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Could the agrochemical poisoning increase suicide attempts in Brazilian rural areas? an econometric approach using spatial analysis methods

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Abstract

The increase of suicide rates has become a serious global health issue. Although there is no clear explanation for this phenomenon, there has been an increasing interest in identifying risk factors related to its attempt, using biological, psychological, cultural, behavioral, economic and social variables. In rural areas, it is possible to see a pattern of high suicide rates in several countries around the world, which characterizes farmers as a high-risk group. Among the means used by the victims, the exogenous poisoning by agrochemicals stands out. In Brazil, more than half of exogenous agrochemical poisoning is supposed to be linked to suicide attempts. In this context, the present study aims to identify the determinants of the suicide attempt by agrochemical ingestion in Brazil, specifically in Paraná state. The hypothesis that guides the study is that the unsafe use of agrochemicals and its intensity can lead to more cases of suicide attempts. We use variables that capture social, economic and demographic in order to control the effects of use and misuse of agrochemicals. Also, the empirical models test if rural suicide is spatially correlated. Using the Poisson Regression, Negative Binomial Regression and Spatial Filtering methods, the results corroborate that municipalities with high agrochemical poisoning, i.e., misuse that input, have a higher number of suicide attempts by agrochemical ingestion. The analysis also evidences the existence of a low spatial correlation rural suicide attempts, and, when filtering such correlation, it is possible to reach estimators that are free from spatial bias. In general, despite its limitations, this study contributes to identify some determinants of rural suicide in Paraná state, Brazil, providing subsidies for public policies able to mitigate such phenomenon.

***Key words**: Intoxication; Pesticides; Public Health*

I. Introduction

Suicide is considered a global public health issue. Approximately 800,000 people die each year for this reason, which is one of the leading causes of death worldwide (World Health Organization - WHO, 2018). In Brazil, according to statistics from the Mortality Information System (SIM), between 2007 and 2016, more than 106,000 suicide deaths were recorded and 5.8 suicides per 100 thousand inhabitants (Ministry of Health, 2018).

The interest in identifying risk factors related to suicide has grown in recent decades, including biological, psychological, cultural, behavioral, economic and social aspects. Although there is no clear explanation for its causes, human factors such as psychiatric disorders, sexual abuse, alcoholism, drug addiction, lack of social and family support, family history related to suicide as well as socioeconomic and demographic factors such as poverty, unemployment, unskilled labor and low levels of education have been all considered as important drivers for an individual attempts suicide (Botega, 2014; World Health Organization - WHO, 2018, 2014).

From a socioeconomic perspective, Altinanahtar and Halicioglu (2009), Andrés and Halicioglu (2010), Andrés et al. (2011) and Okada and Samreth (2013) sought to identify the determinants of suicide in different locations and different time periods. Overall, the authors found that suicide is associated with per capita income, divorce and fertility rates, alcohol consumption, level of urbanization, and unemployment conditions.

Gonçalves et al. (2011) evaluated the determinants of suicide in Brazilian microregions, while Bezerra Filho et al. (2012) and Meneghel et al. (2004) analyzed the association between suicide and socioeconomic, demographic and physiological factors in the states of Rio de Janeiro and Rio Grande do Sul, respectively. Loureiro et al. (2010) and Shikida et al. (2007) investigated the economic determinants of the suicide rate in Brazilian states. Schnitman et al. (2010), on the other hand, analyzed the association between socioeconomic indicators and suicide rate in Brazilian capitals. In general, these authors found significant relationship between socioeconomic variables and suicide, highlighting the existence of specificities in the occurrence of suicides in rural areas.

Lopes and Albuquerque (2018) argue that in addition to environmental impacts, agrochemicals misuse can cause harm to human health. According to Arnautovska et al. (2014) and Alston (2012), farmers are the ones of the high-risk groups with high suicide rates in many countries around the world. According to Hirsch (2006), Hirsch and Cukrowicz (2014) and Zaheer et al. (2011) there are specific local and individual characteristics that increase the risk of suicide in rural areas. However, Fiske et al. (2005) and Page et al. (2007) argues that the causality is not well well-known, encouraging more studies to investigate the relationship between the rural context and suicide rates.

The exogenous intoxication stands out as the major way of suicide attempt (Santos et al., 2013). Approximately 55% of the notifications registered from 2007 to 2013 in the Notification of Aggravation Information System (SINAN) of suicide attempts were related to agrochemical ingestion, being concentrated in the states of São Paulo, Minas Gerais, Paraná and Pernambuco (Ministry of Health, 2016). However, when data on deaths resulting from agrochemical poisoning are analyzed, the state of Paraná in the South Region was the one with the highest number of notifications.

Recent studies show a relationship between agrochemical exposure, depression and suicide, pointing out that they may be due to mental health syndromes, mental disorders such as anxiety and depression (London et al., 2012), suggesting that the high exposure experienced by the rural population may result in psychiatric disorders and suicidal behavior (Freire and Koifman, 2013; Krawczyk et al., 2014). The agrochemicals effects on health are diverse and not well understood, however evidence on substances such as acetylcholinesterase inhibition and serotonin deficiency, which directly affect human behavior, are potential drivers that are leading to disorders that may or not culminate in suicidal behavior (Kamanyire and Karalliedde, 2004; London et al., 2005; Slotkin et al., 2008).

Soares and Porto (2009) estimated the social cost of acute agrochemical poisoning for the state of Paraná and showed that such costs can 64% of all benefits provided by agrochemicals use. In this sense, if there is a relationship between misuse and suicide, the social costs of the pesticide use would be underestimated and thus requiring the inclusion of suicide rates in the estimations of negative externalities.

The understanding of suicide causes and the spatial distribution of suicide attempts is crucial for the proper direction of prevention policies (Chang et al., 2010; Cheung et al., 2012; Helbich et al., 2013). However, studies about rural suicide in Brazil are still incipient.

Therefore, the objective of this paper is to identify the determinants of suicide attempts in rural areas of Paraná state, Brazil. Since databases about rural suicide are scarce, we consider the suicide attempt by agrochemical ingestion as a proxy to rural suicide. The hypothesis of this proxy is that there are no significant suicide attempts of using agrochemicals in urban areas. In this context, two more hypotheses guide the present study. The first is that the misuse of agrochemicals may increase suicide attempts, since it can result in chronic and acute intoxication, leading to psychiatric problems (Freire and Koifman, 2013; Krawczyk et al., 2014). The second hypothesis is that rural suicide is spatially correlated, that is, municipalities with high suicide rates tend to cluster in space due to possible shared characteristics due to proximity. In this sense, this paper aims also to identify possible hot spots of suicide attempts using the spatial econometrics instruments.

