	27.367 (1.213)	-695.855 (-0.673)	5.773 (1.007)	-3.688 (-0.337)	18.014 (7.306)	33.783 (1.422)	-33.216 (-1.804)	-14.344 (-0.722)
Ngawi	28.075 (1.205)	-732.062 (-0.712)	5.489 (0.964)	-3.706 (-0.34)	18.054 (7.345)	35.647 (1.513)	-34.369 (-1.881)	-15.402 (-0.782)
Bojonegoro	24.198 (4.714)	-976.795 (-0.971)	3.673 (0.681)	-1.578 (-0.153)	18.633 (7.739)	38.284 (1.933)	-29.445 (-2.227)	-4.793 (-0.326)
Tuban	25.099 (0.803)	-1381.291 (-1.338)	0.773 (0.139)	-4.422 (-0.413)	18.935 (7.77)	64.91 (2.762)	-51.075 (-2.824)	-28.909 (-1.465)
Lamongan	26.504 (1.2)	-831.39 (-0.811)	4.359 (0.78)	-3.713 (-0.348)	17.94 (7.363)	39.814 (1.714)	-37.708 (-2.099)	-14.143 (-0.735)
Gresik	25.386 (0.809)	-954.721 (-0.896)	4.174 (0.738)	-4.833 (-0.428)	18.609 (7.513)	49.858 (2.087)	-40.779 (-2.194)	-28.018 (-1.363)
Bangkalan	24.901 (0.783)	-1024.588 (-0.959)	3.865 (0.686)	-4.51 (-0.401)	18.623 (7.536)	51.991 (2.176)	-42.208 (-2.277)	-28.697 (-1.398)
Sampang	26.41 (1.188)	-841.541 (-0.821)	4.264 (0.764)	-3.761 (-0.353)	17.959 (7.376)	40.312 (1.738)	-38.028 (-2.119)	-14.331 (-0.746)
Pamekasan	27.133 (0.823)	-1333.834 (-1.265)	1.796 (0.323)	-3.982 (-0.366)	18.9 (7.751)	62.994 (2.641)	-49.35 (-2.698)	-31.147 (-1.531)
Sumenep	26.651 (0.829)	-1368.191 (-1.307)	1.508 (0.272)	-3.802 (-0.353)	18.849 (7.742)	63.366 (2.674)	-49.975 (-2.746)	-29.917 (-1.488)
Kota Kediri	28.108 (1.047)	-768.542 (-0.745)	5.296 (0.93)	-4.529 (-0.407)	18.428 (7.465)	38.99 (1.648)	-35.608 (-1.925)	-19.929 (-0.985)
Kota Blitar	27.461 (0.959)	-829.825 (-0.804)	4.825 (0.853)	-4.929 (-0.442)	18.642 (7.572)	42.425 (1.8)	-37.487 (-2.03)	-22.317 (-1.101)
Kota Malang	26.315 (0.789)	-965.365 (-0.915)	3.544 (0.631)	-6.092 (-0.54)	19.043 (7.737)	53.268 (2.239)	-42.411 (-2.289)	-30.649 (-1.494)
Kota Probolinggo	27.621 (0.811)	-1286.13 (-1.217)	1.789 (0.322)	-4.758 (-0.434)	19.086 (7.817)	63.73 (2.657)	-49.15 (-2.676)	-33.024 (-1.61)
Kota Pasuruan	26.649 (0.774)	-1129.144 (-1.056)	2.762 (0.494)	-5.444 (-0.487)	19.042 (7.757)	59.335 (2.467)	-45.888 (-2.481)	-33.245 (-1.611)
Kota Mojokerto	27.632 (0.927)	-862.61 (-0.826)	4.591 (0.812)	-4.953 (-0.441)	18.587 (7.525)	45.383 (1.918)	-38.646 (-2.089)	-24.923 (-1.224)
Kota Madiun	28.591 (1.193)	-755.071 (-0.734)	5.325 (0.938)	-3.862 (-0.355)	18.139 (7.391)	36.75 (1.563)	-35.033 (-1.921)	-16.137 (-0.82)
Kota Surabaya	25.173 (0.77)	-980.769 (-0.911)	3.916 (0.692)	-5.287 (-0.466)	18.733 (7.556)	52.51 (2.182)	-41.775 (-2.239)	-30.33 (-1.463)
Kota Batu	25.849 (0.807)	-833.921 (-0.788)	4.378 (0.77)	-6.342 (-0.556)	18.89 (7.615)	48.083 (2.012)	-39.035 (-2.085)	-28.589 (-1.38)

