GI_Forum 2017, Issue 2
Page: 164 - 172
Full Paper
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DOI: 10.1553/giscience2017_02_s164

Multi-Criteria Approach with Spatial Analysis and Remote Sensing for Public Security Planning

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Abstract

Crime prevention requires planning, the identification of critical places, and allocating resources correctly. In order to ensure crime reduction, the participation of security decision makers is necessary in evaluating criteria that influence crime prevention. The decision maker needs to analyse the best actions to control violence, as well as define where these actions should be allocated. This paper suggests a multi-criteria spatial model associated with remote sensing to identify those areas most vulnerable to homicide and consequently in greatest need of public-policy intervention. The model was applied in a Brazilian neighbourhood, taking into account social, economic and demographic factors, as well as satellite images. We conclude that the spatial analysis approach using multiple criteria is a viable option for mapping crime-vulnerable places, since the areas identified as vulnerable have a similar pattern to official maps showing homicide density. The proposed approach presents some methodological advantages: (1) integration of different approaches; (2) consideration of rasters, excluding the need for polygons; (3) consideration of remote sensing, excluding unnecessary areas from the analysis; (4) little effort is required on the part of the decision maker.

Keywords:

public security, multi-criteria analysis, remote sensing, raster, weighted overlay

1 Introduction

Crime prevention and public safety involve different fields of research, such as criminal geography and crime behaviour. Crime has a direct impact on society and people's sense of security, and strategies for crime prevention are therefore of interest to the parties concerned. In addition, the proper use of tools that can map crime help in the decision-making process.

A crucial task of public security policies is to identify the places most in need of public resources in order to mitigate crime-related problems. It is important, therefore, that there is a structured way to choose the areas that will be focused on. Several factors can be considered criteria for such a choice. Recent studies (e.g. Menezes et al., 2013; Patino et al., 2014; Pereira et al., 2015) show variables related to homicides. Generally, the variables are related to social, economic and demographic characteristics and can be used to identify regions within a city that are more vulnerable to violence (Figueiredo & Mota, 2016). However, the identification of critical neighbourhoods should be done by evaluating small areas at a time, due to the possibility of heterogeneities; some spaces, like rivers, forests or airports, do not need to be considered at all.

Although the use of variables is interesting for the construction of models that can map which places are more vulnerable to violence, the elaboration of these models is facilitated greatly by the participation of decision-makers. Instead of using only data related to actual occurrences of crime, their participation can capture more subjective information, such as the importance attributed to individual criteria. We therefore believe strongly that these models should allow public security agents to identify places that are more vulnerable to violence.

Recent studies have shown the viability (for decision makers) of using a Spatial Multi-criteria model for the identification of areas that are most vulnerable to violence (Camacho-Collados et al., 2015; Figueiredo & Mota, 2016; Silva et al., 2015). However, models using raster data allow a more detailed study. To resolve this, our aim was to use a multi-criteria spatial model associated with remote sensing (RS) and GIS to obtain a more accurate picture of those urban places that are more vulnerable to violence. As a test location, we chose a small area of Recife city, Brazil.

One of the advantages of RS is the identification and classification of land use for future planning. Recent studies combine RS and a spatial multi-criteria approach to identify groundwater potential (Kumar et al., 2016) or suitable cropping patterns for a flood prone area (Rahman & Saha, 2008), to prioritize environmental restoration (Rahman et al., 2014), or to analyse earthquake vulnerability (Delavar et al., 2015).

This article is organized into five sections. Section 2 offers a short review of spatial multi-criteria evaluation. Section 3 presents our methodology, and section 4 the application of the approach in a neighbourhood of a Brazilian city. Finally, we present some conclusions in section 5.

2 Spatial multi-criteria evaluation

Spatial multi-criteria evaluation emerged as an alternative for assessing situations involving conflicting criteria by considering their spatial aspect. This approach is characterized by the presence of factors that influence the result according to geographic characteristics (distance and location). More details can be found in Malczewski & Rinner (2015).

