2012 2nd International Conference on Environment and Industrial Innovation
IPCBEE vol.35 (2012) © (2012) IACSIT Press, Singapore

Fuzzy Environmental Assessment of Urban Areas Sustainability

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Abstract. Cities are increasingly becoming the engines of national economic growth and the magnets for new residents flooding in from rural areas. Globalization is having a significant effect on cities, forcing them to compete for international business with other cities worldwide and within their own countries. It is noted that this subject of research represent a high interest current in the world. This article presents a model of fuzzy reasoning to evaluate a city's environmental sustainability The model takes into account four components that characterize ecological component of the ecological environment (air, water, soil and biodiversity) which in turn are characterized by a number of specific parameters to assess the sustainability of a certain city. The model can be used to evaluate the city environmental sustainability.

Keywords: city sustainability, fuzzy logic, decision making

1. Introduction

Cities have become the focal points as major consumers and distributors of goods and services. However, many cities tend to be large consumers of goods and services, while draining resources out of external regions that they depend on. As a result of increasing consumption of resources, and growing dependencies on trade, the ecological impact of cities extends beyond their geographic locations. It has been recognized that the concept of sustainable development is an evolving, debatable term. It is quite natural for environmentalists to be involved in the sustainability debate since the environment already is under enormous strain.

In any case, as shown in Figure 1, the economic activity, with the aid of technology, inevitably generates pollution. The understanding is now settling in that without a robust environment we cannot have a healthy economy over a long period. The economy relies on such things as clean air, water, soil, minerals, and other resources, which are products of the physical and biological environment.

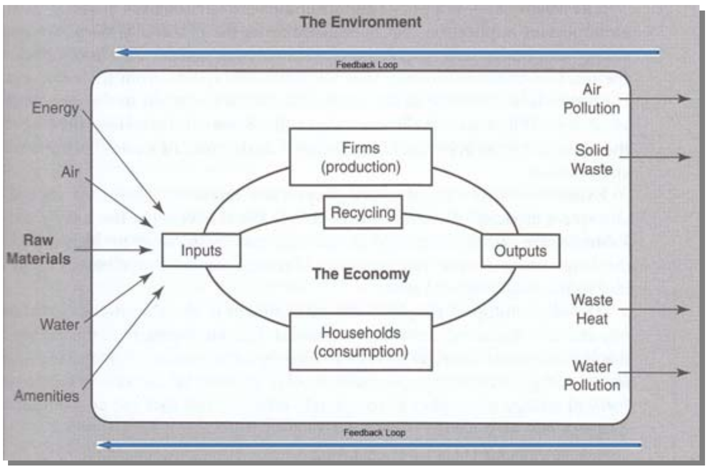

Fig. 1: The economic process

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To assess the performance of an environmental system of a city is necessary to make an integrated analysis of a variety of factors and the existing relationships between these factors often form a complicated problem.There are many approaches and tools available for undertaking analysis of environmental sustainability. Selecting the appropriate method depends upon the purpose and aim of the analysis. Sustainability is a multifaceted concept for which there is no widely accepted definition or measurement method. Certainly, the significance of each of these issues differs in importance from city to city depending on the given city's background. For example, in India the most important urban issue is the migration of people to the cities, while in Europe transportation is important, or in North America urban sprawl is the most pressing issue. As a result, the sustainability of cities is under pressure. Decision-makers at all levels are faced with the task of how to resolve urban problems from transportation to waste management, from drinking water supply to the preservation of urban green space. The sustainability has two broad dimensions, ecological and human. In the following sections we will focus on the environmental dimension of the problem.Fuzzy logic is a scientific tool that permits modeling a system without detailed mathematical descriptions using qualitative as well as quantitative data. Computations are done with words, and the knowledge is represented by IF-THEN linguistic rules. A system based on fuzzy logic can be considered an expert system which emulates the decision-making ability of human expert. Operations performed with fuzzy variables and associated fuzzy rules are based not on precise models of the process, but on understanding physical phenomena, such as: IF (temperature is high) THEN (decrease order)[1].

2. Model Presentation

To assess the performance of an environmental system is necessary to make an integrated analysis of a variety of factors and the existing relationships between these factors often form a complicated problem. Indicators are often used with other types of information. In order to cope with performance assessment of an environmental system specific tools are needed and creative approaches. This is why in this paper we proposed a model based on fuzzy logic to establish ecological sustainability of a specified region. Accordingly, to our methodology the ecological sustainability of the environmental system is composed from three modules: water quality (WATER) soil integrity (SOIL) air quality (AIR) and biodiversity (BIOD). Fig. 2 illustrates the dependencies of sustainability components.

