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Environmental protection zones priorization for the decision making support*

*Luis Alejandro Builes Jaramillo**, Laura Lotero Vélez***, Joan Amir Arroyave Rojas*****

Priorización de zonas de protección ambiental como apoyo a la toma de decisiones

Priorização de zonas de proteção ambiental como apoio à tomada de decisões

ABSTRACT

Introduction. Air quality assessment deal with emission, concentration levels and definition of polluted areas, the results are often related with command and control regulations or restriction to transportation and industrial activities. This kind of approaches gives to environmental and territorial planners areas for special management and use. **Objectives.** Facilitate the priorization of those polluted areas in terms of future interventions to decision makers, integrating public health and demographic indicators to a previous planning exercise through, an Analytic Hierarchy Process (AHP) approach. **Materials and methods**. With an AHP developed via surveys for territorial and environmental planning experts, it was possible to define the importance weight and relevance of new indicators in the decision making exercise of prioritization of polluted areas in Medellin. The indicators were chosen from public databases of demographic and public health information and one of them (demographic) with a prospective time frame. **Results.** Experts in territorial planning tends to give more importance to health indicators for the prioritization of intervention in polluted areas, while the inclusion of a prospective indicator was useful in the definition of which of the areas should be the first or

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Correspondencia: Luis Alejandro Builes Jaramillo, e-mail: luis.builes@colmayor.edu.co

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the most critical for intervention. The results also show that experts seem to have problems in structuring their decisions presenting some inconsistencies in their answers. **Conclusion**. We present clear cut results showing that the inclusion of new variables, especially those dealing with prospective information in previous air quality planning exercise is useful for the strategic decision making process.

Key Words: environmental protection, environmental zoning, environmental planning, multi criteria, AHP, air quality assessment.

RESUMEN

Introducción. La evaluación de la calidad del aire es un proceso basado en el diagnóstico de niveles de emisión e inmisión, para la posterior definición de zonas con altos índices de contaminación. Con frecuencia estas evaluaciones se relacionan con procesos normativos y/o de control vehicular y a la producción industrial. Finalmente, estas zonas se convierten en lugares de manejo especial para procesos de planificación ambiental y territorial. **Objetivos.** Facilitar la priorización de zonas con altos índices de contaminación para la toma de decisiones y la decisión de futuras intervenciones. Para lograrlo, se integran indicadores de salud pública y demográficos a un ejercicio de planificación existente mediante la aplicación de una metodología de Análisis Jerárquico (AHP, por sus siglas en inglés). **Materiales y m**étodos. Con un proceso AHP, desarrollado mediante encuestas a expertos en temas de planificación territorial y ambiental, fue posible definir el peso o importancia de vincular nuevos indicadores en un ejercicio de toma de decisiones para la priorización de zonas contaminadas en la ciudad de Medellín. Los indicadores fueron tomados de bases de datos públicas, y uno de ellos (demográfico) con información prospectiva. **Resultados.** Los resultados indican que los expertos consultados para el desarrollo de la metodología tienden a dar mayor relevancia a indicadores de salud para la priorización de zonas, mientras que la inclusión de un indicador prospectivo fue muy importante para la definición del orden en que las zonas deberían ser intervenidas. De los resultados también se llega a la conclusión de que los expertos presentan cierto grado de inconsistencia en sus respuestas. **Conclusión.** En este trabajo se presentan resultados que dejan por sentado la utilidad de la inclusión de nuevas variables en los procesos de evaluación de calidad del aire para la planificación estratégica.

Palabras clave: protección ambiental, zonificación ambiental, planificación ambiental, multicriterio, AHP, evaluación de la calidad del aire.

