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Monitoring Fatal Road Accidents, Using Spatio-Temporal Statistics and GIS Modeling

Melidoniotis Evangelos[1], Sifaki-Pistolla Dimitra[2], Chatzea Vasiliki-Eirini[3], Tzanakis Nikolaos[4]

[1]Department of Anaesthesiology, University Hospital of Heraklion, University of Crete, Iraklion, Greece
[2]Epidemiology researcher, Faculty of Medicine, University of Crete, Iraklion, Greece
[3]Welfare Management, Faculty of Medicine, University of Crete, Iraklion, Greece
[4]Associate Professor of Epidemiology, Faculty of Medicine, University of Crete, Iraklion, Greece

Email address:
spdimi11@gmail.com (D. Sifaki-Pistolla)

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Abstract: *Background:* Purpose of this study is to monitor the fatal road accidents (FRA) in the Region of Crete, Greece and capture their dynamics in time and space using the Geographical Information System (GIS) technology. It aims to record the FRA spatially from 2001 to 2012, predict their spatio-temporal variance, estimate the number of FRA that should be expected the next years per region and identify the high risk areas. *Methods:* It is a spatio-temporal study using data from the National Emergency Center's database. The SPSS 20 and the Arc map 10 were used for the analysis. Spatio-temporal models were applied; specifically, geographical descriptive, Geary's C, co-kriging interpolation and the Geographical Weighted regression model. *Results:* According to the Geary's C, FRA follow a clustered pattern in Crete, whilst they are not randomly occurred (Geary's C= 0.42; 95%CI= 0.029-0.873; pvalue<0.001). There was a total of 1,039 FRA cases that presented heterogeneous distribution on the island, gathering within the standard distance and ellipse. Time related factors and age were found to be significant to the risk for FRA (pvalue<0.001), [summer months: ExpB=3.43, 95%CI=1.726-5.027 and the night hours: ExpB=2.43; 1.304-4.487]. High risk areas were identified and the expected number of unrecorded FRA was found to vary from 0.0001 to 5.5 cases per 50km^2. *Conclusions:* The present study inserts, for the first time in the Greek bibliography, a new way of monitoring and capturing the FRA dynamics and highlights the use of the GIS technology and dynamic modeling.

Keywords: Fatal Road Accidents, Spatio-Temporal Analysis, High Risk Areas, Interpolation Model, GIS

1. Introduction

Road accidents are steadily increasing, worldwide, mainly due to the development of transportation and the general increase of population [1]. The World Health Organization (WHO) has reported that nearly 1.3 million people die from road accidents every year, worldwide. Additionally, fatal road accidents (FRA) are more frequent among people between 5 and 44 years old and cover the 8th position in the list of leading causes of mortality globally. Unless immediate and effective action is taken, FRA and road accidents are predicted to become the 5th leading cause of mortality, resulting in an estimated 2.4 million deaths each year [2].

Traffic safety is a critical issue in agencies' transportation strategy that depends on various factors and varies from place to place; making the application of comprehensive safety programs difficult. The major problem that traffic officials have to face is the identification of the place and the way (where and how) to implement precautionary measures and provisions in order to have the optimum impact for traffic safety [3]. Consequently, they have to adopt a type of analysis that will provide them with valuable information regarding the hot spots of road accidents -mainly fatal road accidents (FRA)- and potential risk factors.

Geographical Information System (GIS) technology has been a popular tool for visualization of several epidemiological data as well as for capturing disease dynamics and decision making. Road accident data have been analyzed using GIS technology internationally with many traffic agencies using them for systematic monitoring of accidents [4,5]. There are several epidemiological studies as well as official organizations such as WHO, that have used the GIS to estimate the prevalence for FRA in certain locations. They have outlined the emergence of this phenomenon and identified more FRA among men from low income countries or more specifically in highways [6,7].