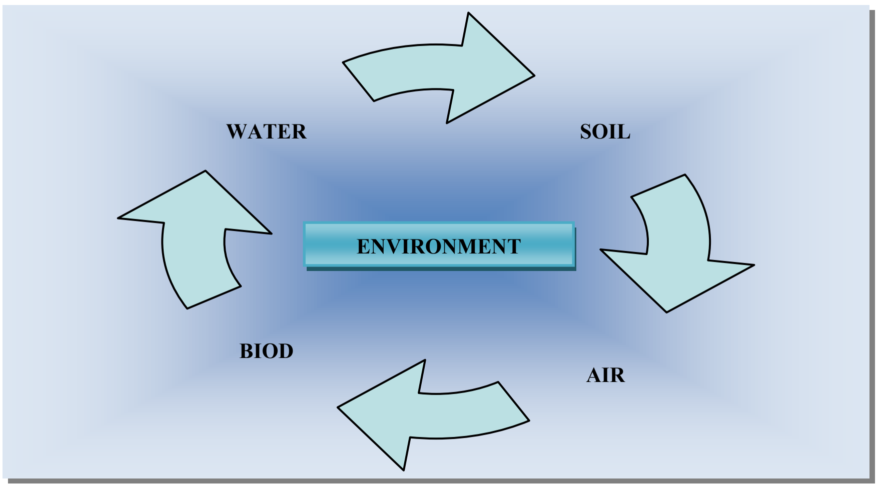

Fig. 2: Dependencies of sustainability components.

According to Fig. 3, the hierarchical structure of the evaluation problem consists of three levels. The first level represents the ultimate aim of the problem (environmental assessment), the second level represents decision criteria, the third level represents the evaluation criteria. The hierarchical structure is very useful for decomposing complex sustainability problems. The problem of environmental assessment is depending of many parameters such as air quality impact, water quality, soil integrity or biodiversity. These parameters are represented by the decision criteria; in the present paper the decision criteria are classified into four main categories namely AIR (air quality), WATER (water quality) SOIL (soil integrity) and BIOD (biodiversity). In order to create the decision criteria several other parameters that affect the criteria are considered.