The use of raster data is a viable technology for state and municipal planning, and for academic departments (Malczewski & Rinner, 2015). The spatial scale of the possible solutions can be modified according to the desired resolution, facilitating the structure of the spatial decision-making process. A raster is composed of pixels, and each pixel represents an option. Each raster is a way of presenting the criteria used in the construction of the multi-criteria decision model. The advantage of using rasters is to allow the exclusion of certain regions that do not need to be evaluated, such as water bodies and airports. In addition, the decision maker assigns scale constants, which determine the degree of importance for each raster. Aggregation is effected by weighting the sum of each raster with its respective value of importance (w), represented in Equation 1:

$$V(A_i) = \sum_{k=1}^{3} w_k v(a_{ik}) \qquad (1)$$

where $v(a_{ik})$ is the performance of the alternative/pixel for each criterion, (a_{ik}) is the value of the *k*-th criterion associated with the *i*-th alternatives (*k*=1, 2, 3, and *i*=1, 2, 3, 4).

Figure 1 below shows the raster structure evaluated according to three criteria.

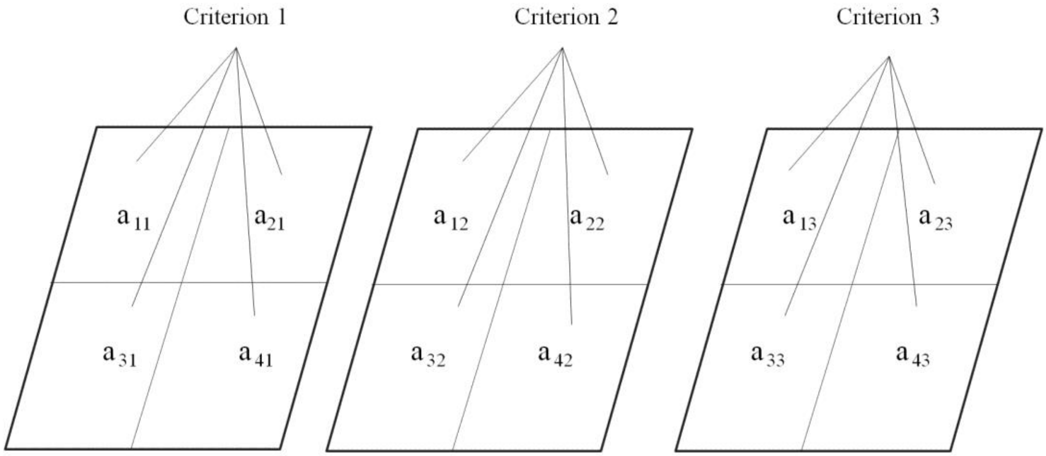

Figure 1: Multi-criteria decision structure considering raster dataset

There are criticisms regarding the use of raster data (see e.g. Marinoni, 2006), but their use also presents advantages (see Chakhar & Mousseau, 2008), notably through the overlay approach. Our aim was therefore to use a raster data model in order to integrate the relevant criteria and RS for decision making in public safety.

3 Methodology

The methodology consisted in choosing the place of study, selecting the criteria that influence criminality, and aggregating the raster dataset using multi-criteria evaluation. In addition, we used RS to exclude certain areas (rivers etc.) which are irrelevant for crime prevention.

The application was in three stages. The first stage consisted in problem structuring and required the following steps:

- Delimitation of the study area;
- Determination of the relevant criteria to evaluate the rasters;
- Consideration of all criteria as separate layers, for digital GIS database development.

The second stage is related to a remote sensing approach:

- Generation of a Land Use/Land Cover (LULC) layer using multispectral imagery from Landsat 8 Enchanced Thematic Mapper (ETM+) and satellite imagery of 30m spatial resolution (Landsat 8);
- Treatment of LULC using the Maximum Likelihood Classification algorithm, using ESRI ArcGIS 10 software. This technique allows a set of raster bands to be stored and creates a classified raster as output.

Finally, the third stage involves a spatial multi-criteria approach:

- Reclassification of the criteria layers as a normalization process;
- Aggregation of criteria layers and LULC layers;
- Multiplication of the value of each input raster by the raster weight (weighted overlay). The multiple criteria are then aggregated. The result is a final map with a vulnerability scale.

The social, economic and demographic variables used in this study were obtained from the Brazilian Demographic Census of 2010 (BIGS, 2015). The Secretariat of Social Defense (SSD) of Pernambuco State provided the homicide data (Secretariat of Social Defense, 2014).

4 Application

This model was applied in a region that combines two neighbourhoods of the city of Recife. The boundaries are between latitudes 08° 09' 56" to 8° 05' 53" N, and longitudes 34° 53' 54" to 34° 54' 21" E. The area measures approximately 13.83 km². Recife is the capital of the state of Pernambuco, northeast Brazil. The images were captured in September 2015. Figure 2 shows a map of Recife and the chosen location.