RESUMO

Introdução. A avaliação da qualidade do ar é um processo baseado no diagnóstico de níveis de emissão e imissão, para a posterior definição de zonas com altos índices de contaminação. Com frequência estas avaliações se relacionam com processos normativos e/ou de controle veicular e à produção industrial. Finalmente, estas zonas se convertem em lugares de manejo especial para processos de planejamento ambiental e territorial. **Objetivos.** Facilitar a priorização de zonas com altos índices de contaminação para a tomada de decisões e a decisão de futuras intervenções. Para conseguí-lo, integram-se indicadores de saúde pública e demográficos a um exercício de planejamento existente mediante a aplicação de uma metodologia de Análise Hierárquica (AHP, por suas siglas em inglês). **Materiais e métodos.** Com um processo AHP, desenvolvido mediante enquetes a experientes em temas de planejamento territorial e ambiental, foi possível definir o peso ou importância de vincular novos indicadores num exercício de tomada de decisões para a priorização de zonas contaminadas na cidade de Medellín. Os indicadores foram tomados de bases de dados públicas, e um deles (demográfico) com informação prospectiva. **Resultados.** Os resultados indicam que os experientes conferidos para o desenvolvimento da metodologia tendem a dar maior relevância a indicadores de saúde para a priorização de zonas, enquanto a inclusão de um indicador prospectivo foi muito importante para a definição do ordem em que as zonas deveriam ser intervindas. Dos resultados também se chega à conclusão de que os experientes apresentam certo grau de inconsistência em suas respostas. **Conclusão.** Neste trabalho se apresentam resultados que deixam por sentado a utilidade da inclusão de novas variáveis nos processos de avaliação de qualidade do ar para o planejamento estratégico.

Palavras importantes: proteção ambiental, zoneamento ambiental, planejamento ambiental, multicritério, AHP, avaliação da qualidade do ar.

INTRODUCTION

Environmental analysis and zoning gives useful information to territorial planners and decision makers for the proposal, definition and implementation of infrastructure projects, pollution control processes or social intervention among other initiatives in the local level. In urban environments this kind of studies are specially complicated, due to the dynamics associated to city growing and the urging needs for new developable land. This expanding process in cities gives place to different urban forms and densities.

Urban densification, understood as the result of location decisions of social agents in urban areas, determines among other things, energy consumption, demand of infrastructure and services, and is considered one of the main factors shaping the urban territory and environment, influencing its sustainable development. In developing countries, the densification of cities is an accelerated process, where socioeconomic complexities, like informality, disintegrated planning and normative control frameworks, contribute to the increase of spatial, social and environmental problems (European Communities, 2007; Skovbro, 2001; Naciones Unidas, 2009).

The time-space dynamics between social actors and land use in the Aburra Valley Metropolitan Region (Colombia) and their sustainability impacts, have been a research theme addressed by different initiatives, and a number of prospective modeling frameworks have been developed to research these issues (Área Metropolitana del Valle de Aburrá, Corantioquia, Cornare y Universidad Nacional de Colombia, 2007; Rave, 2009; Área Metropolitana del Valle de Aburrá, Universidad de Antioquia y Universidad de Medellín, 2001). These frameworks provide a means to understand some of the most important dynamics of the behavior of actors, probable densification processes and sustainability impacts. One of the open questions regarding the impact of densification in terms of environment is related to the conditions surrounding and influencing the quality of life of people in urban areas (Kornov, 2009).

For the Aburra Valley context, environmental planning deals mainly with natural resources and with the following main components: water (quality, supply and demand), air pollution, land use, and waste management. This kind of studies contributes to the development of policy and intervention instruments that are mostly normative or restrictive in nature such as protected areas and emission limits, involving particular regulation in most cases (Área Metropolitana del Valle de Aburrá, Corantioquia, Cornare y Universidad Nacional de Colombia, 2007).

In this paper, we propose a complementary analysis, where citizens play an equally important role in environmental analysis of air pollution zones previously defined for the region. Urban environment concept can integrate behavior of citizens, taking into account information related to population such as rates of urgencies for cardio-respiratory diseases and current and prospective expected densification patterns as decision variables for, a multi criteria, ranking process among the zones defined in prior researches.

We developed an Analytical Hierarchy Process –AHP– (Saaty, 1990), for the introduction of population crowding, and health conditions indicators into a new local strategic and integrated air quality planning. This approach involves the use of surveys for the definition of indicators weights, with the participation of experts in environmental and territorial planning, in order to achieve a consensus in the right use of the proposed indicators.

For the environmental decision making processes, multi criteria approach such as AHP is considered as a tool for planners in order to decide whether to choose or not between different options. Multi criteria analysis has been well received in the Strategic Environmental Assessment –SEA– (Cendex, 2008; Jiliberto y Bonilla, 2008; Kornov, 2009), because it can be applied for all kinds of impacts, and might be quantitative as well as qualitative, making choices about conflicting or multiple objectives explicit, rational and efficient (Finnveden; *et al*, 2003; Garfi; *et al*, 2011, OECD, 2007).