The rest of this paper is organized as follows: the next section presents the methodological approach and the data used; the results are in Section 3, while in Section 4 we present our conclusions and final remarks.

II. Methodology

Database

The state of Paraná, located in the southern region, has 399 municipalities and is the sixth most populous state in Brazil, with a demographic density of 52.40 inhabitants per km². According to IBGE (2019), the population surveyed by the 2010 Population Census was approximately 10.5 million people, of which 15% lived in the rural areas.

Since 2013, the state has the third largest Gross Production Value (GDP) in Brazil. In 2017, for example, the agricultural GDP represented approximately 9% of state GDP (Parana Institute for Social Economic Development - IPARDES, 2019). Soybean, corn and sugarcane crops accounted for approximately 74.21% of agricultural GDP. These crops also stand out for being intensive in the use of agrochemicals (Campanhola and Bettiol, 2003). Paraná is the second state with the largest number of farms that buys agrochemicals and is the third state with the highest amount spent with that input, using more than 100 thousand tons in 2015 (Brazilian Institute of Geography and Statistics - IBGE, 2006; Secretary of Health of the state of Paraná - SESA / PR, 2017).

The selection of Paraná state for this study was not random. Paraná has the one of highest numbers of suicide attempts and deaths by suicide. According to the Surveillance and Health Care Plan of Populations Exposed to Agrochemicals (Secretary of Health of the state of Paraná - SESA / PR, 2017), the average annual rate of death by suicides in the state, from 2007 to 2015, was 5.9 per 100 thousand inhabitants, with 59% of the municipalities presenting values above the state average. Regarding suicide attempts, the state average was 2.2 per 10,000 inhabitants between 2011 and 2016. In Figure 1, there is the spatial distribution of suicide attempts in Paraná state from 2007 to 2010.

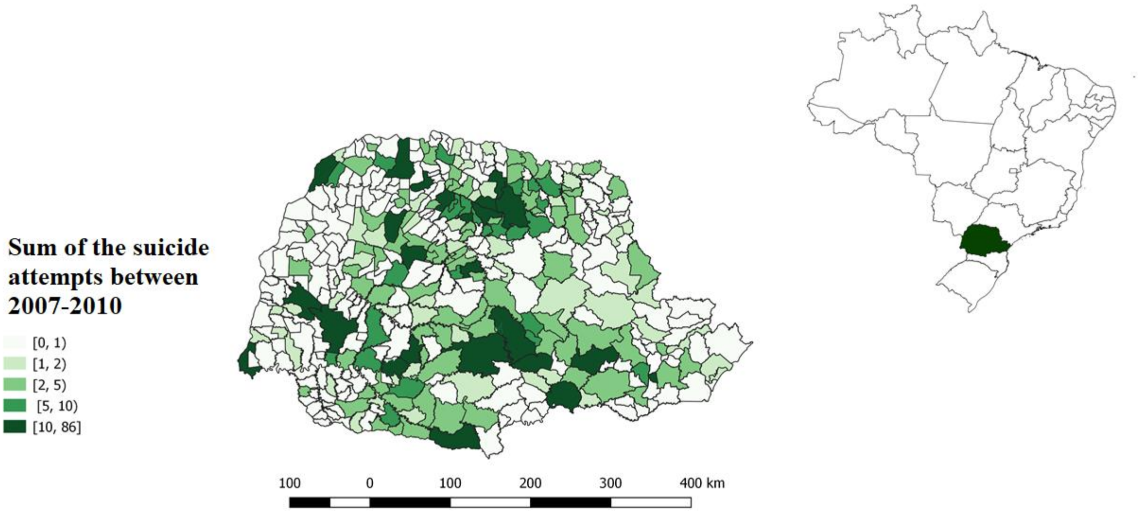

Figure 1: Spatial distribution of suicide attempts in Paraná state from 2007 to 2010.
Source: The authors based on information from SINAN (Ministry of Health, 2019).

Empirical Model

It is common that the empirical analysis of some phenomena does not fit the classical framework of ordinary least squares (Cameron and Trivedi, 2005). This is the case with problems that have counting characteristics. In areas such as ecology, health and demography, counting phenomena are common, as often the object of study is usually underrepresented in the dependent variable with nonnegative and integer values, which are concentrated in low values, have right asymmetry and are intrinsically heteroscedastic (Cameron and Trivedi, 2005).

One of the distributions capable of accommodating counting information is Poisson, but most observable phenomena do not fit this distribution, since it assumes that the mean and variance are identical, so that:

$$E[Y_i|x_i] = V[Y_i|x_i] = \mu_i \,, \qquad i \;=\; 1, 2, \cdots, n \tag{1}$$

where μ_i is equivalent to the intensity of occurrence or the rate of occurrence of the phenomenon in question; and i represents the observation unit, that is, the municipalities of the Paraná state.

To perform the parameterization of a Poisson model, it is assumed that the expected value of Y_i (occurrence rate or expected average) is conditioned to a set of regressors such that:

$$E[Y_i|x_i] = V[Y_i|x_i] = \mu_i = \exp(x_i\beta) \tag{2}$$

where x_i is a vector representing a set of explanatory variables; β is a vector representing the unknown parameters to be estimated.

Since the equidispersion condition (equal mean and variance) is poorly observed and, if untreated, leads to inflated standard deviations, consequently, hypothesis testing for likelihood estimates are inaccurate (Winkelmann, 2008). Thus, it is necessary to model the variance overdispersion, so that:

$$E[Y_i|x_i] = \mu_i \tag{3}$$

$$V[Y_i|x_i] = \mu_i + \alpha\mu_i^2 \tag{4}$$

Thus, it is possible to test the hypothesis of equidispersion, considering H_0: $\alpha = 0$ over H_1: $\alpha \neq 0$. If overdispersion exists, variance can be defined as a quadratic function of the mean (equation 4), resulting in a negative binomial distribution model.

Such models can be estimated via Maximum Likelihood and correct the problem of overdispersion, making standard deviations less inflated and hypothesis tests less permissive (Winkelmann, 2008).

According to Winkelmann (2008), when interpreting the coefficients of a counting model, one is often interested in knowing the impact on the response variable given a unitary increase in an independent variable. Relative change is given by:

$$\frac{\partial E[Y_i|x_i]}{\partial x} = \exp(\beta) - 1 \tag{5}$$

that is, the impact on the dependent variable of a unit variation of x is the exponential of the estimated coefficient minus 1.

