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RESEARCH ARTICLE

Comparision of Kernel Functions in Geographically Weighted Regression Model: Suicide Data as an Application

Coğrafi Ağırlıklı Regresyon Modelinde Kernel Fonksiyonlarının Karşılaştırılması: Bir Uygulama Olarak İntihar Verileri

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ABSTRACT

The traumatic traces of suicide in a society and the emotional devastation due to these losses make it very important to determine the causes of suicide. In this study, the number of suicides data was used for Turkey's 81 provinces in 2019.The effects of factors affecting suicide and spatial differences on suicide were analyzed and predicted with geographically weighted regression models (GWR). GWR models were applied with different kernel functions, and the best GWR model was found with the bisquare kernel function. Factors affecting suicide numbers were established as human development index, proportion of internet users, and numbers of unemployment. When the results were examined, it was seen that the number of suicides in the provinces was affected by different factors. In addition, the 2019 suicide numbers and predicted values were mapped, and the results were found to be quite similar. The province with the highest number of suicides across the country was Istanbul.

Keywords: Geographically Weighted Regression, Kernel Function, Suicide, Spatial

ÖZ

İntiharın toplumda bıraktığı travmatik izler, kayıplara bağlı yaşanılan duygusal yıkımlar intihar nedenlerinin belirlenmesini oldukça önemli kılmaktadır. Bu çalışmada 2019 yılına ait Türkiye'nin 81 ili için intihar sayısı verisi kullanılmıştır. İntiharı etkileyen faktörler ve mekansal farklılıkların intihar üzerindeki etkileri coğrafi ağırlıklı regresyon modeller (GWR) ile analiz edilmiş ve tahmin yapılmıştır. Farklı kernel fonksiyonları ile birlikte GWR modelleri uygulanmış ve en iyi GWR modeli bisquare kernel fonksiyonu ile bulunmuştur. İntihar sayılarını etkileyen faktörler insani gelişim endeksi, internet kullanıcı oranı ve işsizlik sayısı olarak elde edilmiştir. Sonuçlar incelendiğinde illerin yerleşim yerlerine göre intihar sayılarının farklı faktörlerden etkilendiği görülmektedir. Ayrıca 2019 yılı intihar sayıları ve tahmin değerlerinin haritalandırılması yapılmış ve sonuçlar oldukça benzer bulunmuştur. Ülke genelinde intihar sayısının en yüksek olduğu il İstanbul'dur.

Anahtar kelimeler: Coğrafi Ağırlıklı Regresyon, Kernel fonksiyon, İntihar, Mekansal

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1. INTRODUCTION

Although suicide is the result of individual action, it has become a social issue with its results. Every occurrence of suicide is a loss not only for the suicidal person but also for society. Although suicide creates different emotions in people, it is a concept that people generally avoid, are frightened by, and stay away from. Suicide, which has enormous effects on the individual and social level, has been a research subject through different thoughts and theories. The World Health Organization (WHO) and many similar global organizations keep global statistics on suicides. Suicide cases, which increase every year compared to the previous year, can be based on different reasons in terms of regional and socio-cultural conditions. When the suicide rates in our country are examined, it is seen that it is below the world average. Also, when we compare the results with other European research centers, it has been found that the growth rate of suicide is higher than the comparison of Western countries in Turkey (Devrimci-Ozguven and Sayıl, 2003). In suicide statistics, which is one of society's social and economic structure indicators, it is essential to know the number, reason, and form of suicide at the country level (TUIK, 2018). Official data on suicides in our country are compiled and published by the Turkey Statistical Institute (TUIK). According to TUIK data, the reasons for suicide occurring in the country are illness, family incompatibility, financial difficulties, emotional feelings, business failure, educational failure, unknown, and other causes. These reasons may differ according to regional conditions and social lifestyles.