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Air pollution critical zones in the Aburra Valley Metropolitan Region

The Aburra Valley Metropolitan Region (AVMR), has experienced from the early XXI century a growing concern about air pollution problems and its influence in public health. As a result of this interest, there have been a numerous research initiatives for the evaluation of air pollution conditions around the region (Builes; *et al*, 2008; Rave; *et al*, 2008; Área Metropolitana del Valle de Aburrá, 2010), taking as a starting point the air pollutants measurements and modeling available.

In a collaborative research between the academic and the planning sectors (Área Metropolitana del Valle de Aburrá, 2001), there were proposed areal pollution sources for the metropolitan region, according to the standards given by the Decree 948 of 1995 (Ministerio de Ambiente, Vivienda y Desarrollo Territorial de Colombia, 1995), and based on the evaluation of Total Suspended Particles (TSP) measurements made by the stations of the network of air quality vigilance (REDAIRE for its Spanish initials), installed all around the region (21 stations). As a result of this study one of the ten municipalities that integrate the AVMR was declared as an area source (Área Metropolitana del Valle de Aburrá, 2001).

Then, in 2007, there were defined the normative area sources in the AVMR by the evaluation of the measurements of the REDAIRE stations (Toro y Marín, 2005). This proposal was established as a regional decree and finally made official by the Metropolitan Agreement N° 25 of 2007 (Área Metropolitana del Valle de Aburrá, 2010; González, 2009). Those two administrative initiatives mapped the area sources for the region that should follow the regulation of obligatory and punishable character, defined by the national order Decree 979 of 2006 (Ministerio de Ambiente, Vivienda y Desarrollo Territorial, 2006). This regulation goes from the constant measurement of TSP, to the total stop of industrial activities, if such is necessary.

In the framework of the Ordering and Management Plan for the Aburra River, which flows through the metropolitan region, were defined 7 critical zones due to air pollution conditions (Área Metropolitana del Valle de Aburrá, Corantioquia, Cornare y Universidad Nacional de Colombia, 2007; Rave; *et al*, 2008). The construction of these zones was based in a multi-scale and multilayer analysis of pollutants emissions and concentrations, using the measurements of TSP from REDAIRE and including the results of dispersion modeling for different pollutants in the region (O_3, NO_2, SO_2 y CO) and industrial and transportation emissions modeling (MP_{10} and CO_2). Finally the zones chosen as critical, for the municipality of Medellin, the largest among the ten that forms the metropolitan area are presented in figure 1, were those with the greatest emissions concentration levels.

Local researchers are getting more specialized in air pollution and environmental health subthemes, but the integration of these research initiatives is mandatory. We propose to go further AMVA (2007) and to achieve a greater understanding in the prioritization of air pollution critical areas at the local context, and to give more relevance to environmental health and population crowding in air pollution local management. A plausible way to do that is through a multi criteria AHP analysis. This methodological proposal may be understood as an air quality SEA focused in the achievement of sustainable environmental development for urban areas in developing countries.

MATERIALS AND METHODS

The methodological framework for this study is based in three steps: 1) definition of subjects to be added at the local air management processes, 2) identification and choosing of indicators for each subject and 3) definition of the weights of indicators. Once the indicators are selected and weighted, we can give a value according to the new indicators to each critical zone defined in AMVA 2007. The greater the value in a zone, the more important is the public intervention for pollution control or reduction.