FRA are a major concern of the Greek Ministry of Health since there has been recorded a significant increase from 2004 until today [8]. Specifically, 1,484 FRA occurred in 2004, while their number reached the 1,501 in 2006. In 2010, more than 2,000 people died from FRA and over than 3,000 were seriously injured, among them young children and pedestrians. Several regions of Greece presents very high rates, such as the capital of the country; Athens, Crete and the driving highways of Southern Greece. Additionally, the explanatory factors were recorded and surprisingly the road related factors weren't the major ones. Anxiety, sadness, low income, personal problems, age and alcohol consumption were the factors most related to FRA [9]. Thus, the road traffic accidents are the leading cause of human mortality in many countries and should be studied extensively in order to be prevented [10]. The purpose of this study is to monitor the FRA in the Region of Crete, Greece and capture their dynamics in time and space using the GIS technology. It aims to record the FRA spatially from 2001 to 2012, predict their spatio-temporal variance, estimate the number of FRA that should be expected the next years per region and identify the high risk areas. Moreover, several prevention and management actions are proposed.

2. Materials and Methods

2.1. Sample and Study Design

The present study is a geo-epidemiological study using secondary data of the island of Crete, Greece. Data were selected from the National Emergency Center's (NEC) private database after receiving a relevant authorization with the protocol number:50 (http://www.ekab.gr/web/). Privacy of personal information was ensured, according to the principles of the Helsinki Declaration of Human Rights. The study variables included gender, age, the number of fatal road accidents per place of occurrence and the exact time of the accident during a twelve years period (from 2001 to 2012).

Data were selected from the NEC database separately for each case and thereafter organized in one dataset. The data were checked for possible duplicates or errors. Three exclusion criteria were set: a) cases regarding non-fatal road accidents, regardless their severity, b) duplicate cases, c) cases with missing values, especially regarding the place of the FRA occurrence.

2.2. Spatial and Statistical Analysis

Descriptive statistics were exported using the SPSS 20, while test of randomness for nominal and scale variables was performed and proved the non-normality of the variables distribution. In addition, the non-parametric chi-square test was applied at a significance level of 0.05.

Spatial statistics and thematic maps of FRA distribution and geo-descriptive measures were exported using the Arc map 20 (GIS) (http://www.esri.com/). Geo-data of Crete's coastline (data in the form of a spatial environment of analysis, with x and y coordinates) were used and geo-referenced according to the Greek Grid projection system [11].

Specifically, thematic maps for FRA distribution per year (from 2001 to 2010) were created using the exact place of incidence and by calculating the number of cases per 100,000 people per Municipality. The spatial mean and median centre as well as the standard distance and the directional distance (ellipse) were estimated and mapped in the final distribution map [11,12]. In parallel to the statistical test of randomness, the spatial autocorrelation test Geary's C was applied to re-test the data's distribution and levels of autocorrelation at a level of significance of 0.05. Spatial autocorrelation was chosen to be applied due to the fact that it is about proximity in (two-dimensional and bi-directional) space, making it more complex and precise. The value of Geary's C lies between 0 and 2 (1 means no spatial autocorrelation; values<1 demonstrate increasing positive spatial autocorrelation; values>1 illustrate increasing negative spatial autocorrelation [13].

Then, an interpolation method (co-kriging) was applied to determine the spatio-temporal variance of FRA in the whole island of Crete even in areas where we had no FRA records; estimating the expected number of unrecorded FRA cases. The following variables were imported in the model: current FRA records, number of total population per Municipality, age and gender. This model is a reliable method of producing a prediction surface and provides measures of the certainty or accuracy of the predictions (through a semi-variogram). The semi-variogram is the key function in geostatistics because it is used to fit a model of the temporal/spatial correlation of the observed phenomenon [14-16].

Finally, the Geospatial Weighted Regression (GWR) was applied in order to identify the high risk areas per Municipality. This model is a local version of spatial regression that generates parameters disaggregated by the spatial units of analysis. This allows assessment of the spatial heterogeneity in the estimated relationships between the independent and dependent variables. The independent variables imported in the GWR model were the temporal factors (year, month, day period), age and gender [17,18]. The estimated rates were at a significance level of 0.05 and the final risk was presented as Exposure B (Exp B) with 95% CI both for each factor and Municipality [17].