This region was selected because of its coastal location. It has a high concentration of hotels and tourist attractions, as well as of commercial points (malls, galleries, restaurants). The region is heterogeneous in terms of land occupation, since it is composed of residential and commercial areas as well as areas of vegetation.

Approximately 50,000 people have been murdered in Brazil every year since 2000 (Waiselfisz, 2012), a homicide rate of about 25–30 per 100,000 inhabitants per annum (Ministry of Health, 2015). In Recife, the homicide rate fell by 48.52% between 2000 and 2010; in 2010, the rate was 47.2 per 100,000.

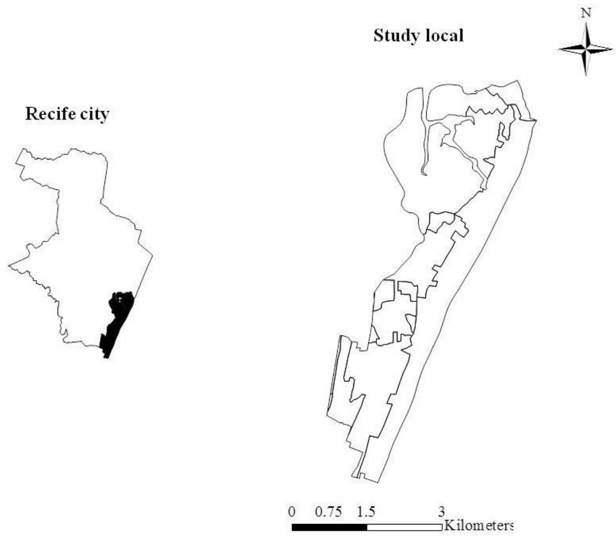

Figure 2: Study area

In Figueiredo & Mota (2016), a multi-criteria model was applied to classify the more vulnerable areas regarding violence in this same region. The authors used vector data and criteria obtained through the Brazilian Institute of Geography and Statistics (BIGS), but this approach does not allow a detailed analysis of the area by decision makers. For example, within the same area there may be rivers, sewage plants and hills, making detailed public security planning difficult. In the present study, the use of satellite imagery allows the identification of these sites with greater precision, making strategic and operational actions possible.

Selection of variables

In the literature, a large number of papers investigate statistically significant relations between homicides and numerous different factors; many of the studies deal with the Brazilian context (e.g. Gawryszewski & Costa, 2005; Lima et al., 2005; Menezes et al., 2013; Pereira et al., 2015; Sachsida et al., 2007). These papers generally relate social, economic and demographic variables collected by BIGS (2015) to homicide rates.

Pereira et al. (2015) investigated the relationships between 29 variables and homicides that occurred in the city of Recife between 2009 and 2013. The study shows how homicide in Recife can be understood by social disorganization theory. The authors found that the following factors were statistically significant, contributing to the homicide rate: population density, education, inequality, lighting in public places, and rented housing. Therefore, we opted to use their variables as criteria in this application.

In addition, using both the raster obtained from Landsat 8 ETM+ and the Maximum Likelihood Classification technique, we were able to identify different points in the region using RGB 654 false colour, allowing us to exclude sites such as environmental protection areas and rivers, as already discussed.

Results and discussion

Using Weighted Overlay, we aggregated the criteria with the composition of clustered images. We used an equal distribution for all criteria and the raster image dataset in relation to the degree of importance of each layer. We obtained a classification of 1 to 10, using natural breaks for the criteria layers.

The final map can be seen in Figure 3, where the darker the area, the more vulnerable it is. The darkest areas are concentrated in the north and south, with some in the centre. We used ArcGis to generate maps in raster form, combining the Landsat data as well as the data for the variables population density, education, inequality, lighting in public places, and rented housing. The most vulnerable and homicide-prone areas are those with weak performance in these variables.