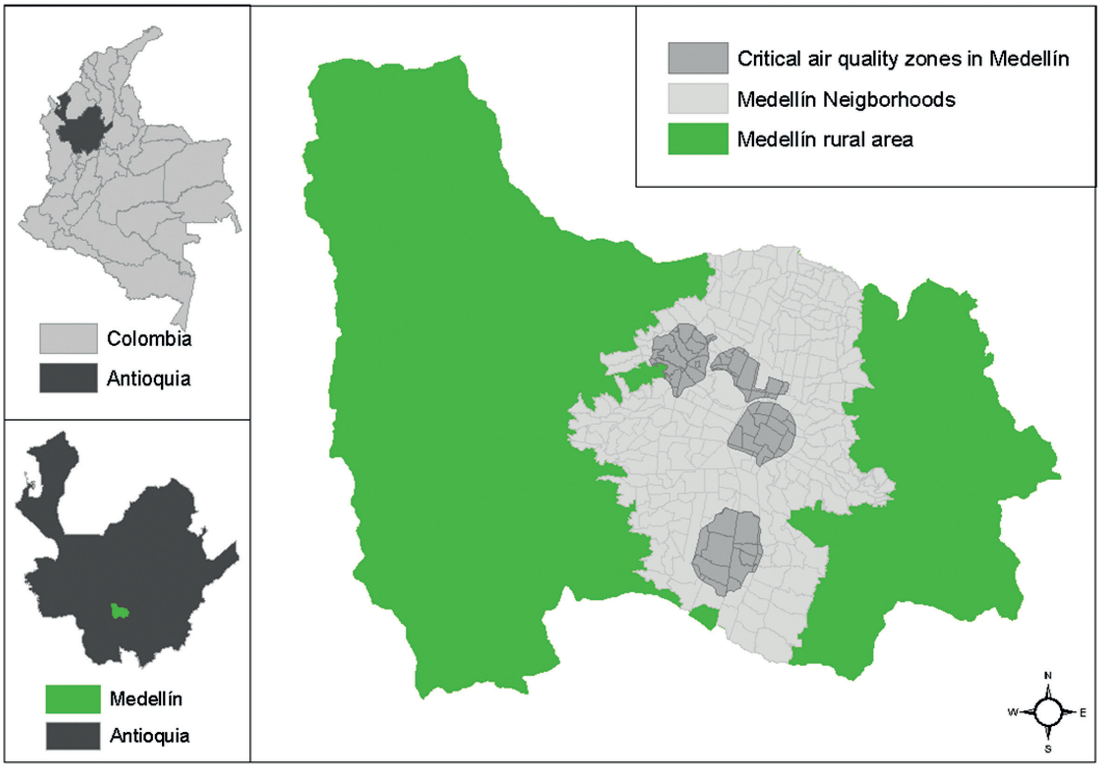

Figure 1. Air quality critical zones at the study area (Medellin, Colombia)

The air quality or in general environmental assessment practitioner, at the local level, needs to introduce the concept of integrated planning to its framework; integration makes possible to address and take into account the interdependency and relationship between variables in environmental processes.

In order to achieve this integration, the use of new subjects as important as pollution in air quality management is needed. Taking into account the considerations of programs such as UN healthy cities (World Health Organization, 1999; World Health Organization, 2007), and air quality SEA guidelines for Colombia (Jiliberto y Bonilla, 2008), we identify four subjects to incorporate at the local air quality management: *environmental health*, *population crowding, urban densification* and *prospective growth*, all related to the developing countries city context.

Once the subjects are clear, the next step is to choose suitable indicators for undergoing the analysis; to guarantee its replicability, these indicators might be developed or taken from public information with an easy access from all kinds of researchers. For this particular study, the information is obtained at the public administration and academic fields by the Land and Real Estate Market Observatory –OSMI for the Spanish acronym– (Departamento Administrativo de Planeación de Medellín, 2011), the National Public Health Faculty at the University of Antioquia (Facultad Nacional de Salud Pública, 2006) and the Laboratory of Territorial Analysis and Modeling –LAMAT for the Spanish acronym – at the National University (Rave, 2011).

The chosen indicators must provide appropriate information and quantifications, becoming powerful tools that can help decision makers to conceptualize and enable the objectives and targets of their analysis, and most important, to help them choosing among alternatives, for the proposal or adjustment of policies (Bell; *et al,* 2001; Donnelly, 2007).

In this study, four indicators were chosen, each one representing one of the subjects to integrate in the air quality management analysis, 1) *Total Inhabitants* [Persons] 2) *Urgencies rate for cardio-respiratory diseases* [Urgencies/x1000 inhabitants] 3) *Inhabitants density* [Persons/Ha] and 4) percentage of *housing density rise in ten years ahead* . For the inclusion of these indicators, and for the integration in the analysis, is necessary to define the importance of each one of them in the decision making process. To estimate the importance between different criteria, a pairwise comparison methodology is required, and we decided to go with AHP methodology for its several advantages as a flexible and simple multi criteria approach that allows the stakeholders participation (Garfi; *et al*, 2011).

