ENVIRONMENTAL JUSTICE AND SULPHUR DIOXIDE ATMOSPHERIC POLLUTION IN MADRID: A SPATIO-TEMPORAL ANALYSIS AND ASSESSMENT WITH GIS

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INTRODUCTION

Last years there is a growing awareness about the fact that pollutant emissions produced by human activities, when spreading across space, do not fairly affect to different social categories. The evidence that the most disadvantaged groups often suffer more severely these negative externalities has set the focus on the environmental justice issue. It may be anticipated that this principle will play an increasing role in the current and future evaluation studies of any kind of spatial public policies, specifically those concerning to urban and territorial planning, because no discrimination of citizens or protection to more disadvantaged people are basic values of democracy.

The environmental justice concept has been properly elucidated in the literature by several authors, and for short it has been pointed that it concerns to the fair distribution of amenities and damages produced by some agents among people and places. In recent studies, the geographical approach on the question has emphasized the search for evidences of spatial association between social status and environmental quality. The need of an accurate measurement of this hypothetical relation, considering different aspects of environmental equity, temporal variation and spatial scales offer a stimulating research agenda for Geography, because the foreseen demand of applied knowledge, particularly methods and diagnostics.

Alongside this basis, this paper tackles the exam of spatial relation between two features of the Madrid metropolis: the atmospheric pollution by sulphur dioxide and the income status of population. To this end three objectives have been envisaged here. Firstly, to uncover in a precise way, that is quantitatively, the pollution level beard in Madrid by

the different income groups in the urban areas they live, in order to make clear if there are proportional inequalities or discrimination and for which socio-spatial class. Secondly, and from the methodological side, it has been intended to design and test a GIS based procedure to conveniently measure the spatial relation between two spatial attributes, one environmental and other social, quite distinct in character. In addition, the analysis has a third valuable goal, to assess this relation in two periods, ten years apart, 1995 and 2005, along which changes in the atmospheric pollution and intra-urban population location and incomes have happened. So, the outcomes of some public policies looking for sustainability can be better assessed.

DATA SOURCES AND METHODS

Several data sources have been integrated in the study. To describe the atmospheric pollution it has been used the information provided by the Automatic Surveillance Network of Atmospheric Quality of the Madrid municipality and also by some of the surrounding stations, belonging to the Pollution Surveillance Network of the Environment Office of the Madrid Regional Government. Among the atmospheric characteristics, a single and relevant component has been considered in this research, sulphur dioxide SO_2; the yearly average values for each station, expressed in $\mu g/m^3$, have been the data used to synthesize one aspect of the air quality during the above mentioned years, 1995 and 2005. These sample data have been treated with ArcGIS Spatial Analyst to model, in a raster layer, the pollution surface covering the whole populated area of Madrid. A 200 m. resolution for the resulting grid has been selected as spatial standard units in the study.

For population income data the source was the «Spatial household net income per capita indicator», published by the Statistical Institute of Madrid Regional Government. This indicator was available for small areal units (called «secciones censales») defined for statistical and electoral purposes and containing between 1000-2000 people. These polygon data were converted to raster with ArcGIS to obtain layers consistent with the pollution layers formerly mentioned. It must be pointed that income data have been available only for 1997 and 2000, fact that hinder somehow our temporal analysis. However, given the spatial permanence of intra-urban socioeconomic status differences and its low rhythm of temporal change, this trouble does not disturb seriously the analysis and conclusions.

To delimit the specific area where both the environmental and the social indicators should be compared an additional criterion was applied: the urban populated space in the municipality. Provided that some areas have not urban land uses, e.g. rural, forest, etc. the actual and relevant space to be considered should be that where the population live and deploy its daily activities. For sake of simplicity a convenient departure point to set this space is the home address and, for our purposes here, population data geographically referenced by building (as a layer point) were spatially distributed according the Kernel density estimator (available in ArcGIS), using a 500 m. bandwidth. It produced a population density grid where cells having values > 0 were considered as integrating the zone for validly examining the man-environment interaction, that is, to overlay the pollution and income grid layers.