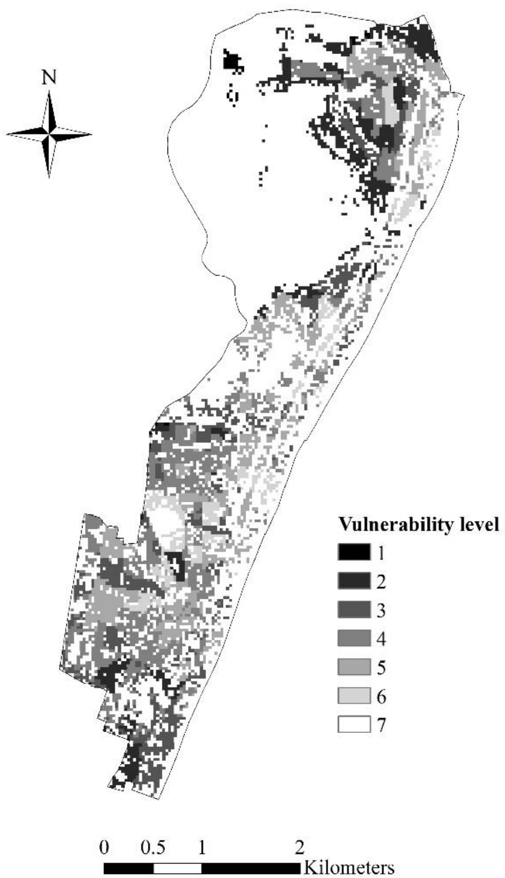

Figure 3: Final map, vulnerability level

Actions on the problems of poverty, inequality, poor education and poor infrastructure in these areas need to be taken by government in order to reduce vulnerability and thus, in the longer term, violence.

Figure 4 shows two maps of the neighbourhood: the first presents the results of our application, and the second is a density map for homicides in Recife during 2009 to 2013. The data were collected by the Department of Social Defense of the state of Pernambuco, through georeferencing. However, as a matter of security, we did not insert the points identifying where the homicides had occurred. According to the density map, homicides are spread throughout the area, but with hotspots in the north, centre and southwest.

We can observe similarities between the density map and the spatial multi-criteria map, the darkest areas of which are also located in the north, centre and southwest, showing that many of the homicides occurred in those areas that our application indicated as being more vulnerable. Therefore, the results of an overlay approach and remote sensing combined can satisfactorily identify areas that need more attention from policies.

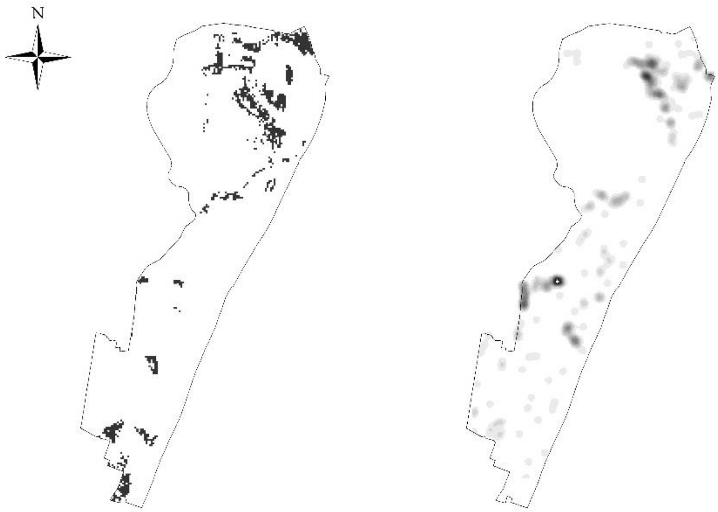

Figure 4: Maps for vulnerability level and density of homicides

Furthermore, the use of a multi-criteria method makes the process more structured and transparent, while also taking into consideration the decision makers' preferences. In this study, we used a weighted overlay method, because this is the most common method for handling spatial problems when using raster datasets. The effort of the decision maker is restricted to defining the importance of the criteria.

5 Conclusions

This study presented a spatial multi-criteria approach to identify more vulnerable areas, through a Weighted Overlay method. In addition, we integrated this tool with remote sensing, in order to identify locations that require intervention through public safety policies.

One of the advantages of the proposed approach is the generation of a raster which divides the area into pixels, excluding the needing of polygons, such as census tracts or blocks; the integration with RS also excludes areas that do not require classification.

We believe that this study can contribute to the decision-making process for public policies. The approach allows the decision agent to use several criteria, to which degrees of importance are assigned, through their simultaneous aggregation. Ini our study area specifically, the classification may help decision makers to allocate funding, focusing on disadvantaged parts of neighbourhoods, reducing violence in the longer term thanks to improved welfare in these vulnerable areas.

Acknowledgement

This work was supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) under Grant: 140375/2017-1.

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