TABLE IV

DISTRICT GROUPING BASED ON PREDICTOR VARIABLES WITH A SIGNIFICANT EFFECT ON THE GWR MODEL

Variables with Significant Influence	Locations
X4 and X6	Pacitan, Ponorogo, Kediri, Jombang, Nganjuk, Madiun, Magetan, Ngawi, Kota Kediri, Kota Madiun
X4, X5, and X6	Trenggalek, Tulungagung, Blitar, Malang, Lumajang, Jember, Banyuwangi, Bondowoso, Situbondo, Probolinggo, Pasuruan, Sidoarjo, Mojokerto, Bojonegoro, Tuban, Lamongan, Gresik, Bangkalan, Sampang, Pamekasan, Sumenep, Kota Blitar, Kota Malang, Kota Probolinggo, Kota Pasuruan, Kota Mojokerto, Kota Surabaya, Kota Batu

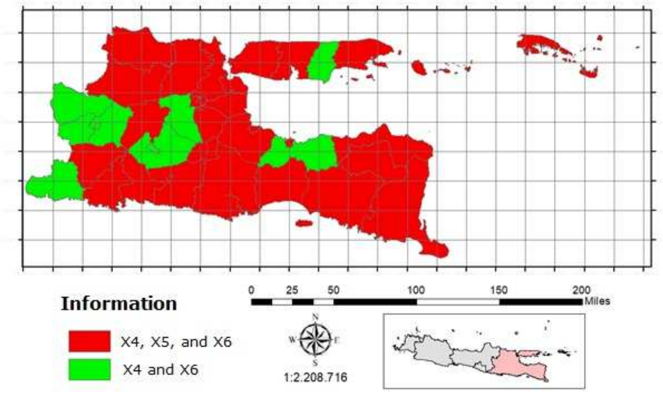


Fig. 1 The locations that had a significant effect

The R^2 value of GWR Model was 0.8206, which meant that predictor variables could explain 82.06% of the diversity of LBW cases in East Java, and other variables outside the GWR model explain the remaining 17.94%.

D. Flexible Model Analysis Results

The process of estimating the flexible model parameters was carried out using the help of Eureqa 1.24 software. The generated model was firstly constructed by making the mean model. Furthermore, the model generation process was carried out by considering the model's complexity. In this study, the process of generating models was conducted as many as 2,040,795 models were built. After generating models with a stability level of 85.6%, a maturity of 87.9%, and converging at 100%, there were 21 possible best models based on the R^2 value as follows:

TABLE V
POSSIBLE BEST MODEL OF FLEXIBLE MODEL

No.	Size	Model
1	3	Y = X1*X3
2	7	Y = 13.747*X3 + 9.168*X1
3	5	Y = 32.341 + X1*X3
4	9	Y = 1.126*X3*X4 - X3*X5
5	11	Y = X1 + 1.120*X3*X4 - X3*X5
6	1	Y = 515.038
7	13	Y = 3.030*X1 + 1.102*X3*X4 - X3*X5
8	15	Y = 3.977*X1 + 1.107*X3*X4 - 27.551 - X3*X5
9	16	Y = 1.122*X3*X4 + X1^2/X3 - X3*X5
10	18	Y = 1.127*X3*X4 + X1^2/X3 - 19.274 - X3*X5
11	19	Y = 5.450*X1 + X3*X4 + 0.100*X3^2 - 0.945*X3*X5
12	20	Y = 1.136*X3*X4 + 1.969*X1^2/X3 - 65.984 - X3*X5
13	22	Y = 1.137*X3*X4 + (X6 + 1.903*X1^2)/X3 - 68.371 - X3*X5
14	23	Y = 7.858*X3 + 6.338*X1 + 0.025*X4*X3^2 - 0.025*X5*X3^2
15	25	Y = 0.003 + 7.858*X3 + 6.338*X1 + 0.025*X4*X3^2 - 0.025*X5*X3^2
16	28	Y = 7.860*X3 + 6.348*X1 + -13.160/X3 + 0.025*X4*X3^2 - 0.025*X5*X3^2
17	29	Y = 5.277*X1 + 0.404*X3*X6 + 0.027*X4*X3^2 - 28.534*X3 - 0.027*X5*X3^2
18	31	Y = 8.527 + 5.301*X1 + 0.402*X3*X6 + 0.027*X4*X3^2 - 28.904*X3 - 0.027*X5*X3^2
19	40	Y = 81.097 + 2.707*X1 + 0.439*X3*X6 + X1^2/X3 + 0.027*X4*X3^2 - X4 - 29.456*X3 - 0.027*X5*X3^2
20	38	Y = 2.681*X1 + 0.439*X3*X6 + X1^2/X3 + 0.027*X4*X3^2 - 17.375 - 29.501*X3 - 0.028*X5*X3^2
21	36	Y = 2.365*X1 + 0.438*X3*X6 + X1^2/X3 + 0.027*X4*X3^2 - 29.588*X3 - 0.028*X5*X3^2

The Goodness of fit model is presented in Table 6.

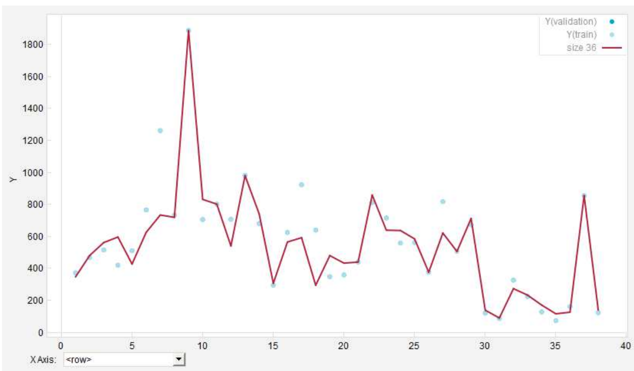
TABLE VI
THE GOODNESS OF FIT OF THE POSSIBLE MODEL

No	R^2 Goodness of Fit	Correlation Coefficient	Mean Squared Error	Mean Absolute Error
1	0.630899	0.831614	45098.29	155.32
2	0.652136	0.845634	42503.53	126.5399
3	0.636805	0.831614	44376.72	150.7134
4	0.800566	0.904219	24367.75	107.1201
5	0.807872	0.907373	23475.03	103.6562
6	-0.02205	0	124878.8	259
7	0.801526	0.908448	24250.46	98.94801
8	0.810721	0.908758	23126.95	97.50299
9	0.8173	0.913195	22323.02	96.65672
10	0.819185	0.913197	22092.74	95.15313
11	0.816777	0.912748	22386.99	93.38805
12	0.826445	0.914721	21205.75	91.53855
13	0.826851	0.915456	21156.09	90.6909
14	0.837344	0.919709	19873.95	86.01576
15	0.837345	0.919709	19873.9	86.01575
16	0.837229	0.919818	19888.11	85.91098
17	0.845164	0.923727	18918.52	81.11174
18	0.844784	0.923412	18964.97	80.99485
19	0.847676	0.925554	18611.59	78.30158
20	0.845804	0.925089	18840.36	79.00386
21	0.848453	0.924816	18516.62	79.32668