To test operationally the existence of environmental equity-inequity in the case study a procedure, approaching a sort of «justicemeter», was designed. It involves the following steps:

- Setting and classifying in appropriate intervals both the SO_2 pollution and the income grid values.
- Cross-classification of the SO_2 pollution and income layer values for each date, to obtain statistical tables containing the cells frequency according to the intervals of both variables. Therefore, the numbers refer to the amount of space having a specific pollution and income level.
- For each income interval, computing cells percentages over its marginal total, to allow a comparison between income groups. Then, the exam of this table could make evident which groups were bearing more or less proportionally pollution charge in the city, and so displaying the degree of environmental equity-inequity.
- Computing of statistical association coefficients, Cramer's V and Goodman-Kruskal γ for the cross-tabulation tables.

To perform these operations, the ArcGIS Spatial Analyst extension and NCSS statistical package were used.

RESULT ANALYSIS AND DISCUSSION

The results have shown a strong and general reduction of atmospheric sulphur dioxide in Madrid, due to policies implemented during the period focusing to substitute one of the major emission sources, the coal based heating systems in buildings, by other energy sources (mainly natural gas). The intra-urban pattern of the pollutant shows clear differences, with higher values in the centre and inner areas and lower in the periphery; to a great extent, it remains true for the two years considered.

Concerning the income per capita levels in Madrid, they also exhibit intra-urban variation, being particularly remarkable the rough distinction between the richer North and the poorer South of the city. Provided the nearness of reference dates for these data, temporal changes have not been deeply scrutinized here.

With regard to the main hypothesis investigated here, whether environmental discrimination or injustice is present, taking into account the spatial patterns of SO_2 pollution and net income, it has been possible to make evident the following findings.

In 1995, the air quality, as manifested by the SO_2 concentration, was particularly worse in upper income zones compared to other income groups (Table 5). Association coefficients such as Cramer's V (0,19) and Goodman-Kruskal's γ (0,37) indicate a low medium, but significant, relation between the two variables. This can be linked to the centrality of these social groups and to the presence in these zones of the main sulphur dioxide emission sources. In other words, it can be stated that richer and more polluting areas were also charging and suffering the derived negative externality. At first glance this link seems to be aligned to the environmental justice principle; however, provided the spatial spread of atmospheric pollution over surroundings areas, it seems likely that the emissions should affect also the

poorer proximal areas, whose contribution as pollutants would be lower. This fact has not measured here, but we begin to see the hypothesis of spillover effects on lower socio-spatial classes.

In 2005, the atmospheric quality, as regards the SO_2 levels, had changed dramatically displaying a striking improvement; this fact is clearly manifested by the reduction of several statistical indicators and the distribution of pollution levels for different income intervals (Table 7). It implied a general benefit for all people, and it can be stated that the policies of pollution reduction have had a plain consequence: an equalization of pollution levels affecting the different socio-spatial groups, compared to those existing ten years before. Shortly, an improvement of the socio-environmental equality was promoted. Concerning the environmental justice perspective, the statement claimed in 1995 could be repeated, because higher SO_2 levels again affected more proportionally to higher income zones. The association coefficients, V and γ (Table 7), although slightly reduced as regards to 1995, again confirmed the portrayed relation. On this evidence, environmental discrimination or injustice against the residential areas of lower income groups has no proof in Madrid.

Notwithstanding that, a sharper interpretation of the results allows to assert that the improvement of environmental quality has been slightly higher, i. e. more favourable, in the upper income areas. Indeed, if SO_2 average values for 1995 and 2005 are compared between the two lower income intervals it is observed a nearly 10 $\mu g/m^3$ diminution. However the reduction for the two higher income groups reached to 11.57 and 14.94 10 $\mu g/m^3$ respectively. This means a proportional more beneficial change for affluent zones than for those economically disadvantaged. For a more exact interpretation it must be added that the public policy stimulating the substitution of coal heaters systems for other less polluting ones involved an important part of private funding, but also public grants.

FINAL COMMENT

As a final reflection, and from a wider perspective, it must be claimed more attention among scientific community and experts to the assessment, as it has been tried here with promising results, in a deep and accurate way, the sometimes elusive socio-environmental benefits and costs, in order to promote a wider awareness of fair / unfair distribution of them among places and people and to make better informed and grounded policy decisions, considering the environmental justice principle. We are convinced that it is now feasible, thanks to the availability of appropriate data and technologies as GIS that allows an efficient data handling and analysis, as manifested in this case study.