For this reason, it is essential to investigate the factors affecting suicide rates by region, which is also the subject of our study. There are many studies about suicide in the literature. Tunalı and Özkaya (2016) analyzed the VAR model that looked into the effect of unemployment on the rate of suicide in Turkey. According to the results, a bidirectional causality relationship was found between these two cases between 1980 and 2014. Kyonne (2019) applied a multiple regression analysis to examine whether the government's social service expenditures affect the suicide rate in Asian countries. Bulut and Aydın (2020) determined the factors affecting suicide rates through beta regression analysis and multiple linear regression analyses. They found that per capita alcohol consumption, the unemployment rate, and labor force participation rate affected suicide. Ha and Tu (2018) examined the relationship between suicide rates and the altitude of provinces using the Geographically Weighted Regression (GWR) method. They found in their study that there was an overall positive relationship varying between altitude and suicide. Bektas (2015) published a study named "why suicide occurred between the years 2002-2012 in Turkey," which used spatial analysis. Frutos et al. (2018) modeled atmospheric pressure on suicide rates in the USA using the Geographically Weighted Regression method. Tran and Morrison (2020) found that the effects of income inequality on suicide rates differ between districts in the United States via the GWR model. The GWR model identified two statistically significant country groups, and a negative relationship was found between income inequality and suicide rates in both groups. Vaz et al. (2020) examined the spatial distribution of suicide rates between 2004-2011 in Toronto using the conditional autoregressive (CAR) method. In the study, the landscape mosaic was found to have a tremendous effect on suicide (it has been observed that women are particularly affected). Iyanda et al. (2021) examined the link between HIV and suicide in 186 countries using spatial autoregressive and multiscale geographically weighted regression methods.

In this study, factors affecting suicide numbers were investigated. Whether the spatial effects on suicide numbers are significant was determined by the GWR model. GWR model structures with different kernel selections were compared according to information criteria. The article is divided as follows: In section 2, the Geographically Weighted Regression and kernel function form are defined. Section 3 explains the application of the Geographically Weighted Regression with suicide data. Finally, a brief discussion is given in Section 4.

2. MATERIALS AND METHODS

2.1. Geographically Weighted Regression Model

Geographically weighted regression (GWR) is a nearby form of spatial analysis introduced in 1996 in the geographical literature drawing from statistical techniques for curve-fitting and smoothing applications (Stojanova et al., 2012). Although the GWR is based on the multiple linear regression model, the GWR model's coefficients are not constant. The coefficients of each spatial point are created (Lu et al. 2018). The GWR model is given as

$$y_i = \beta_0(u_i, v_i) + \sum_{k=1}^{m} \beta_k(u_i, v_i)x_{ik} + \varepsilon_i \quad i = 1,2, \dots, n$$

In equation (2), (u_i, v_i) are the latitude and longitude coordinates of the location in space ith. y_i is the dependent variable. $x_i(k = 1,2, \dots, m)$ is the independent variable. β_k is the coefficient of the GWR regression model, and ε_i is the error of ith location, which is assumed to be an independent and identically distributed normal random variable with mean zero and constant variance σ^2 .

The weighted least square methods provide a basis for estimating the GWR parameters. Parameter estimation of the GWR model are obtained as follows:

$$\hat{\beta}(u_i, v_i) = [X^T W(u_i, v_i)X]^{-1} X^T W(u_i, v_i)Y$$

where X is the matrix of independent variables and consists of m+1 column. $Y = (Y_1, Y_2, \dots, Y_n)^T$ is the dependent variable matrix, and W(i) is a diagonal matrix of w_{ij} values and is as shown below (Fotheringham et al., 2003).

$$W(i) = \begin{bmatrix} w_{i1} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & w_{in} \end{bmatrix}$$

w_{ij} is the neighborhood ratio between the regression point and the reference point. w_{ij} is determined by a kernel function.

w_{ij} is calculated using Box-Car, Exponential, Gaussian, Bi-Square, and Tri-Cube (Gollini et al. 2013). The main kernel function equations are given in Table 1.

Tablo1.

Kernel functions

Kernels	w_{ij}
Gaussian	$w_{ij} = \exp\left[-\frac{1}{2}\left(\frac{d_{ij}}{bw}\right)^2\right]$
Exponential	$w_{ij} = \exp\left[-\frac{1}{2}\left(\frac{\lvert d_{ij}\rvert}{bw}\right)\right]$
Bisquare	$w_{ij} = \left[1 - \left(\frac{d_{ij}}{bw}\right)^2\right]^2 if \ \lvert d_{ij}\rvert < bw$, 0 otherwise
Tricube	$w_{ij} = \left[1 - \left(\frac{\lvert d_{ij}\rvert}{bw}\right)^3\right]^3 if \ \lvert d_{ij}\rvert < bw$, 0 otherwise
Boxcar	$w_{ij} = 1 \ if \ \lvert d_{ij}\rvert < bw$, 0 otherwise

Where bw is bandwidth value, d_{ij} is the distance between regression point *i* and reference point *j*. d_{ij} the Euclidean distance is usually calculated as shown below, where u and v are point coordinates.