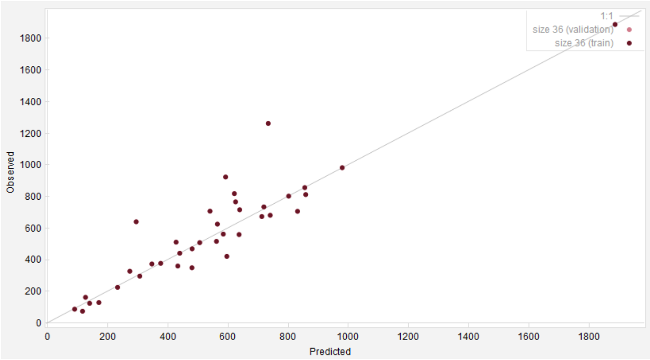
Based on the Goodness of fit coefficients in the table above, it is projected that the 21st model has the highest R^2 value and the lowest Mean Squared Error. From this coefficient, it was proven that the 21st model has better accuracy than the other models. Therefore, the model used to predict LBW is as follows:

$$Y = 2.365\,X_1 + 0.438\,X_3X_6 + \frac{{X_1}^2}{X_3} + 0.027\,X_4{X_3}^2 - 29.588\,X_3 - 0.0275\,X_5{X_3}^2 \quad (2)$$

The following is a plot graph between the incidences of LBW with the predicted value of the selected model.



(a)



(b)

Fig. 2 Scatter plot of actual and predicted LBW (a) Relationship between actual with predicted LBW (b)

Based on the graph above, it is displayed that the red line, namely the predicted value of LBW, is close to the incidence of LBW in East Java province. This proves that the model built has a high degree of accuracy (Figure 2a). Likewise, when viewed from the scatter plot, the relationship between LBW incidences in East Java province and the predicted results showed a positive relationship. The closer the diagonal line, the closer the relationship is and the predicted value is getting closer to the true value (Figure 2b).

E. Comparison of the GWR Model and the Flexible Model

Based on the results of modelling using GWR, we get one global model and 38 local models with an R^2 of 82.06%. From this model, it is suggested that the variable K1 Visit (X4) and Fe consumption (X6) had a significant effect on LBW in East Java in all districts/cities. While the flexible model with the deep learning approach obtained 1 model with R^2 of 84.85%, only the variables of Income per Capita (X2) and Fe3 Consumption (90 tablets) (X7) were not significant and were eliminated from the model. Besides, from this flexible model, it was also found that there was a non-linear effect of variables X3 and X5.

F. Discussion

Based on the results of the predictive modeling of LBW in East Java Province using either GWR or using a flexible model, it was shown that not all determinants had a significant effect on LBW cases. Early marriage was not proven to have a significant effect on LBW cases. It might occur because not all women who get married early experience pregnancy at an early age [37]. Many young women are found to postpone pregnancy until maturity.

The incidence of LBW was also not influenced by per capita income and the number of midwives. Unlike Nguyen's [38] and Kusrini's [39] research, this study proved that an increase in family income positively affected babies' birth weight. The insignificant effect of the number of midwives indicated that the role of midwives in assisting pregnant women during K1 needed to be improved. Counseling for pregnant women, especially for chronic lack of energy sufferers, needed to be asserted [10], [40]. The pattern of nursing care for newborns with appropriate LBW is proven to reduce infant mortality due to LBW [41]. The role of practicing midwives should be attained to monitor the development of pregnant women during pregnancy [42]. Likewise, the consumption of Fe3 90 tablets also did not have a significant effect on reducing LBW. This occurs because pregnant women who carry out routine checks are always given Fe tablets, whether the mother is in normal condition or experiencing Hb deficiency [15], [43].

The frequency of pregnant women in checking their pregnancy progress is crucial for the condition of the babies born [13], [39]. By then, problems that occur in pregnant women, for example, lack of nutritional intake or chronic lack of energy, can be immediately handled [44], [45]. Preferred pregnancy checks are during the first trimester. Fortunately, the awareness of pregnant women in checking pregnancy was very high; it was more than 90%. This study suggested that K1 visits had a significant effect on reducing LBW cases.