3. Results

3.1. Monitoring FRA in Crete

The FRA distribution was statistically and spatially tested and found to be non-random. According to the Geary's C, FRA follow a clustered pattern in Crete, whilst they are not randomly occurred (*increasing positive autocorrelation:* Geary's C= 0.42; 95%CI= 0.029-0.873; pvalue<0.001).

In figure 1A, FRA are presented using spots by the place of incidence and a color per Municipality referring to the number of FRA cases per 100,000 people. The total number of FRA from 2001 to 2012 in Crete is 1,039 and presents a heterogeneous distribution. The spatial mean and median are distributed and placed in the Municipalities of Heraklion and Maleviziou, respectively. Furthermore, the 68% of these FRA is "enclosed" inside the standard distance (red circle) while the directional distance (blue ellipse) identifies the spatio-temporal direction of the 68% of the FRA. Additionally, the 58% of the FRA occur in the Mucipality of Platania at western Crete, which presents 555.20 FRA/100,000 people. The Municipality of Heraklion follows with 440.78 FRA/100,000 people. FRA seem to be gathered around the island's coastline and the Municipalities' spatial limits. Furthermore, the FRA time distribution for the whole island is observed in figure 1B. It is obvious that there is a pick in 2005 (20.79 FRA/100,000 people) and their variance ranges from 5.32 in 2001 to 20.79 in 2012. The other years of significant increase were the year 2006 (17.63 FRA/100,000 people) and the year 2008 (19.46 FRA/100,000 people). On the contrary, there are years that present lower rates such as the year 2012 (6.44 FRA/100,000 people) although there was an intense increase in the year 2011.

In figure 2, several graphs are presented to describe gender, age, nationality and time related factors' distribution. Particularly, the FRA distribution in the sample varies between men and women (80.85% and 19.02% respectively). Additionally, a significant variation is presented in the nationality pie between Greek and other nationality (pvalue<0.001; 81.20% and 1.80% respectively). The mean age of people that died due to road accidents was equal to 34 years old (std.dev=18.14; min-max: 0-89). Furthermore, FRA seem to follow a different distribution according to month and day period. Significant variations are observed among months (pvaue=0.017) with June to present the highest rates (12%). September, August and July follow with the FRA occurring more frequently (11%, 10.5% and 10% respectively). Conversely, February has the lowest frequency of FRA (5%). During the clustering of the 24hours, significant differences among the day periods and FRA were observed, indicating a strong correlation (pvalue= 0.003). The highest numbers of FRA cases were occurring between 18.00-0.00pm (53%) and 12.01-18.00pm (32%), whereas the other two day periods followed with lower rates.

3.2. Capturing FRA' Spatio-Temporal Dynamics

After having monitored the FRA cases on Crete through time and space, spatial statistics were used in order to export further conclusions about FRA's dynamics. The results of the co-kriging interpolation are presented through a prediction map (figure 3A) that estimated the expected number of unrecorded FRA cases per 50km^2 in the whole island of Crete in the next years. This prediction is reliable only for the next years (the next 2 years) neither for a long-term. Values range from 0.0001 to 5.5 FRA cases per 50km^2. This is translated to a range of 0.0001 to 36.91 FRA cases per Municipality. Although the predicted number was transformed to cases per Municipality, it is of high interest to observe the FRA expected number of cases per 50km^2 due to its significant variation even among regions of the same Municipality. As it is observed the FRA estimations do not follow the spatial limits. Higher number of expected FRA cases is presented in most of the areas of the Prefectures of Heraklion and Chania mainly in their Southern and central parts. Yet, there are some regions (green and yellow color) in these Prefectures and in the Prefecture of Lasithi that have extremely low rates (less than 1.01 FRA cases per 50km^2). In table 1, the expected number of FRA cases per 50km^2 and Municipality are presented in comparison to the present number of FRA per Municipality.