Spatial Filter [1]

According to Anselin (2013), the core of spatial dependence assumes that observations are not independent of each other and that the covariance is due to spatial relationship. Also, if the data is arranged in space, the randomness of the sample is often not guaranteed, leading to error terms that are dependent on each other among the variables. Thus, by inserting the concept of spatiality into regression, two basic principles of the classical regression model cannot be verified: the independence of observations and error terms, since they share characteristics that are common to the space they occupy. Therefore, in order to know the real process that generates a phenomenon correlated in space, it is necessary to define the neighboring relationship between the sample observations. Anselin (2013) states that a sensitive point in

[1] In the regression analysis, we use the ME command in R-program, from ‘spdep’ package (Bivand et al., 2011).

spatial modeling is the definition of neighborhood matrix that best represents the spatial phenomenon. Moreover, one way of constructing the neighborhood matrix is to define neighborhood by the concept of contiguity, that is, it is assumed that neighboring regions interact spatially with each other. Thus, the value 1 is assigned to those contiguous locations and 0 otherwise. There are some types of contiguity, all inspired by the movements of chess's game. For example, in "queen" contiguity, vertices are considered contiguous. In the "tower" matrix, the vertices are neglected (Arbia, 2014).

Among the spatial correlation metrics, the most common is Moran's I statistic, an autocorrelation test based on the relationship between cross-product self-covariance and variance. Following Anselin (2013), the value of this index is expressed in the function:

$$I = \frac{z'W_z}{z'z} \tag{8}$$

where:
z are the values of the variable in question (error terms) and W_z represents the standard values of the variable of interest by the spatial weighting matrix.

Thus, the null hypothesis of spatial randomness is tested. To define the best spatial weighting matrix, the one that obtained the largest Moran's I of the residuals of a regression is chosen, that is, the one that best captures the spatial dependence between observations. In addition to defining the best matrix, the test result reflects the existence and degree of spatial dependence (Anselin, 2013).

Given the characteristic of the phenomenon studied in the present study is counting information, the classical regression methods do not apply, being necessary in turn the estimation of generalized linear models (REF). Such models have not received much attention from the literature in recent years, thus there is a lacking a robust methodological pattern to represent a process that generates a spatially correlated phenomenon and that is a counting data (Griffith and Peres-Neto, 2006). Given the difficulty of modeling such a process, the spatial filtering approach was chosen.

The spatial filtering procedure proposed by Tiefelsdorf and Griffith (2007) is an attempt to extract "synthetic" proxies from a spatial weighting matrix, whose function is to define a proximity relationship between observations, giving greater weight to those bordering locations, through the principle that the closer the proximity of different localities, the greater their shared relationship.

These proxies, which are eigenvectors of the spatial autocorrelation matrix, are included in the model as nonparametric variables (Moran eigenvector), in order to isolate the stochastic component of spatial dependence and allow observations to be treated as independent from each other (Griffith and Chun, 2014). Although the process that generates spatial dependence is not identified, it is guaranteed that the coefficients are not biased as a result of it.

The counting regression model that takes into account the spatial filtering to be estimated can be written as:

$$SUI_i = \sum_{k=1}^{3} \beta_k PES_{k,i} + \sum_{j=1}^{10} \beta_j SEV_{j,i} + \sum_{n=1}^{4} \beta_n SFR_{n,i} + \beta_f SF_i \tag{9}$$

where:

SUI_i represents the sum of suicide cases for municipalities i, $\beta_k, \beta_j, \beta_n, \beta_f$ are the coefficients to be estimated;

$PES_{k,i}$ represents the group of *k* variables for agrochemical use;

$SEV_{j,i}$ comprises *j* variables referring to the socioeconomic controls of municipalities *I;*

$SFR_{n,i}$ represents the *n* regressors that capture aspects of social fragmentation;

SF_i is the eigenvector chosen as the spatial filter (or, that one with the highest Moran I statistics).

For the estimated model, only one eigenvector (EV10) was defined according to the criterion proposed by Tiefelsdorf and Griffith (2007).

Model Variables

Three groups of variables to use in our empirical model were defined. The first group refers to the use and misuse of agrochemicals. It is expected to verify the role and the intensity of agrochemical use and agrochemical poisoning in the incidence of suicide attempts. The second group includes demographic density, health and sanitation expenses, average income in the rural areas, age and human capital, racial and gender aspects. Finally, we include also to capture social fragmentation, such as the proportion of divorced individuals, fertility and migration patterns. The variables along with their respective descriptions and sources are described in Table 1.

Since databases do not segment suicide notifications by the areas of occurrence (urban or rural), the choice of the “suicide attempts by agrochemical ingestion” is adopted as the dependent variable. This proxy leads to an assumption that suicide is attempted via agrochemical ingestion and is not significant in the urban areas.

Table 1: Model variables

Variables	Mean	S.D.	Description	Database
suicide	3.0579	6.9855	Sum of cases of suicide attempts with pesticides between 2007 to 2010.	Ministry of Health (2019)
Organic	1.9639	3.1623	% of rural establishments using organic practices.	
Pesticide	51.6305	23.6852	% of rural establishments that use pesticides.	IBGE (2006)
Intoxicated	0.4994	0.5906	% of rural units reporting intoxication on their properties.	
expenditure	4,629,394	12,592,585	Health and sanitation expenses (For municipalities without information in 2006, the average of 2005 and 2007 was reported).	IPEA (2019)
MHDI	0.7015	0.0381	Municipal Human Development Index.	ADHB (2019)
Income	581,1816	197.7419	Average income in rural areas by municipality.	
Pop. Density	0.1480	0.4657	Rural population divided by rural area	
Blacks	2.8300	2.4000	% of black individuals in relation to the total rural population of the municipality.	
>25	1.9601	1.2433	% of individuals less than 25 years old by the total rural population by municipality.	
<55	26.0000	4.7500	% of individuals over 55 by total rural population by municipality.	IBGE (2010)
Illiterate	22.1397	14.9858	% of rural residents who have no or almost no education by total rural population per municipality.	
High School	3.8775	2.3745	% of rural residents with average education by total rural population by municipality.	
College	0.6029	0.4699	% of rural residents with higher education by total rural population by municipality.	
Divorced	2.4100	1.0900	% of resident rural population that is divorced.	
Migrants	4.9300	3.9800	% of resident rural population living in the municipality for a maximum of 10 years.	
Men/Woman	1.1065	0.0528	Proportion of male population residing in capo in relation to female.	IBGE (2010)
Fertility	1.9421	0.2494	Fertility Rate. It is given by the proportion of children born alive in relation to the female population living in the countryside.	