IV. Conclusion

This study concludes that the awareness of pregnant women in checking pregnancy, especially K1 and consumption of Fe tablets reduces the cases of LBW in East Java Province. The GWR model has high accuracy in predicting LBW cases with an R^2 of 82.06%. The flexible model also has an accuracy level that is relatively the same as the GWR model with an R^2 of 84.85%, but the flexible model has the advantage of detecting non-linear effects of explanatory variables.

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References

[1] A. Banerjee, A. K. Singh, and H. Chaurasia, "An exploratory spatial analysis of low birth weight and its determinants in India," *Clin. Epidemiol. Glob. Heal.*, vol. 8, no. 3, pp. 702–711, Sep. 2020.

[2] E. Banchani and E. Y. Tenkorang, "Determinants of Low Birth Weight in Ghana: Does Quality of Antenatal Care Matter?," *Matern. Child Health J.*, vol. 24, no. 5, pp. 668–677, May 2020.

[3] A. Endalamaw, E. H. Engeda, D. T. Ekubagewargies, G. M. Belay, and M. A. Tefera, "Low birth weight and its associated factors in Ethiopia: A systematic review and meta-analysis," *Italian Journal of Pediatrics*, vol. 44, no. 1. BioMed Central Ltd., 26-Nov-2018.

[4] S. A. Desta, A. Damte, and T. Hailu, "Maternal factors associated with low birth weight in public hospitals of Mekelle city, Ethiopia: A case-control study," *Ital. J. Pediatr.*, vol. 46, no. 1, Sep. 2020.

[5] United Nations Children's Fund (UNICEF) and World Health Organization (WHO), *Low birthweight estimates*. Geneva: World Health Organization, 2019.

[6] Z. T. Tessema, K. S. Tamirat, A. B. Teshale, and G. A. Tesema, "Prevalence of low birth weight and its associated factor at birth in Sub-Saharan Africa: A generalized linear mixed model," *PLoS One*, vol. 16, no. 3 March, Mar. 2021.

[7] A. K. Wandira and R. Indawati, "Faktor Penyebab Kematian Bayi Di Kabupaten Sidoarjo," *J. Biometrika dan Kependud.*, vol. 1, no. 1, pp. 33–42, 2012.

[8] I. Hartiningrum and N. Fitriyah, "Bayi Berat Lahir Rendah (BBLR) di Provinsi Jawa Timur Tahun 2012-2016," *J. Biometrika dan Kependud.*, vol. 7, no. 2, p. 97, 2019.

[9] C. L. Cutland *et al.*, "Low birth weight: Case definition & guidelines for data collection, analysis, and presentation of maternal immunization safety data," *Vaccine*, vol. 35, no. 48, pp. 6492–6500, 2017.

[10] S. Mohammed, I. Bonsing, I. Yakubu, and W. P. Wondong, "Maternal obstetric and socio-demographic determinants of low birth weight: A retrospective cross-sectional study in Ghana," *Reprod. Health*, vol. 16, no. 1, May 2019.

[11] W. Mueller *et al.*, "Exposure to ambient particulate matter and biomass burning during pregnancy: associations with birth weight in Thailand," *J. Expo. Sci. Environ. Epidemiol.*, 2021.

[12] X. Li *et al.*, "The association between symptoms of depression during pregnancy and low birth weight: A prospective study," *BMC Pregnancy Childbirth*, vol. 20, no. 1, Mar. 2020.

[13] C. Xi *et al.*, "Association between maternal lifestyle factors and low birth weight in preterm and term births: A case-control study," *Reprod. Health*, vol. 17, no. 1, Jun. 2020.

[14] L. Liao, Y. Deng, and D. Zhao, "Association of Low Birth Weight and Premature Birth With the Risk of Metabolic Syndrome: A Meta-Analysis," *Frontiers in Pediatrics*, vol. 8. Frontiers Media S.A., 28-Jul-2020.