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

The value of the bw bandwidth parameter can be constant for a whole model in the GWR model, or it can be variable according to the point density in the location. The optimal value of bandwidth can be determined by Cross-validation (CV), Generalized cross-validation (GCV), Akaike Information Criteria (AIC), and Bayesian Information Criteria (BIC) methods (Taşyürek and Çelik,2020). In this study, the optimal bandwidth value is determined by obtaining the minimum value of the cross-validation criterion given below (Bowman, 1984).

$$CV = \sum_{i=1}^{n} (y_i - \hat{y}_{\neq i}(bw))^2$$

where $\hat{y}_{\neq i}(bw)$ is the fitted value of y_i by omitting the ith point from the process (Fotheringham et al., 2003).

3. APPLICATION

In this study, the number of suicides data was used for Turkey's 81 provinces in 2019. The data obtained is available from TUIK. A set of 8 continuous variables were used in this paper and described as a dependent variable: number of suicides (Y) or independent variables: the number of illiteracy (x1), number of higher education population (x2), divorce rate (%) (x3),

human development index (x4), the proportion of internet users (%) (x5), number of unemployment (x6), and expenditures of alcoholic beverages, cigarette, and tobacco (%) (x7). Independent variables affecting suicide numbers were selected from the literatüre (Sueki, 2013; Sedgwick et al. 2019; Harmancı, 2015; Tunalı, 2016).

Geographical weighted regression (GWR) models were used to obtain the importance of spatial effects in determining the factors affecting the number of suicides. Different models are defined by selecting gaussian, exponential, bisquare, tricube, and boxcar kernel functions in the GWR method, and the most suitable model was determined. Analyses used the "spgwr" and "GWmodel" package in R software packages.

Table 2

Comparisons of model criteria in GWR methods

Models	AIC	BIC	R^2
Model1 (Gaussian)	774.119	803.294	0.783
Model2 (Exponential)	770.048	796.345	0.801
Model3 (Bisquare)	763.235	782.132	0.833
Model4 (tricube)	766.864	786.962	0.823
Model5 (boxcar)	771.116	797.889	0.797

In table 1, GWR with bisquare kernel (Model3) gives the lowest AIC and BIC information criteria. The highest R^2 values were found as R^2=0.8328 in Model 3, and the fit is quite good. Model 3 is established with the value of CV criterion= 86807.52 and the bandwidth = 7.59 with the variables. The coefficients of Model 3 are as given in Table 3.

Table 3

Coefficients for the Model 3

Coefficient	F statistic	Numerator d.f.	Denominator d.f.	p-value
(Intercept)	1.764	30.239	61.481	0.030
x1	0.091	32.352	61.481	1.000
x2	0.192	32.689	61.481	1.000
x3	0.852	30.909	61.481	0.681
x4	7.064	23.350	61.481	0.000
x5	2.169	25.912	61.481	0.007
x6	4.822	28.951	61.481	0.000
x7	0.363	19.032	61.481	0.992

According to Model 3, the factors affecting the suicide numbers were found to be the variables of x4, x5, and x6. The spatial differences of significant variables are given in table 4.

Table 4

Parameter estimates of the Model 3 by province

Provinces	Human Development Index	The proportion of internet users	Number of unemployment	Provinces	Human Development Index	The proportion of internet users	Number of unemployment
Adana	201.29	-203.89	0.20	**İzmir**	-701.82	-335.90	0.33
Adıyaman	-365.41	-446.66	0.12	Kahramanmaraş	-108.28	-341.10	0.18
Afyonkarahisar	-87.47	-108.02	0.29	Karabük	189.62	23.24	0.27
Ağrı	-283.81	-669.06	-0.02	Karaman	271.95	-176.80	0.23
Aksaray	253.00	-135.02	0.25	Kars	-312.59	-683.15	-0.02
Amasya	10.08	-181.13	0.25	Kastamonu	188.99	-44.00	0.27
Ankara	208.24	-39.31	0.27	Kayseri	131.77	-180.43	0.24
Antalya	-135.23	-304.47	0.27	Kırıkkale	224.96	-72.44	0.27
Ardahan	-312.21	-662.76	-0.02	Kırklareli	-543.18	2.62	0.34
Artvin	-282.90	-597.30	-0.01	Kırşehir	220.90	-123.77	0.26
Aydın	-623.32	-350.00	0.32	Kilis	-147.54	-378.88	0.16
Balıkesir	-486.62	-140.38	0.32	Kocaeli	-113.94	56.06	0.30
Bartın	181.39	50.32	0.27	Konya	186.25	-130.60	0.25
Batman	-272.99	-578.49	0.01	Kütahya	-156.71	-70.90	0.30
Bayburt	-296.58	-497.99	0.02	Malatya	-365.61	-439.86	0.13
Bilecik	-119.14	-13.51	0.30	Manisa	-631.55	-289.65	0.33