The results of the GWR model are presented in figure 3B and table 2 (that identify the high risk Municipalities and factors respectively). According to table 2, younger people have higher risk of having a FRA, whilst it is estimated that for every year they get older they the probability of having a FRA decreases (ExpB=0.87; 95%CI= 0.428-0.997; pvalue<0.001). Nationality plays an integral role too (ExpB=1.35;95%CI=1.106-2.036;pvalue<0.001).Furthermore, FRA presented higher risk of occurring in 2008 and 2005 (ExpB=3.87, 95%CI=1.972-5.038, pvalue<0.001; ExpB=2.79, 95%CI=1.873-4.736, pvalue<0.001 respectively). Two more significant time related factors were imported in the GWR model; month and day period. June, September and August are the three months that FRA are more likely to occur (pvalue=0.017) with almost three times higher probability than the other months (ExpB=3.43, 95%CI=1.726-5.027; ExpB=3.27, 95%CI=1.593-4.656; ExpB=2.97, 95%CI=1.273-3.798 respectively). As far as the time period is concerned, higher risk presented between 18.01-00.00 pm (ExpB= 2.43; 95%CI= 1.304-4.487) and the 12.00-18.00pm (ExpB= 1.68; 95%CI= 1.028-3.092) with pvalue= 0.003. Based on these factors as well as the total population of each Municipality the high risk areas were identified in figure 3B. Municipalities of increased risk (red color) presented around 2.48 times higher risk for FRA (95%CI= 1.369-3.627; pvalue<0.001). There were also Municipalities of lower risk (orange color) that are neighboring to the high risk areas. Specifically, they presented 1.34 time higher probability of FRA incidence. Contrary to these Municipalities, the rest regions of Crete presented no current high risk and were characterized as areas of no risk (ExpB=0.65, 95%CI=0.272-0.927, pvalue<0.001).

4. Discussion

4.1. Main Findings

In general, during this 12 years period the FRA were found to follow a clustered pattern in Crete. FRA presented a heterogeneous distribution, having more cases within the areas that are included in the standard distance and the ellipse. Currently, these areas could be considered as areas of major risk. Furthermore, several increases and decreases of FRA from 2001 to 2012 were observed. There was a general decrease of their rate after 2010 (particularly in 2012) probably due to the dramatic decrease of the private cars usage during times of economic crisis. Nevertheless, FRA remain a major public health problem.

Using the spatial statistics as analyzing tools, we managed to estimate the future spatial variance of FRA at a smaller scale and identified the high risk areas in relation to the potential risk factors and population variation. It was significant to estimate new FRA cases (the expected unrecorded FRA cases by the prediction map) since it provided an integrated FRA capture. Several hot spots were identified mainly in the highways as well as across the Municipalities. It was significant to find the important role of time in FRA occurrence. Month and day period were found to affect the FRA incidence, with summer months presenting higher risk. This could be explained due to the fact that people tend to drive more often during these months (vacations, excursions) accompanied with an increase in alcohol consumption. Also, higher risk was observed during the afternoon or night hours either due to the traffic jam or the physical and mental exhaustion of the drivers at the end of the day.