Source: The authors.

The estimation procedure followed five steps: (i) First, we estimate the Poisson model and, (ii) we test the hypothesis of equidispersion, which consists in verifying if the parameter α of equation (4) is equal to zero. If the equidispersion hypothesis is rejected, so the Negative Binomial model is more appropriated; (iii) Then, we estimate the Negative Binomial model and, after the estimation, (iv) we test the hypothesis of spatial randomness of the residuals. Finally, since the test rejected spatial randomness, (v) we estimate the Negative Binomial model with Spatial Filtering. Figure 2 presents an outline of all methodological procedures adopted.

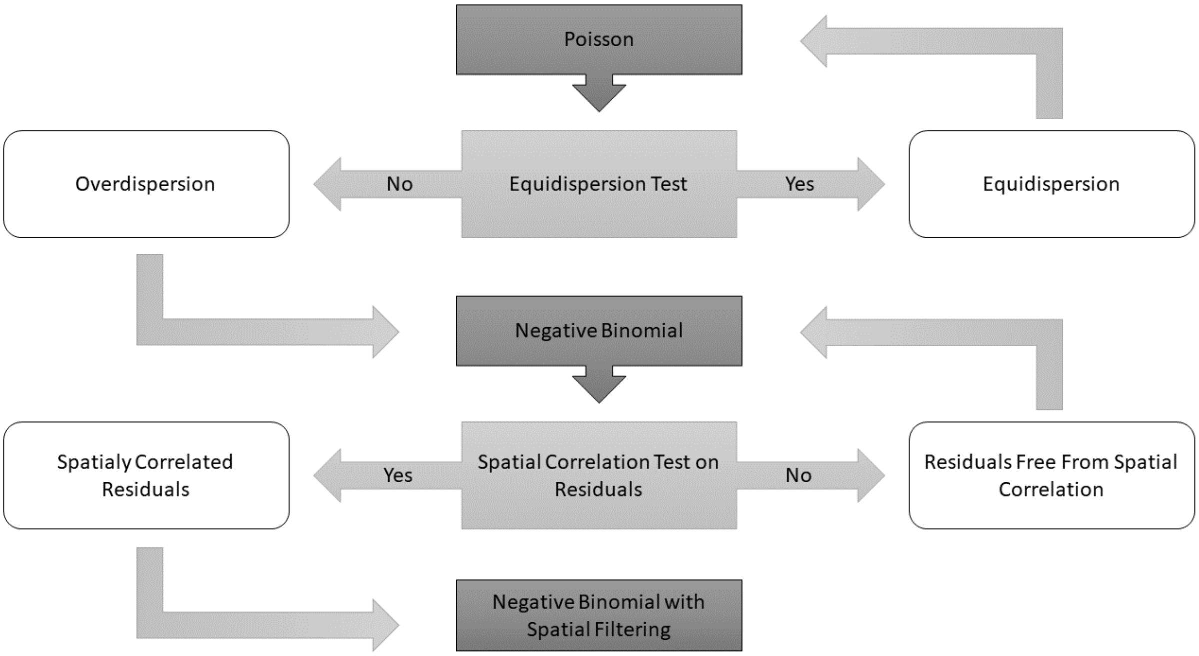

Figure 2: Flowchart of the estimation procedure.
Source: The authors.

III. Results and Discussion

After the Poisson model estimation, the first step is to check if the equidispersion hypothesis is not reject. The observed average number of suicides for the 2007-2010 period of the municipalities of Paraná was 3.07 suicide attempts, while the variance is about 16 times higher, equivalent to 48.79. A likelihood ratio overdispersion test is checked, and the equidispersion hypothesis is rejected. Therefore, a negative binomial model is chosen for the analysis.

It is worth noting that Moran's I spatial correlation statistics for regression residues is considering a “queen” neighborhood[2] indicating that both Poisson and Negative Binomial models present spatially correlated residues about 0.1191 and 0.1063, respectively. So, the spatial filtering variable is required to capture the spatial dependence. The presence of spatial correlation in suicide attempt cases has been observed in the literature by Helbich, et al. (2013). In this paper, the authors also opted for the spatial filtering procedure to ensure the statistical consistency of the estimators. By including the eigenvector chosen as a nonparametric regressor (EV10) in the model, the spatial dependence is reduced to 0.06 and, no longer a significant at the 1% significance level is observed. This result is a strong evidence that spatial dependence on residues is controlled by the procedure accordingly.

Table 2 presents the results of the estimated models. In general, the models present similar results. However, among them, the Negative Binomial with Spatial Filtering (SF) is the most statistically robust model and also has the lower Akaike criteria.

Table 2: Results of the estimated models.

Variables	**Poisson**	**Negative Binomial**	**Negative Binomial (SF)**
Intercept	0.7421***	0.7310***	0.70614***
	(0.0380)	(0.0632)	(0.0624)
Organic	-0.1886***	-0.2282***	-0.2739***
	(0.0469)	(0.0865)	(0.0857)
Pesticide	0.1469***	0.1420*	0.1275*
	(0.0400)	(0.0777)	(0.0770)
Intoxicated	0.1616**	0.1510**	0.1354**
	(0.0307)	(0.0690)	(0.0679)
Expenditures	0.1809***	0.4032***	0.3790***
	(0.0115)	(0.0589)	(0.0572)
MHDI	0.4522***	0.2235*	0.2697**
	(0.0552)	(0.1193)	(0.1175)
Income	-0.1666***	-0.2091***	-0.1938**
	(0.0404)	(0.0812)	(0.0796)
Pop. Density	-0.0248	-0.0518	-0.0544
	(0.0598)	(0.0933)	(0.0893)
Blacks	-0.1895***	-0.1120*	-0.1754***
	(0.0341)	(0.0653)	(0.0662)
<25	0.1811***	0.1922***	0.1821**
	(0.0340)	(0.0739)	(0.0727)
>55	-0.1671***	-0.1396**	-0.1321*
	(0.0406)	(0.0795)	(0.0785)
Illiterate	0.3551***	0.1248	0.2098

[2] A matrix that presented the largest spatial correlation for the regression error terms.