Bingöl	-276.35	-550.34	0.02	Mardin	-291.46	-584.66	0.02
Bitlis	-262.32	-608.66	0.00	Mersin	315.23	-170.16	0.21
Bolu	91.93	24.31	0.28	Muğla	-594.96	-405.89	0.31
Burdur	-233.71	-272.50	0.28	Muş	-263.99	-589.55	0.00
Bursa	-262.45	-17.29	0.31	Nevşehir	255.38	-110.54	0.27
Çanakkale	-715.13	-227.48	0.35	Niğde	279.26	-127.43	0.25
Çankırı	211.93	-55.80	0.27	Ordu	-339.72	-392.40	0.18
Çorum	150.96	-99.52	0.28	Osmaniye	42.20	-267.94	0.20
Denizli	-398.21	-285.60	0.30	Rize	-288.85	-527.95	0.01
Diyarbakır	-303.69	-555.51	0.02	Sakarya	-44.97	41.66	0.30
Düzce	49.63	47.20	0.29	Samsun	-97.96	-227.10	0.24
Edirne	-663.42	-102.79	0.35	Siirt	-262.36	-602.86	0.00
Elazığ	-389.33	-471.52	0.07	Sinop	65.88	-64.35	0.29
Erzincan	-354.82	-467.52	0.06	Sivas	-162.76	-322.18	0.20
Erzurum	-267.89	-562.30	0.01	Şanlıurfa	-459.73	-482.29	0.07
Eskişehir	-63.97	-28.77	0.29	Şırnak	-258.02	-634.96	-0.01
Gaziantep	-197.47	-395.54	0.15	Tekirdağ	-499.41	-37.67	0.34
Giresun	-419.92	-426.05	0.15	Tokat	-100.55	-265.97	0.22
Gümüşhane	-351.80	-461.86	0.06	Trabzon	-331.54	-463.87	0.04
Hakkari	-242.82	-737.28	-0.03	Tunceli	-362.56	-470.46	0.06
Hatay	14.45	-306.62	0.18	Uşak	-282.45	-165.80	0.30
Iğdır	-313.21	-748.42	-0.04	Van	-266.01	-701.79	-0.02
Isparta	-122.07	-201.99	0.28	Yalova	-213.32	26.90	0.31
İstanbul	-245.35	56.39	0.32	Yozgat	185.05	-114.56	0.27
				Zonguldak	132.09	72.59	0.28

Table 4 presents estimates of the Model 3 parameters for each province in Turkey. The formula “abs (coefficient estimate) -2standard error” was used to calculate the values in Table 4. If this value is greater than zero, it is statistically significant (Dennet, 2014). Provinces where human development index values affected suicide numbers were Amasya, Ankara, Bartın, Bolu, Çankırı, Düzce, Hatay, Karabük, Karaman, Kastamonu, Kayseri, Kırşehir, Konya, Mersin, Nevşehir, Niğde, Osmaniye, Yozgat, and Zonguldak while provinces affected by the variable of the proportion of internet users were Bartın, Bolu, Düzce, İstanbul Yozgat, Zonguldak, Sakarya, Kocaeli and Kırıkkale. Unemployment affects suicide numbers in all provinces except for Ağrı, Artvin, Hakkari, Iğdır, Van, and Şırnak. On the maps, the places where the effect is darkest, meaning the highest value coefficients, are shown in red. Lighter colors show less effect. In other words, the blue-colored provinces are impacted least.

In Figure 1, the effects of the human development index variable on the number of suicides are presented on the map.