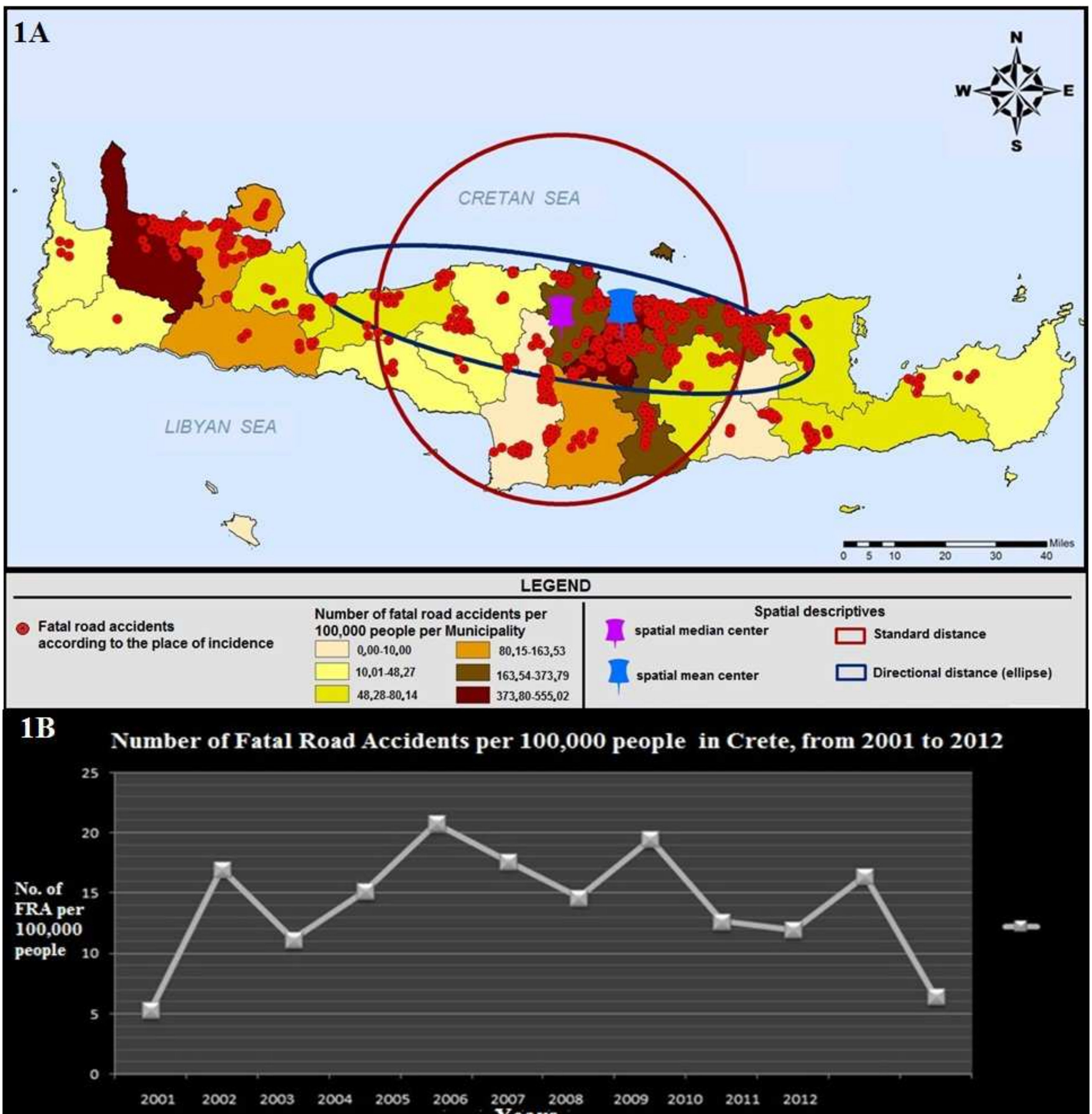

Figure 1. *Map (1A) and graph(A2) of FRA distribution in Crete, from 2001 to 2012.*