Variables	Poisson	Negative Binomial	Negative Binomial (SF)
	(0.0811)	(0.1645)	(0.1629)
High School	-0.5868***	-0.3925***	-0.3907***
	(0.0714)	(0.1297)	(0.1276)
College	-0.1048*	-0.0534	-0.1050
	(0.0597)	(0.1045)	(0.1036)
Divorced	-0.0044	-0.0038	-0.0096
	(0.0325)	(0.0688)	(0.0679)
Migrants	-0.1639***	-0.2102***	-0.2305**
	(0.0411)	(0.0751)	(0.0772)
Men/Woman	-0.0250	0.0122	0.0044
	(0.0299)	(0.0675)	(0.0660)
fertility	-0.1112***	-0.1065	-0.1302*
	(0.0351)	(0.0743)	(0.0733)
EV10			4.8571***
			(1.2788)
AIC	2151.6	1606.3	1594.4
Moran's I	0.1191***	0.1063***	0.0629**

Source: Model results.
*** significant at 1%, ** significant at 5%, * significant at 10%

One of the main paradigms about agrochemical use concerns the effects of its unsafe use on the physical and mental health of farm workers (Meyer et al., 2010). The statistically significant effects of agrochemical use and agrochemical poisoning (Table 2) suggest that there may be a relationship between its unsafe use and the number of suicide attempts. The suicide by pesticide ingestion phenomena shows an epidemiology pattern all over the world, especially in developing countries (London et al., 2005). Therefore, to understand the relationship between suicide rates and pesticide exposure seems to be equally relevant.

The first way that the pesticide exposure could affect the suicide attempt rates is by the method availability, that means, which method the individual tries to attempt against their own life intentionally. Since trying to commit suicide might be an impulsive act, the availability of highly toxic and lethal methods such as pesticide might increase the suicide attempts. This fact could explain the differences of suicide patterns between developed and developing countries. In industrialized nations, the availability of pesticide and the number of exposed people is less than in developing countries. The impulsivity is "pretty much the same", i.e., the difference lays in the availability of the different methods to cause self-harm (Gunnell and Eddleston, 2003).

Recently, new evidence is trying to identify some relationship between acute and chronical intoxications, caused by over-exposure of pesticides, in people's behavior, associated it with affective disorders such as depression, impulsivity and anxiety (Beseler and Stallones, 2008; Ross et al, 2010). Effects such serotonin suppress could directly affect human behavior, potentially leading to suicidal tendencies.

However, a systematic review conducted by Freire and Koifman (2013) points out that studies relating mental disorders and suicidal behavior linked to high agrochemical exposure are still limited and presents different methodological approaches, being difficult to establish a clear causal relationship. To overcome this issue, London, et al (2005) points out the necessity of rigorous epidemiological studies with stronger study designs, capable to distinguish between short and long term exposure.

Krawczyk et al. (2014) also found that the risk of suicide is linked to exposure to agrochemicals by studying tobacco cultivation areas with intensive agrochemical use in Brazil. Meyer et al. (2010) found that the risk of death from suicide is substantially higher to rural workers particularly the ones who are living in areas with high expenditure of agrochemical by comparing the mortality rates of populations living in agrochemical-intensive areas with some reference populations.

Overexposure to agrochemicals represents only one aspect of suicide attempts. Economic, social, cultural and social fragmentation aspects are fundamental to explain the phenomenon (Faria et al., 2006; Gonçalves et al., 2011).

Three variables are included in the model to capture the effects of life quality, income and health system by municipality. Both the MHDI variable and health expenditures had a statistically significant positive effect. This result seems counterintuitive, since the higher the health expenses (Milner et al., 2012; Minoiu and Andrés, 2008) and the better the quality of life of the municipality (Rehkopf and Buka, 2006), the lower should be the cases of suicide attempts. However, it is hypothesized that such variables capture an intrinsic sample selection bias of reporting data, in which municipalities with better structure tend to have a greater ability to identify the occurrence of these cases.

According to Rehkopf and Buka (2006), there are divergent results in the literature regarding the association between socioeconomic characteristics and suicide rates, with studies finding a direct relationship, while others find an inverse or no association. Our estimates also indicate a negative effect of income in rural area over suicide attempt, that is, the higher the income, the lower the suicide occurrences, which corroborates the hypothesis that the higher the income, the higher the expected utility and the lower the incentives for suicide (Altinanahtar and Halicioglu, 2009; Andrés and Halicioglu 2010).

The population density is no statistically significant effect at the 5% level of significance, although isolation is a risk factor according to the literature (Gonçalves et al., 2011; Hirsch and Cukrowicz, 2014; Otsu et al., 2004; Santos et al., 2013). Other determinants such as the high degree of farm associations among farmers may mitigate the effect of human isolation.

About the effect of the population's age group on suicide attempts, the younger the rural population, the greater the number of suicide attempts; just as the larger the rural population over 55 is, the lower the suicide attempts are reported. Overall, the literature relates the elderly population to greater exposure to the risk of committing suicide. In other hand, they point out that young people and adults are likely more vulnerable to family problems such as parental relationship problems, separation, divorce, violence and all kinds of harassment (Chen et al., 2012; Hirsch, 2006; Hirsch and Cukrowicz, 2014).

One of the hypotheses in the literature of suicide determinants is also that the higher degree of social integration, the lower the suicide attempt is expected. In this sense, social structures that define the social *status quo* as family, religion and work are critical to increasing individual support and social ties and, consequently, mitigating suicide rates (Evans et al., 2004). Societies called “fragmented”[3] tend, by hypothesis, are most likely to high the risks of developing mental illnesses, increasing the cases of suicide attempts

The fertility rate, given by the ratio between number of live births and the female population in the rural areas, reduces the number of suicides, which indicates parenting to be a potential factor for strengthening family ties. In other hand, the proportion of individuals who migrated at most 10 years ago also reduces the number of suicides. It is expected that the higher the proportion of individuals not born in the municipality, the lower is the social integration. It is noteworthy that in our database the origin of the migrant is not known, which may have affected this result, since migration between similar and not so far municipalities should not substantially affect the degree of fragmentation for a given locality.

Finally, even dealing with the global spatial dependence of the residue via spatial filtering, some local autocorrelation patterns may be being hidden (Anselin, 1995). Clustering the analysis of residues due to the local Moran I index; it allows the identification of clusters of municipalities with related residues in space. That is, even controlling for spatial correlations with spatial filtering, there is still a component in the residue that is common to clusters and

[3] Congdon (1996), through the hypotheses of Durkheim et al. (1996), built a social fragmentation index to check its causality with suicide rates.

affects suicide attempts. The clusters defined by the local Moran's I are presented in Figure 3, highlighting those municipalities which have high values of the local Moran's I and whose neighboring municipalities also have high spatial dependence on the residues. The suicide attempt hotspots identification is of fundamental for the direction and improvement of policies to combat and prevent suicide.