The estimation of each indicator weight is made through surveys. The questions in the survey were made according to the AHP framework (Saaty, 1990); each question represents a comparison between two different indicators. With the results of these comparisons we calculate the relative weight of each indicator compared with the others. Each zone is divided in neighborhoods and as the public information is produced for these socio political areas of the city, the indicator values are given by neighborhood. The neighborhoods have total or partial areas inside the critical zone; and we use the percentage of the area contained in each zone as a weighted average factor for the calculation of the whole zone qualification. Once the indicators are weighted, we can give a qualification to each neighborhood, using the product of the value of each indicator, its weight, and the percentage of area inside the zone. The final zone qualification is given by the maximum value calculated for the neighborhoods inside the zone.

Surveys were sent to local and international experts and practitioners in environmental and territorial planning, and were intentionally designed to be answered in two stages; the first stage comparing the first three indicators to each other, and the second stage comparing the first three indicators with the prospective indicator. By doing so, we can divide the analysis in pre-prospective and post-prospective indicator introduction. With this kind of analysis, it is possible to evaluate the impact for expert decision makers, when there is prospective information available in air quality management assessment.

RESULTS

Looking forward the conceptual integration of information related to population in air quality assessment, we separate the survey analysis in two different matrices, the first matrix has to deal with the answers before the introduction of the prospective indicator, and the second one analyses all the indicators integrated. A methodological proposal like this can give us insights about the expert decision making process, and how prospective indicator integration could change relative importance between indicators in air quality management assessment.

Using AHP as an analysis tool, we have to verify the consistency of the answers for each survey and therefore for each expert (Alonso, 2006; Pecchia; e*t al*, 2010). In this particular case we evaluate consistency in each one of the matrices, and the results show that for the first case, without the prospective indicator, only 20% of the surveys can be considered as consistent, while for the second matrix, the consistency of experts reaches 33% of the surveys analyzed. Finally, to go on with the analysis, we decided to use only consistent surveys to guarantee the use of consequent and consistent expert decision making.

In table 1 and figure 2 we present the weight results for each indicator in the two stages of analysis, for both matrices the *Urgencies rate* indicator, with weights of 40% and 28%, was the most relevant for decision makers, while the *Total inhabitants* is the least attractive with weights of 29% and 23%. The prospective indicator of *Housing density rise* reach in the second analysis reaches a weight of 24%, showing that decision makers tend to give equal importance to all the indicators, but maintaining their preference for the health and density related indicators. Table 1 presents a comparison between the weights calculated with non consistent and consistent surveys. For the consistent surveys, the *Urgencies rate* indicator has the greatest rise in value, showing that the direct impacts on population are main drivers in a consistent expert decision making.

Consistent decision makers give the least importance to the *Total inhabitants* indicator, not only in pre prospective but also in post prospective analysis. Considering both analysis weights as shown in table 1, the indicator that experiences the greatest reduction in importance (of the 30%) for decision makers is the *Urgencies rate* while the *Housing density* and *Total inhabitants* decreases 20%. Prospective information, in this case, gives enough information to decision makers to rethink about their preferences.

Table 1. Indicators and average weights per indicator for the consistent surveys in each analysis matrix

Indicators in first analysis	NonConsistent Weight	Consistent Weight	Behavior
Total Inhabitants (Persons)	0,29	0,30	↑
Urgencies rate for cardiorespiratory diseases (Urgencies/x1000 inhabitants)	0,40	0,51	↑
Inhabitants density (Persons/Ha)	0,31	0,19	↓
Indicators in second analysis	**NonConsistent Weight**	**Consistent Weight**	**Behavior**
Total Inhabitants (Persons)	0,23	0,24	↑
Urgencies rate for cardiorespiratory diseases (Urgencies/x1000 inhabitants)	0,28	0,31	↑
Inhabitants density (Persons/Ha)	0,25	0,21	↓
Housing density in ten years ahead (%)	0,24	0,23	↓