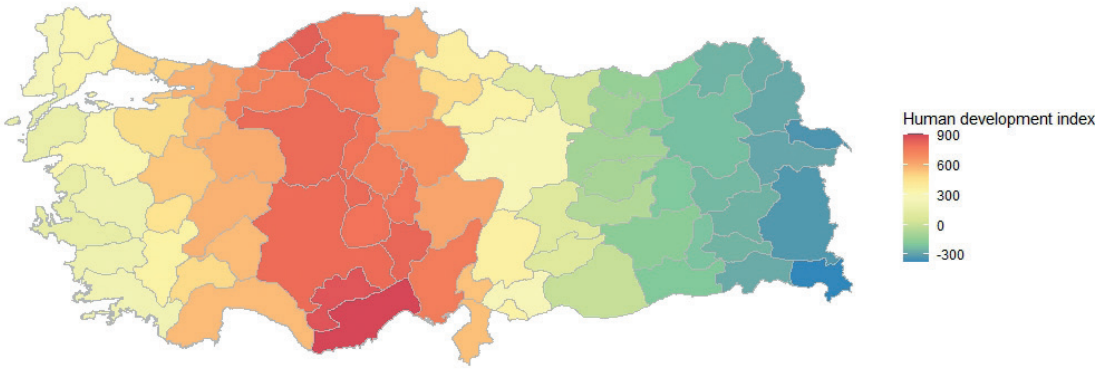

Figure 1. Spatial distribution of the human development index variable

The basic principle underlying the geographically weighted analysis is that provinces that are close to each other are more related than those that are far away. In Figure 1, Mersin, Karaman, Bartın, and Karabük are the provinces where the human

development index (HDI) has the most significant effect on the number of suicides. In eastern Turkey, there is a negative correlation between the HDI value and the number of suicides. The lower the HDI is, the higher the suicide rate is. The middle region of Turkey has a positive relationship between the HDI value and the number of suicides. The higher the HDI is, the higher the suicide rate is. As a result, the effect of provinces close to each other on the number of suicides is similar.

Figure 2 shows the spatial distribution of internet users by province.

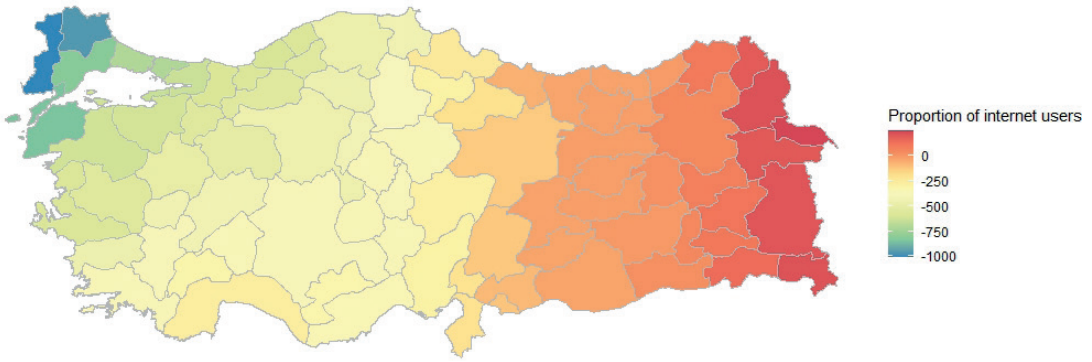

Figure 2. Spatial distribution of the internet users

In Figure 2, there is a negative relationship between the rate of internet users and the number of suicides. This relationship is highest in Edirne and Kırklareli provinces. Therefore, the number of suicides affected the most by internet user rate is Edirne and Kırklareli. It can be interpreted that the number of suicides is higher in these provinces, where the number of internet users is low. The region where suicide numbers are least affected by internet usage rates is the eastern region of Turkey. In other words, it can be said that the number of suicides is lower in the eastern region, where internet use is high.