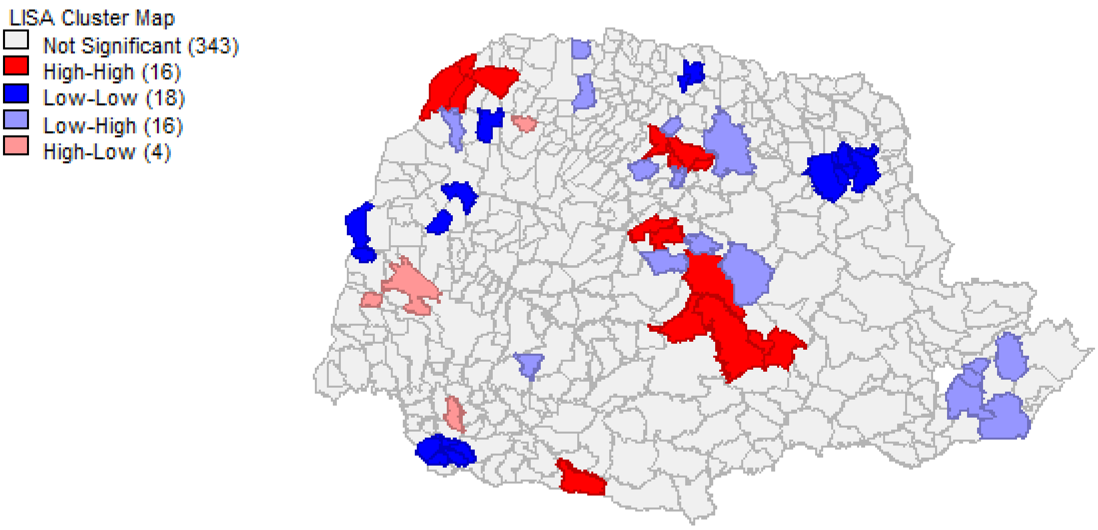

Figure 3: Local spatial correlation of persistent suicide attempts after spatial filtering procedures.
Source: Model results

IV. Concluding Remarks

Despite of all robust relationship found by our empirical models, the dependent variable only refers to suicide attempts by agrochemicals ingestion, which reduces the whole number of suicide attempts in rural area to that proxy. In addition, some regressors that are fundamental to understanding the phenomenon were not included due to the lack of information at the municipal level, such as alcohol and drug abuse, mental disorders, among others. Even so, the empirical model could capture some determinant of suicide attempts in rural areas and provide helpful information to mitigate that issue.

The results also indicate that suicide attempts by agrochemical ingestion is correlated in space, that is, the municipalities in Parana state share characteristics common to space, not controlled with the available database, and these characteristics affect the incidence of suicide attempts. As it is a counting model, the methodological approach is limited to filtering the spatial dependence, thus not defining the actual process that generates the phenomenon. In any case, our proposed model was able to filter the spatial dependence and eliminate the spatial bias from the estimators. To track the geographical distribution of suicide attempts in rural areas is a valuable information for the planning and prevention policies.

Some limitations of this study include that the dependent variable has a sample selection bias, since larger municipalities with better structure tend to concentrate the reported cases. In addition, the public health agents could improve the database including both information about personal attributes and chemical agent used in suicide attempt. Despite the limitations, the analysis suggests a causal relationship between agrochemical misuse and suicidal attempts. However, we strongly encourage new research to evaluate carefully how agrochemical poisoning could lead to a suicide attempt and, so, consolidate causal inferences. Thus, our results contribute to the literature by suggesting that the social costs of agrochemical poisoning may be underestimated, and that suicide is a potential negative externality linked to its misuse. The perception of agrochemical misuse and its relationship with the mental health status of the rural population is extremely important, since the burden of social cost incurred in such poisonings is mainly neglected by the rural population.

In addition, we also hope that our results can support the design, planning and implementation of more effective public policies and also intervention strategies to mitigate rural suicide worldwide, particularly in the context of the Sustainable Development Goals (SDGs) established by the United Nations in 2015.

REFERENCES

Abbas, M.J., Alhemiary, N., Razaq, E.A., Naosh, S., Appleby, L., 2018. The Iraqi national study of suicide: Report on suicide data in Iraq in 2015 and 2016. J. Affect. Disord. 229, 56–62. https://doi.org/10.1016/J.JAD.2017.12.037

Alston, M., 2012. Rural male suicide in Australia. Soc. Sci. Med. 74, 515–522. https://doi.org/10.1016/J.SOCSCIMED.2010.04.036

Altinanahtar, A., Halicioglu, F., 2009. A dynamic econometric model of suicides in Turkey. J. Socio. Econ. 38, 903–907. https://doi.org/10.1016/j.socec.2009.05.008

Andrés, A.R., Halicioglu, F., 2010. Determinants of suicides in Denmark: Evidence from time series data. Health Policy (New. York). 98, 263–269. https://doi.org/10.1016/j.healthpol.2010.06.023

Andrés, A.R., Halicioglu, F., Yamamura, E., 2011. Socio-economic determinants of suicide in Japan. J. Socio. Econ. 40, 723–731. https://doi.org/10.1016/j.socec.2011.08.002

Anselin, L., 2013. Spatial econometrics: methods and models. Springer Science & Business

Media.

Anselin, L., 1995. Local indicators of spatial association—LISA. Geogr. Anal. 27, 93–115.

Arbia, G., 2014. A primer for spatial econometrics: with applications in R. Springer.

Arnautovska, U., McPhedran, S., De Leo, D., 2014. A regional approach to understanding farmer suicide rates in Queensland. Soc. Psychiatry Psychiatr. Epidemiol. 49, 593–599. https://doi.org/10.1007/s00127-013-0777-9

Atlas do Desenvolvimento Humano no Brasil - ADHB, 2019. Índice de Desenvolvimento Humano Municipal [WWW Document].

Beseler, C. L., & Stallones, L. (2008). A cohort study of pesticide poisoning and depression in Colorado farm residents. *Annals of Epidemiology*, *18*(10), 768–774.

Bezerra Filho, J.G., Werneck, G.L., Almeida, R.L.F. de, Oliveira, M.I.V. de, Magalhães, F.B., 2012. Estudo ecológico sobre os possíveis determinantes socioeconômicos, demográficos e fisiográficos do suicídio no Estado do Rio de Janeiro, Brasil, 1998-2002. Cad. Saude Publica 28, 833–844. https://doi.org/10.1590/S0102-311X2012000500003

Bivand, R., Anselin, L., Berke, O., Bernat, A., Carvalho, M., Chun, Y., Dormann, C.F., Dray, S., Halbersma, R., Lewin-Koh, N., 2011. spdep: Spatial dependence: weighting schemes, statistics and models.