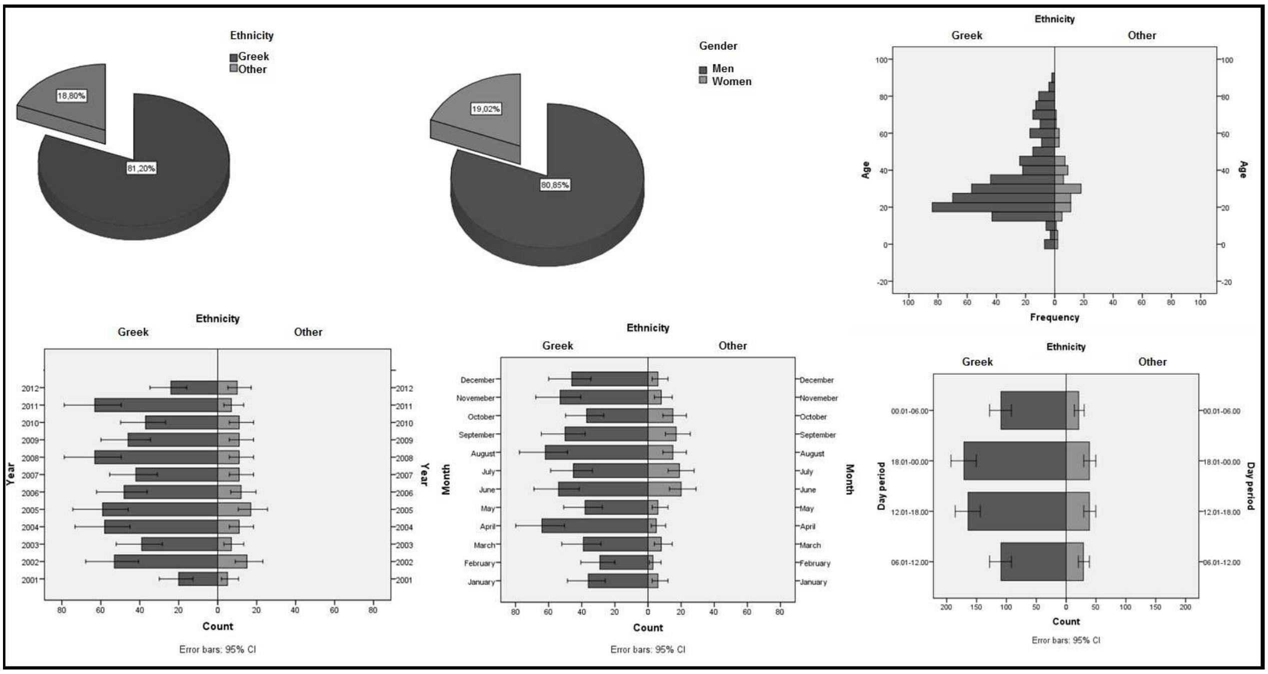

Figure 2. *Demographic characteristics and time variables.*

4.2. Other Findings in Bibliography

There is plenty of bibliography in the international databases regarding the FRA or other road accidents and the use of GIS technology. It is supported that the probability of accident occurrence, and its severity, can be determined by monitoring the current cases using techniques that simulate the real environment and dynamic analyzing modeling [19-21]. These studies have introduced several findings regarding the road accidents' distribution or their causation. For instance, Chao Wang et al, support that traffic congestion has little or no impact on the frequency of road accidents, whereas there are other factors that should be explored [23].

N.Levine et al and V.Prasannakumar et al, tested the randomness of the road accidents incidence, similar to our study, and they proved that they are not randomly occurred. They aimed to observe the accidents patterns in order to propose the optimum prevention measures [19,24]. However, the nonrandom distribution of accidents, both in time and space, raises questions regarding the location/time and reasons for that location/time. This was a significant question in our study too, since these reasons should be identified and studied to offer an effective solution. The task of devising effective solutions warrants analysis of spatial and temporal patterns of traffic accidents and FRA, which can be achieved through the application of geospatial technology. Furthermore, a number of epidemiological studies agree with several results of the present study, such as the high risk of FRA occurrence during the night hours or among the younger age groups [25-27].

4.3. Proposed Measures and Implementations

Several prevention measures are proposed, based on the present results and the findings in bibliography. These measures aim to develop a system of traffic accidents control and management that would be able not only to accommodate human error and take into consideration the vulnerability of the human body, but also to prevent and guide people to adopt safer behavior. In order for these to be achieved, systematic on-going monitoring is suggested trough the development of a national Cretan system that will focus on the regional and local particularities. The quality of data collection at a regional level and their analysis should be improved through organized research supported by the Regional Department of Crete. Special focus should be given on the road networks (especially, where hot spots are identified), as well as on the high-risk age groups during the night hours, aiming to safer road users. Furthermore, building capacities for post-crash response should be organized in every Municipality.

Finally, increased funding to road safety at a national level, better use of existing resources, road infrastructure projects and information campaigns in the Cretan community should be promoted. These campaigns will target to increase awareness of road safety risk factors and prevention measures in a comprehensive way.

4.4. Future Impact, Study Power and Limitations

The present study was designed in order to record the FRA in Crete at a large extent and consists the first step for further research in the region of Crete which is the largest island in Greece with intense geographical, environmental and behavioral variations. Power of this study lies on three main parameters: the reliable number of sample size and its source, the way of recording using the exact point of the incidence and the use of GIS technology. As it was mentioned, the NEC database was used due to the fact that it is the most reliable in the island and records the majority of FRA, apart from those that are delivered directly to the hospital. This is also the main limitation of this study that was managed through the application of an interpolation model that predicted the missing FRA cases as expected unrecorded cases spatio-temporally.