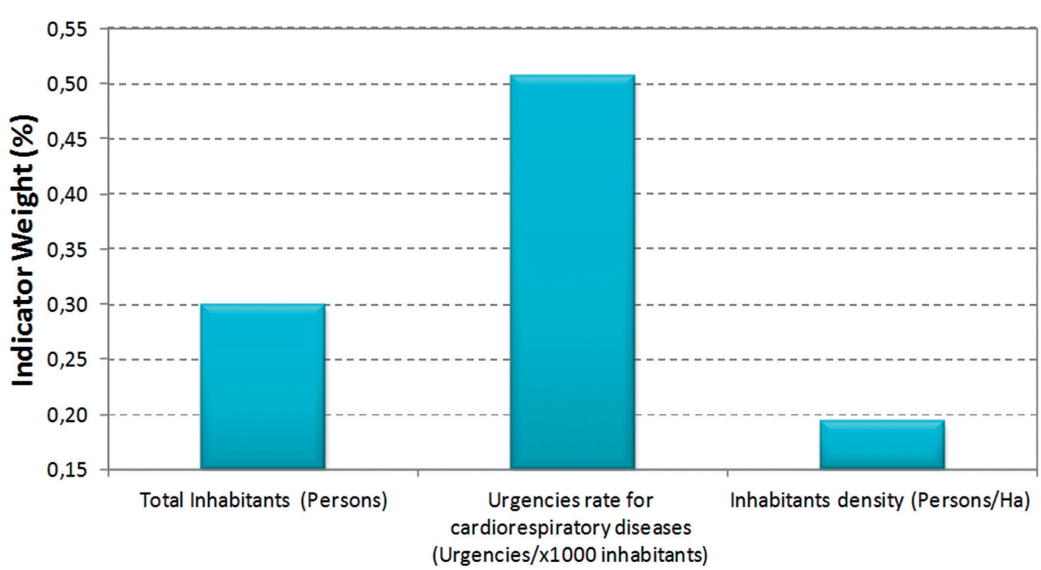

Figure 2. Comparison of consistent indicators weight between the two stages of analysis

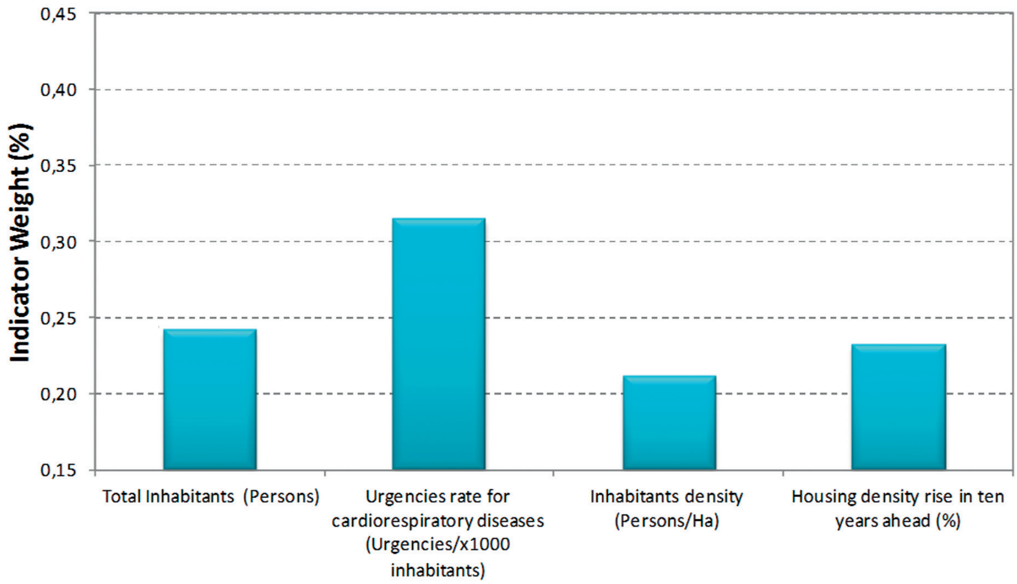

Figure 2. (Continuación) Comparison of consistent indicators weight between the two stages of analysis

In figure 3 we show the comparison between the analysis before and after the use of the prospective indicator in the weights definition. In the first analysis, consistent experts could not define one zone with greater relevance for the prioritization of action, but when the prospective indicator was included in the analysis, only one of the zones is presented as more critical and with greater priority for intervention than the others.