[15] A. C. M. G. Figueiredo *et al.*, "Maternal anemia and low birth weight: A systematic review and meta-analysis," *Nutrients*, vol. 10, no. 5. MDPI AG, 12-May-2018.

[16] D. Valenzuela-Stutman, G. Marshall, J. L. Tapia, G. Mariani, A. Bancalari, and Á. Gonzalez, "Bronchopulmonary dysplasia: risk prediction models for very-low- birth-weight infants," *J. Perinatol.*, vol. 39, no. 9, pp. 1275–1281, 2019.

[17] A. Singh, S. Arya, H. Chellani, K. C. Aggarwal, and R. M. Pandey, "Prediction model for low birth weight and its validation," *Indian J. Pediatr.*, vol. 81, no. 1, pp. 24–28, 2014.

[18] M. B. Bekela *et al.*, "Determinants of Low Birth Weight among Newborns Delivered at Public Hospitals in Sidama Zone, South Ethiopia: Unmatched Case-Control Study," *J. Pregnancy*, vol. 2020, 2020.

[19] M. Raja, S. K. K, and V. Deneshkumar, "Regression Modeling for Maternal Determinants of low birth weight," *Int. J. Stat. Syst.*, vol. 12, no. 3, pp. 585–591, 2017.

[20] D. Anggraini, M. Abdollahian, and K. Marion, "Review of Low Birth Weight Prediction Models In Indonesia," *Int. J. Adv. Sci. Eng. Technol.*, vol. 3, no. 4, pp. 105–111, 2015.

[21] F. Yanuar, A. Zetra, C. Muharisa, D. Devianto, A. R. Putri, and Y. Asdi, "Bayesian Quantile Regression Method to Construct the Low Birth Weight Model," in *Journal of Physics: Conference Series*, 2019, vol. 1245, no. 1.

[22] I. Trisnawati, H. Salimo, and B. Murti, "Biopsychosocial and Economic Determinants of Low Birth Weight in Jambi, South Sumatera: Path Analysis," *J. Matern. Child Heal.*, vol. 03, no. 01, pp. 385–394, 2017.

[23] S. Shrestha, S. Shrestha, U. Shakya Shrestha, and K. Gyawali, "Predictors of Low Birth Weight at Lumbini Provincial Hospital, Nepal: A Hospital-Based Unmatched Case Control Study," *Adv. Prev. Med.*, vol. 2020, pp. 1–7, 2020.

[24] A. Davoudi-Kiakalayeh, R. Mohammadi, A. A. Pourfathollah, Z. Siery, and S. Davoudi-Kiakalayeh, "Alloimmunization in thalassemia patients: New insight for healthcare," *Int. J. Prev. Med.*, vol. 8, no. 53, pp. 1–10, 2017.

[25] M. Z. Rahfiludin and Y. Dharmawan, "Risk Factors Associated with Low Birth Weight," *Kesmas Natl. Public Heal. J.*, vol. 13, no. 2, pp. 75–80, 2018.

[26] S. Kaur *et al.*, "Risk factors for low birth weight among rural and urban Malaysian women," *BMC Public Health*, vol. 19, no. Suppl 4, pp. 1–10, 2019.

[27] S. Mukherjee, "Statistical Modeling for Findings the Determinants of Neonates ' Very Low Birth Weight," *Am. J. Clin. Exp. Med.*, vol. 6, no. 6, pp. 125–135, 2018.

[28] A. Chevalier and V. O'Sullivan, "Mother's education and birth weight," *IZA Discuss. Pap.*, no. 2640, 2007.

[29] C. V. Paredes Mondragón, H. Molano Dorado, S. Y. Martínez Gómez, R. A. Ortiz Martínez, S. Arias Linthon, and A. C. López Benavides, "Relationship Between the Absence of Adequate Social Support During Pregnancy and Low Birth Weight," *Rev. Colomb. Psiquiatr.*, vol. 48, no. 3, pp. 140–148, Jul. 2019.