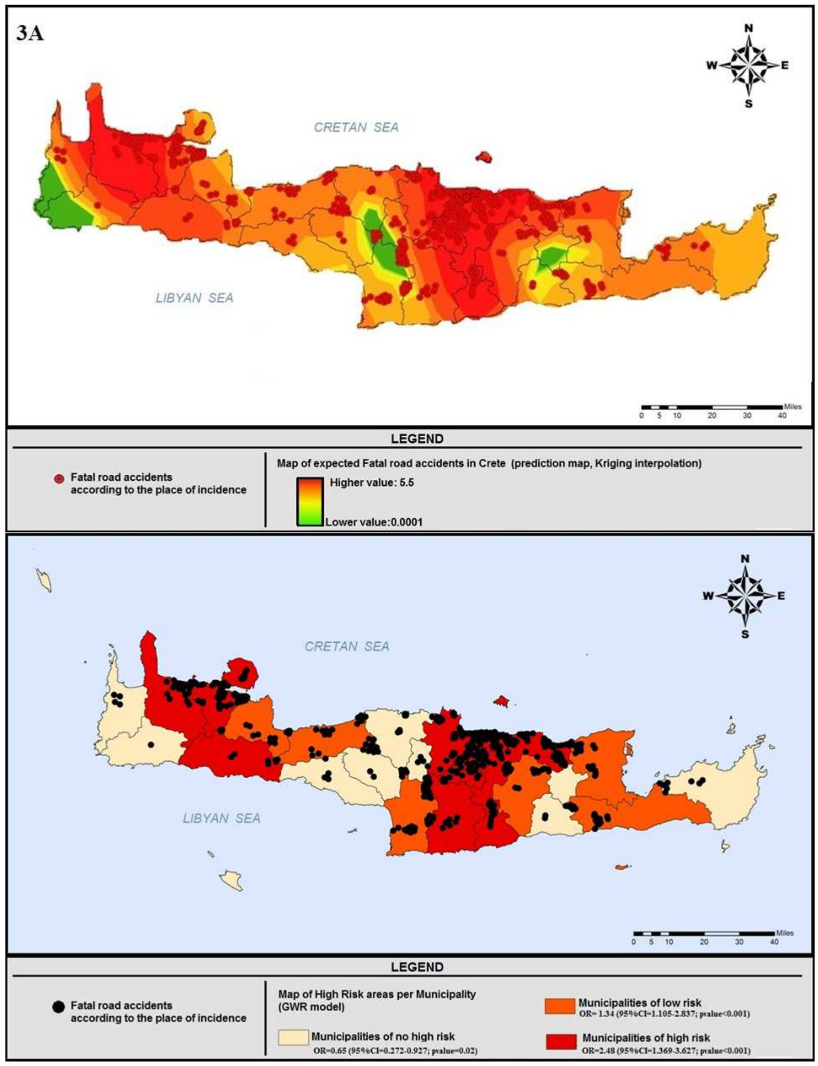

Figure 3. *Prediction map(3A) and map of high risk areas (3B) for FRA.*

Furthermore, several factors could be tested and correlated to the FRA incidence in Crete since they were found to be non-random, but this will be presented in our next study, focusing on the etiological factors.

The findings of this study will be useful to the local community for planning interventions in order to reduce the FRA incidence as well as for the research community as a reliable methodological tool for monitoring FRA. Hence, FRA occurrence can be reduced by the systematic analysis of the incident scenario in relation to spatio-temporal factors.

5. Conclusions

The present spatio-temporal study of FRA in Crete inserts for the first time in the Greek bibliography, a new way of monitoring and capturing the FRA dynamics. It suggests several preventive measures and innervations at a local level while it gives an incentive for future research in relation to etiological risk factors, such as alcohol drinking, stress, speed, environmental factors and driving behavior or road network. Furthermore, the use of GIS techniques in decision management and the extraction of reliable results is supported. Finally, it highlights areas, age groups and time periods that need direct intervention to minimize the future FRA incidence rates.

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