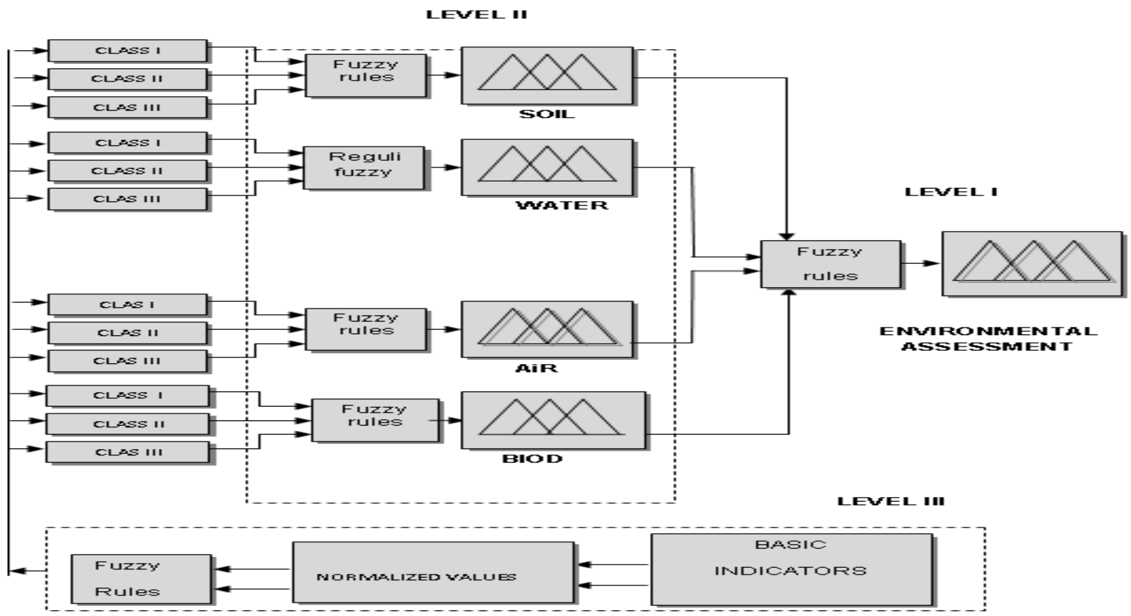

Fig. 3: Configuration of environmental sustainability model

These parameters are represented by evaluation criteria and so on. The model uses a number of relevant knowledge levels to represent the interrelations and principles governing the various indicators and components and their contribution to the final decision of fuzzy system. When the environmental sustainability of a given city is assessed, the model to be used should be tuned to the particular realities of the specific urban area. The model is flexible in the sense that users can choose the set of indicators and adjust the rules of any knowledge level according to their needs and the characteristics the environmental system to be assessed. The indicators from the third level were divided into three types of parameters (CLASS I, CLASS II and CLASS III) because each and every one of these parameters is characterized by *Pressure* (PR), *State* (ST), and *Response* (RE) indicators. [2]. The Pressure-State-Response approach was originally proposed by Organization of Economic Cooperation and Development (OECD 1991) to assess the environmental component of sustainability. A detailed review and variants of this approach are presented in Spangenberg and Bonniot (1998).

3. Case studies

3.1. Basic Indicators

To test the environmental assessment methodology the model has been applied on the town of Iasi in Romania. Iasi is located in the northeast part of Romania, having an area of 3770 ha and a population of 340.000. Until the middle of '90 the town was an important industrial centre in Romania. Since then, the economy is unfortunately decreasing, and air, land and water pollution has reached high values. The choice of basic indicators depends on the type of zone under consideration. Norm and targets for these indicators are dictated by legal requirements and expert knowledge. Below are presented basic indictors taken under consideration for our case and their most desirable and least desirable values related to the specific industry. For the presented case the model is depicted in figure 4.

AIR indicator:

- *GHG: Greenhouse gas (GHG) emissions per capita* (tons of CO2 equivalent).
- *Atmospheric concentrations of NO_2 , SO_2 and total suspended particulates* (AC µ g/m3 of air):

SOIL indicator:

- *Municipal waste generation-MWG* (kg per capita per year):
- *Population growth rate-PGR* (percentage):
- *Protected area –PA* (ratio to surface area):

WATER indicator:

- *Total water withdrawals- TWW* (percent of total renewable resources):
- *Organic water pollutant emissions-OWPE* (BOD, biological oxygen demand in kg per capita per day)
- *Public wastewater treatment plants- PWTP* (percent of population connected):

BIOD indicator:

- *Threatened species* – TS (percentage)

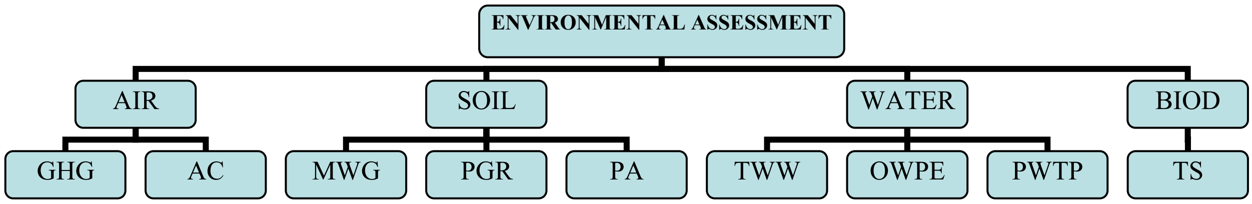

Fig. 4: Environmental assessment

3.2. Normalization and Fuzzification

Basic indicators come in a variety of scales and units. Lower values mean better sustainability performance for some indicators but worse performance for others. For example, land sustainability improves when municipal waste generation decreases but weakens when forest area decreases. To make indicators comparable and to facilitate analysis, the data are normalized on a 0–1 scale by assigning the value 0 to the least desirable indicator values and the value 1 to the most desirable indicator values or targets, which are determined by experts, standards, laws, etc. Normalized values are computed by linear interpolation between most desirable (target) and least desirable indicator values. In order to smooth the normalized values, weighted sum of present and past indicator data is used as input to the model. The normalized time series for each indicator are aggregated into a single normalized value using the method of weighted sum. The results are shown in Table 1. In order to fuzzify the values of basic indicators must use the membership functions whereby a crisp value is transformed into a linguistic variable. Each and every one linguistic variable has a number of fuzzy sets. In our case the linguistic variables of basic indicators have three fuzzy sets with linguistic values "weak" (W), "medium" (M), and "strong" (S), whose membership functions are shown in Fig. 4[3].