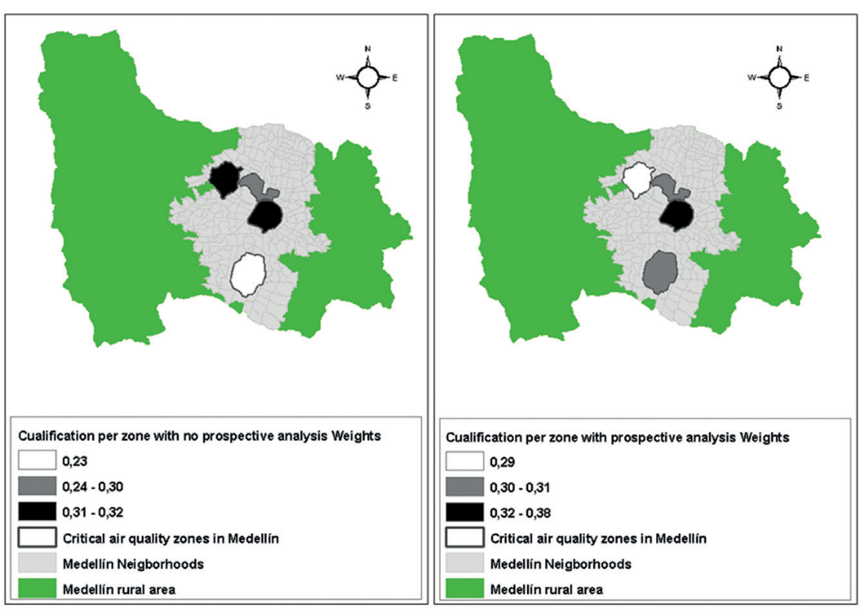

Figure 3. Comparison of consistent qualifications for each zone in the two stages of analysis

This are clear cut results that for decision making in environmental and in policy making prospective information can clarify the decision process to experts, giving more consistency to their analytical evaluation of indicators, and facilitating the prioritization in intervention, that could be via command and control actions or via policy making and normative approaches.

CONCLUSIONS

In this work we present a tool for the development of an integrated planning in air pollution control in a developing country city. This tool could be expanded in order to integrate more available information in terms of the environmental issue of analysis. Using public available information we achieve to main conclusions for the air pollution control in the AVMR region, prospective data should be included in environmental planning since it became a main driver in decision making, and through survey analysis we found that experts are not always consistent with their opinions.

Each day we have more available information that can be used in decision making process. Through the consulting of expert knowledge and opinion, via surveys, we can decide the most relevant criteria in decision and policy making for each environmental scenario (air pollution and population in this case), and provide more refined and accurate the decisions. Including future concerning criteria in the information available for decision making (prospective data), made possible to define in a consistent way the intervention priorities for overcoming a socio-environmental issue.

In this work we found that, according to national and international experts, the relationship between atmospheric pollution and health is a very important driver when making environmental related decisions. We also found that the indicator of urgencies rate for cardio-respiratory diseases is the most relevant in terms of air pollution impact control. We used information regarding health issues for one year, the development of timeline indicators, showing the behavior in time of these impacts in the population quality of life, may be useful for a more accurate decision making and policy making.

Most of the decision makers consulted in this work, are not consistent with their answers in the AHP prioritization developed. Future research includes improving the expert survey by means of some software feature that warns the decision maker of possible inconsistencies in their decisions. Although this could lead to an interesting research problem, we do not agree to interfere with the decision process of experts through warnings, since this could generate biased answers.

The results show that the use of non consistent weights may lead to a more similar weights of the indicators, making difficult the prioritization of zones and furthermore the choosing of one zone for particular intervention. So in survey methodologies and in AHP analysis, the verification of consistency is essential for achieving accurate interventions.

Future work includes considering alternative scenarios for prospective indicators, since it brings a wider panorama regarding the information and its uncertainty and the inclusion of cost-benefit indicators for the intervention in air pollution control for each one of the zones, in order to develop a more accurate methodology decision and policy making.

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