Botega, N.J., 2014. Comportamento suicida: epidemiologia. Psicol. USP 25, 231–236. https://doi.org/10.1590/0103-6564D20140004

Cameron, A.C., Trivedi, P.K., 2005. Microeconometrics: methods and applications. Cambridge university press.

Campanhola, C., Bettiol, W., 2003. Panorama sobre o uso de agrotóxicos no Brasil., in: Métodos Alternativos de Controle Fitossanitário. Embrapa Meio Ambiente, Jaguariúna, SP, pp. 1–40.

Chang, S.-S., Gunnell, D., Wheeler, B.W., Yip, P., Sterne, J.A.C., 2010. The evolution of the epidemic of charcoal-burning suicide in Taiwan: a spatial and temporal analysis. PLoS Med. 7, e1000212.

Chen, J., Choi, Y.J., Mori, K., Sawada, Y., Sugano, S., 2012. SOCIO-ECONOMIC STUDIES ON SUICIDE: A SURVEY. J. Econ. Surv. 26, 271–306. https://doi.org/10.1111/j.1467-6419.2010.00645.x

Chen, K.C., Chivakul, M., 2008. What drives household borrowing and credit constraints? Evidence from Bosnia and Herzegovina. International Monetary Fund.

Cheung, Y.T.D., Spittal, M.J., Pirkis, J., Yip, P.S.F., 2012. Spatial analysis of suicide mortality in Australia: Investigation of metropolitan-rural-remote differentials of suicide risk across states/territories. Soc. Sci. Med. 75, 1460–1468. https://doi.org/10.1016/j.socscimed.2012.04.008

Congdon, P., 1996. Suicide and parasuicide in London: a small-area study. Urban Stud. 33, 137–158.

Durkheim, E., Spaulding, J.A., Simpson, G., 1996. Suicide: A study on sociology.

Evans, J., Middleton, N., Gunnell, D., 2004. Social fragmentation, severe mental illness and suicide. Soc. Psychiatry Psychiatr. Epidemiol. 39, 165–170. https://doi.org/10.1007/s00127-004-0733-9

Faria, N.M.X., Victora, C.G., Meneghel, S.N., Carvalho, L.A. de, Falk, J.W., 2006. Suicide rates in the State of Rio Grande do Sul, Brazil: association with socioeconomic, cultural, and agricultural factors. Cad. Saude Publica 22, 2611–2621.

Fiske, A., Gatz, M., Hannell, E., 2005. Rural suicide rates and availability of health care providers. J. Community Psychol. 33, 537–543. https://doi.org/10.1002/JCOP.20069

Freire, C., Koifman, S., 2013. Pesticides, depression and suicide: A systematic review of the epidemiological evidence. Int. J. Hyg. Environ. Health 216, 445–460. https://doi.org/10.1016/j.ijheh.2012.12.003

Gao, J., Cheng, Q., Duan, J., Xu, Z., Bai, L., Zhang, Y., Zhang, H., Wang, S., Zhang, Z., Su, H., 2019. Ambient temperature, sunlight duration, and suicide: A systematic review and meta-analysis. Sci. Total Environ. 646, 1021–1029. https://doi.org/10.1016/j.scitotenv.2018.07.098

Gonçalves, L.R.C., Gonçalves, E., Oliveira Júnior, L.B. de, 2011. Determinantes espaciais e socioeconômicos do suicídio no Brasil: uma abordagem regional. Nov. Econ. 21, 281–316. https://doi.org/10.1590/S0103-63512011000200005

Gould, M.S., Fisher, P., Parides, M., Flory, M., Shaffer, D., 1996. Psychosocial Risk Factors of Child and Adolescent Completed Suicide. Arch. Gen. Psychiatry 53, 1155. https://doi.org/10.1001/archpsyc.1996.01830120095016

Griffith, D., Chun, Y., 2014. Spatial autocorrelation and spatial filtering. Handb. Reg. Sci. 1477–1507.

Griffith, D.A., Peres-Neto, P.R., 2006. Spatial modeling in ecology: the flexibility of eigenfunction spatial analyses. Ecology 87, 2603–2613.

Gunnell, D., & Eddleston, M. (2003). Suicide by intentional ingestion of pesticides: a continuing tragedy in developing countries. *International Journal of Epidemiology*, *32*(6), 902–909.

Hassanipour, S., Kazemi, H., Ghayour, A.-R., Kazemi-Najafabadi, A., Nikbakht, H.-A., Ghaem, H., 2018. Epidemiological trend of suicide in center of Iran from 2012 to 2016. Clin. Epidemiol. Glob. Heal. https://doi.org/10.1016/j.cegh.2018.12.009

Helbich, M., Blüml, V., Leitner, M., Kapusta, N.D., 2013. Does altitude moderate the impact of lithium on suicide? A spatial analysis of Austria. Geospat. Health 209–218.

Hirsch, J.K., 2006. A Review of the Literature on Rural Suicide. Crisis 27, 189–199. https://doi.org/10.1027/0227-5910.27.4.189

Hirsch, J.K., Cukrowicz, K.C., 2014. Suicide in rural areas: An updated review of the literature. J. Rural Ment. Heal. 38, 65–78. https://doi.org/10.1037/rmh0000018

Instituto Brasileiro de Geografia e Estatística - IBGE, 2019. Paraná [WWW Document]. Cidades@.

Instituto Brasileiro de Geografia e Estatística - IBGE, 2010. Censo demográfico 2010 [WWW Document].

Instituto Brasileiro de Geografia e Estatística - IBGE, 2006. Censo Agropecuário 2006: segunda apuração [WWW Document].

Instituto de Pesquisa Econômica Aplicada - IPEA, 2019. Ipeadata [WWW Document].

Instituto Paranaense de Desenvolvimento Econômico Social - IPARDES, 2019. Produto Interno Bruto - PIB [WWW Document]. Indicadores.

Kamanyire, R., Karalliedde, L., 2004. Organophosphate toxicity and occupational exposure. Occup. Med. (Chic. Ill). 54, 69–75.

Kposowa, A.J., 2001. Unemployment and suicide: a cohort analysis of social factors predicting suicide in the US National Longitudinal Mortality Study. Psychol. Med. 31, 127–138.