Table 1: Normalized value using weighted sum

Indicator	Normalized value
GHG	0.7245
AC	0.469
MWG	0.674
PGR	0.208
PA	0.715
TWW	0.695
OWPE	0.314
PWTP	1

In order to combine two or more fuzzy inputs into a composite indicator it must use more fuzzy sets to represent the composite fuzzy variable. For composite indicators are used five fuzzy sets with linguistic values "very bad" (VB), "bad" (B), "average" (A), "good" (G), and "very good" (VG), as depicted on Fig.4. To represent the output (ENVIRONMENTAL ASSESSMENT) a larger number of fuzzy sets must be used, but for simplicity it has been considered five membership functions will do as in fig.5.

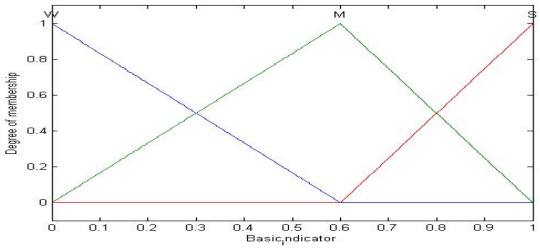

Fig. 4: Membership functions for basic indicators

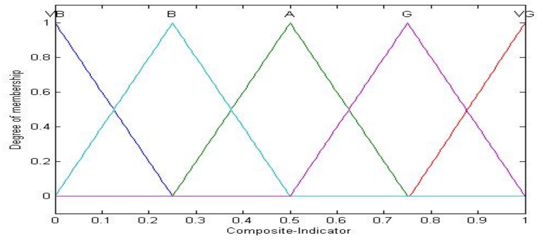

Fig. 5: Membership functions for composite indicators

4. Conclusions and Results

To be able to evaluate the environmental sustainability of a particular region, first of all we must have the possibility to assess the sustainability, using different instruments. Without these tools it is difficult to formulate a coherent strategy. The model we developed is intended to be such an instrument for the formulation of strategies for environmental sustainability. This will take into account a number of parameters considered most significant for the problem addressed. When these indicators change, and their change has impact on sustainability, we can identify the most important parameters that help or hinder its progress towards environmental sustainability.

Table 2: Gradient value of indicators

Description of indicator		Gradients of environmental sustainability
SOIL		
1	Municipal waste generation	-0,00214
2	Population growth rate	0,0000
3	Protected area	-0,0049
WATER		
4	Total water withdrawals	-0,00246
5	Organic water pollutant emissions	-0,00249
6	Public wastewater treatment plants	-0,00485
AIR		
7	Greenhouse gas (GHG) emissions per capita	-0,00159
8	Atmospheric concentrations of NO2 , SO2 and total suspended particulates	-00247
BIOD		
9	Threatened species	-0,005418

As a result, the next step is materialized in recommending actions to increase or decrease the values of the indicators identified as having a role in promoting or hindering sustainable environmental development. Sensitivity analysis plays an important role because it determines the change of a representative parameter on system performance. Sensory analysis involves calculating the partial derivatives (gradients), AIR, WATER and SOIL with respect to their basic indicators. Derivatives of one basic parameter substantiate the increase of environmental sustainability per unit increase of indicator.

If the derivative with respect to a basic indicator is positive, then the indicator is considered as promoting indicator because an increase of his value will lead to a higher sustainability. On the other hand, if the derivative is negative, then the indicator is classified as impeding indicator, because an increase of his value will reduce the degree of sustainability. If the derivative is zero, then it is accepted the idea that the respective parameter has no substantial effect upon de sustainability (Table 2)[4].

The fuzzy model can be implemented for the assessment of ecological systems, to determine appropriate methods of action for reducing adverse effects on population and implicit the environment. The developed model, represent an attempt to provide an explicit and comprehensive description of the concept of environmental sustainability. The model proposed provides new insights of sustainable development, and it may serve as a practical tool for decision –making and policy design at the local or regional levels.

5. Acknowledgements

This work was supported by CNCSIS-UEFISCSU, project number PN II-RU 627/2010, PN II-RU 342/2010 and by the project PERFORM-ERA "Postdoctoral Performance for Integration in the European Research Area" (ID-57649), financed by the European Social Fund and the Romanian Government and Sectorial Operational Programme for Human Resources Development through the project "4D-POSTDOC" POSDRU/89/1.5/S/52603.

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