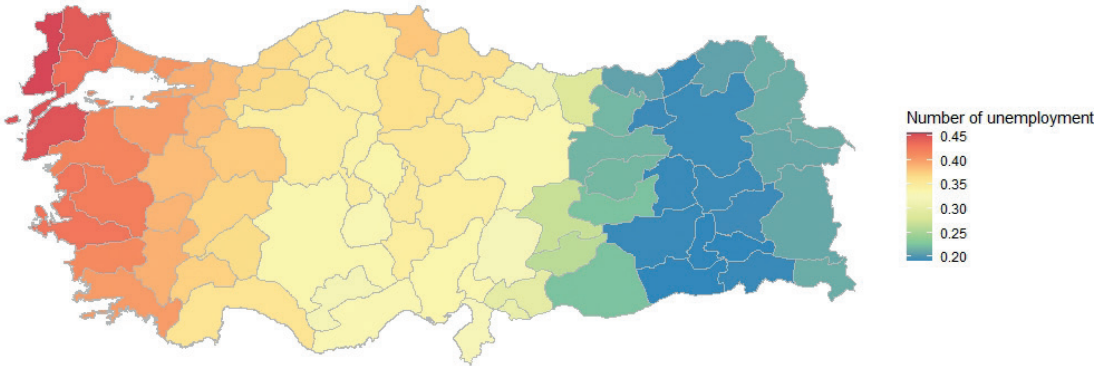

Figure 3. Spatial distribution of the unemployment numbers

According to Figure 3, unemployment has a positive relationship with the number of suicides. The provinces that have the most significant impact on the number of suicides from unemployment are located in western Turkey. Therefore, it is the region where the number of suicides is most affected by the number of unemployment. However, the number of suicides in the eastern region of Turkey is less affected by unemployment than in the western region of Turkey.

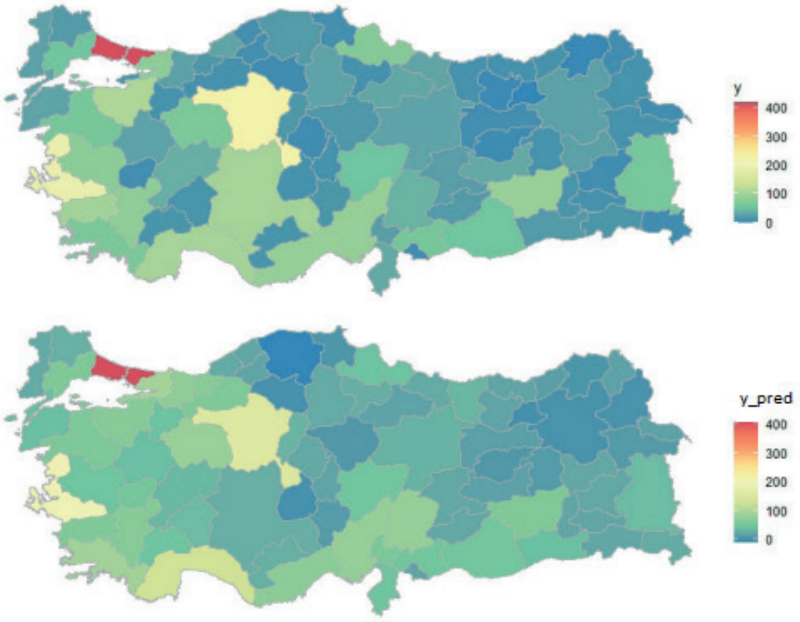

Figure 4. Spatial distribution of suicide numbers and estimates

Figure 4 shows the number of suicides in 2019 and the estimated values of the map. When the GWR model with the Bisquare kernel function is established, it is seen from the maps that it is a suitable model for estimating the number of suicides in the provinces, and it performs well. Also, Istanbul is the city with the most suicides.

4. CONCLUSION AND DISCUSSION

In this study, factors affecting suicide and spatial effects on suicide were analyzed and estimated with GWR models. GWR models were applied with different kernel functions, and the best GWR model was found with the bisquare kernel function. Factors affecting suicide numbers were found to be the human development index, the proportion of internet users, and unemployment numbers. There was a negative relationship between the number of suicides and the human development index value in eastern Turkey and a positive relationship in the middle region. The human development index is a value that measures health, education, and income levels, and a low value is a high risk factor for suicide attempts (Harmancı, 2015). A negative correlation was found between the proportion of internet users and suicide. This relationship was highest in pronvinces of Edirne and Kırklareli. It can be interpreted that the number of suicides is higher in these provinces, where the number of internet users is low. The region where suicide numbers are least affected by internet usage rates is the eastern region of Turkey. The unemployment variable has a positive effect on suicide numbers across the country. Unemployed individuals are highly prone to suicide because they cannot meet their needs and feel inadequate (Tunalı, 2016). The provinces where unemployment has the greatest impact on suicide were located in western Turkey. 2019's suicide numbers and forecast values were mapped, and the results were found to be quite similar. Istanbul was the province with the highest number of suicides in the country. Briefly, the GWR model is suitable for estimating the number of suicides in the provinces. This study contributes to the literature in estimating the number of suicides for future studies.

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