Krawczyk, N., Meyer, A., Fonseca, M., Lima, J., 2014. Suicide mortality among agricultural workers in a region with intensive tobacco farming and use of pesticides in Brazil. J. Occup. Environ. Med. 56, 993–1000. https://doi.org/10.1097/JOM.0000000000000214

London, L., Beseler, C., Bouchard, M.F., Bellinger, D.C., Colosio, C., Grandjean, P., Harari, R., Kootbodien, T., Kromhout, H., Little, F., 2012. Neurobehavioral and neurodevelopmental effects of pesticide exposures. Neurotoxicology 33, 887–896.

London, L., Flisher, A.J., Wesseling, C., Mergler, D., Kromhout, H., 2005. Suicide and exposure to organophosphate insecticides: cause or effect? Am. J. Ind. Med. 47, 308–321.

Lopes, C.V.A., Albuquerque, G.S.C. de, 2018. Agrotóxicos e seus impactos na saúde humana e ambiental: uma revisão sistemática. Saúde em Debate 42, 518–534. https://doi.org/10.1590/0103-1104201811714

Loureiro, P.R.A., de Mendonça, M.J.C., Sachsida, A., 2010. Os determinantes econômicos do suicídio: um estudo para o Brasil. Texto para Discussão.

Meneghel, S.N., Victora, C.G., Faria, N.M.X., Carvalho, L.A. de, Falk, J.W., 2004. Características epidemiológicas do suicídio no Rio Grande do Sul. Rev. Saude Publica 38, 804–810. https://doi.org/10.1590/S0034-89102004000600008

Meyer, A., Koifman, S., Koifman, R.J., Moreira, J.C., de Rezende Chrisman, J., Abreu-Villaca, Y., 2010. Mood disorders hospitalizations, suicide attempts, and suicide mortality among agricultural workers and residents in an area with intensive use of pesticides in Brazil. J. Toxicol. Environ. Heal. Part A 73, 866–877.

Milner, A., McClure, R., De Leo, D., 2012. Socio-economic determinants of suicide: an ecological analysis of 35 countries. Soc. Psychiatry Psychiatr. Epidemiol. 47, 19–27.

https://doi.org/10.1007/s00127-010-0316-x

Ministério da Saúde, 2019. Sistema de Informação de Agravos de Notificação em Saúde [WWW Document].

Ministério da Saúde, 2018. Sistema de Informações de Mortalidade [WWW Document]. Eventos Vitais.

Ministério da Saúde, 2016. Relatório Nacional de Vigilância em Saúde de Populações Expostas a Agrotóxicos.

Minoiu, C., Andrés, A.R., 2008. The effect of public spending on suicide: Evidence from U.S. state data. J. Socio. Econ. 37, 237–261. https://doi.org/10.1016/J.SOCEC.2006.09.001

Okada, K., Samreth, S., 2013. A study on the socio-economic determinants of suicide: Evidence from 13 European OECD countries. J. Socio. Econ. 45, 78–85. https://doi.org/10.1016/j.socec.2013.04.009

Otsu, A., Araki, S., Sakai, R., Yokoyama, K., Scott Voorhees, A., 2004. Effects of urbanization, economic development, and migration of workers on suicide mortality in Japan. Soc. Sci. Med. 58, 1137–1146. https://doi.org/10.1016/S0277-9536(03)00285-5

Page, A., Morrell, S., Taylor, R., Dudley, M., Carter, G., 2007. Further increases in rural suicide in young Australian adults: Secular trends, 1979–2003. Soc. Sci. Med. 65, 442–453. https://doi.org/10.1016/J.SOCSCIMED.2007.03.029

Rehkopf, D.H., Buka, S.L., 2006. The association between suicide and the socio-economic characteristics of geographical areas: a systematic review. Psychol. Med. 36, 145–157. https://doi.org/10.1017/S003329170500588X

Ross, S. J. M., Brewin, C. R., Curran, H. V., Furlong, C. E., Abraham-Smith, K. M., & Harrison, V. (2010). Neuropsychological and psychiatric functioning in sheep farmers exposed to low levels of organophosphate pesticides. *Neurotoxicology and Teratology, 32*(4), 452–459.

Santos, S.A., Legay, L.F., Lovisi, G.M., 2013. Substâncias tóxicas e tentativas e suicídios: considerações sobre acesso e medidas restritivas. Cad. Saúde Coletiva 21, 53–61. https://doi.org/10.1590/S1414-462X2013000100009

Schnitman, G., Kitaoka, E.G., Arouca, G.S. de S., Lira, A.L. da S., Nogueira, D., Duarte, M.B., 2010. Taxa de mortalidade por suicídio e indicadores socioeconômicos nas capitais brasileiras. Rev. Baiana Saúde Pública 34, 44–59.

Secretária da Saúde do estado do Paraná - SESA/PR, 2017. Plano de Vigilância e Atenção à Saúde de Populações Expostas aos Agrotóxicos do Estado do Paraná 2017 a 2019. Curitiba.

Shikida, C.D., Jr., A.F.A., Gazzi, R.A.V., 2007. Teoria econômica do suicídio: estudo empírico para o Brasil. Análise Econômica 25. https://doi.org/10.22456/2176-5456.10897

Slotkin, T.A., Ryde, I.T., Levin, E.D., Seidler, F.J., 2008. Developmental neurotoxicity of low dose diazinon exposure of neonatal rats: effects on serotonin systems in adolescence and adulthood. Brain Res. Bull. 75, 640–647.

Soares, W.L., de Souza Porto, M.F., 2009. Estimating the social cost of pesticide use: An assessment from acute poisoning in Brazil. Ecol. Econ. 68, 2721–2728.

Thapaliya, S., Sharma, P., Upadhyaya, K., 2018. Suicide and self harm in Nepal: A scoping review. Asian J. Psychiatr. 32, 20–26. https://doi.org/10.1016/j.ajp.2017.11.018

Tiefelsdorf, M., Griffith, D.A., 2007. Semiparametric filtering of spatial autocorrelation: the eigenvector approach. Environ. Plan. A 39, 1193–1221.

Winkelmann, R., 2008. Econometric analysis of count data. Springer Science & Business Media.

World Health Organization - WHO, 2018. National suicide prevention strategies: progress, examples and indicators. World Health Organization.

World Health Organization - WHO, 2014. Preventing suicide: a global imperative. World Health Organization.

Zaheer, J., Links, P.S., Law, S., Shera, W., Hodges, B., Tsang, A.K.T., Huang, X., Liu, P., 2011. Developing a Matrix Model of Rural Suicide Prevention. Int. J. Ment. Health 40, 28–49. https://doi.org/10.2753/IMH0020-7411400403