[30] E. Toledano, N. Zussman, R. Frish, and D. Gottlieb, "Family Income and Birth Weight," *Isr. Econ. Rev.*, vol. 10, no. 2, pp. 107–145, 2013.

[31] W. Zhang and T. C. Yang, "Maternal Smoking and Infant Low Birth Weight: Exploring the Biological Mechanism Through the Mother's Pre-pregnancy Weight Status," *Popul. Res. Policy Rev.*, vol. 40, no. 2, pp. 211–229, Apr. 2021.

[32] J. Hao *et al.*, "A time series analysis of ambient air pollution and low birth weight in Xuzhou, China," *Int. J. Environ. Health Res.*, 2021.

[33] BPS-Provinsi Jawa Timur, *Provinsi Jawa Timur dalam Angka 2018*. 2018.

[34] Dinas Kesehatan Propinsi Jawa Timur, *Profil Kesehatan Provinsi Jawa Timur Tahun 2017*. Surabaya: Kementerian Kesehatan Republik Indonesia, 2018.

[35] Dinas Kesehatan Propinsi Jawa Timur, *Profil Kesehatan Provinsi Jawa Timur Tahun 2018*. Surabaya: Kementerian Kesehatan Republik Indonesia, 2019.

[36] Ikatan Bidan Indonesia Jawa Timur, "Data Jumlah Bidan Provinsi Jawa Timur 2018," 2019. [Online]. Available: http://ibijatim.or.id/. [Accessed: 24-Mar-2020].

[37] S. Lumbanraja, D. Lutan, and I. Usman, "Maternal Weight Gain and Correlation with Birth Weight Infants," *Procedia - Soc. Behav. Sci.*, vol. 103, pp. 647–656, 2013.

[38] T. huong Nguyen, "Birth weight and growth during the first two years of life : a study in urban and rural Vietnam," Nordic School of Public Health NHV, 2014.

[39] I. Kusrini, S. Supadmi, D. K. Mulyantoro, and A. D. Laksono, "Demographic characteristics of mother as predictor of low birth weight in eastern Indonesia," *Syst. Rev. Pharm.*, vol. 12, no. 1, pp. 1514–1518, 2021.

[40] A. Goisis, H. Remes, K. Barclay, P. Martikainen, and M. Myrskylä, "Advanced Maternal Age and the Risk of Low Birth Weight and Preterm Delivery: A Within-Family Analysis Using Finnish Population Registers," *Am. J. Epidemiol.*, vol. 186, no. 11, pp. 1219–1226, Dec. 2017.

[41] D. Wanda, Y. Rustina, H. Hayati, and F. T. Waluyanti, "Pengembangan model pelayanan asuhan keperawatan bayi berat lahir rendah," *J. Ners*, vol. 9, no. 1, pp. 83–90, 2014.

[42] Ç. H. Hüseyin, H. Muazzez, and P. Yadigar, "A study of low birth weight prevalence and risk factors among newborns in a public-hospital at Kilis, Turkey," *Afr. Health Sci.*, vol. 20, no. 2, pp. 709–714, Jun. 2020.

[43] E. A. Lake and R. Olana Fite, "Low Birth Weight and Its Associated Factors among Newborns Delivered at Wolaita Sodo University Teaching and Referral Hospital, Southern Ethiopia, 2018," *Int. J. Pediatr.*, vol. 2019, pp. 1–7, 2019.

[44] C. K. Nyamasege *et al.*, "Determinants of low birth weight in the context of maternal nutrition education in urban informal settlements, Kenya," *J. Dev. Orig. Health Dis.*, vol. 10, no. 2, pp. 237–245, Apr. 2019.

[45] M. M. Hughes, R. E. Black, and J. Katz, "2500-g Low Birth Weight Cutoff: History and Implications for Future Research and Policy," *Matern. Child Health J.*, vol. 21, no. 2, pp. 283–289, 2017.