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Environmental Assessment for Sustainability Determination based on Fuzzy Logic Model

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***Abstract*—In the recent years, the scope of environmental studies has expanded dramatically all over the world. This paper aims to build a system based on fuzzy models that can be implemented in the assessment of ecological systems, to determine appropriate methods of action for reducing adverse effects on environment and implicit the population. It is noted that this subject of research represent a high interest current in the world. In situations difficult to approach methods with modeling conventional, are proposed as a reliable alternative pathways to fuzzy logic-based modeling.**

Keywords-environmental assessment, fuzzy logic, sustainability;

I. INTRODUCTION

The present era of fast development and growth is aimed at raising the quality of human life by providing greater opportunities for employment, better provisions of basic amenities and comforts, healthy environment ensuring physical and mental well-being of humans.

Issues like global warming, depletion of ozone layer, dwindling forests and energy resources, loss of global biodiversity etc. which are going to affect the mankind as a whole are global in nature and for that we have to think and plan globally.

Human development, especially in the twentieth century, represents an intrusion into the overall balance that maintains the earth as a habitable place. We are recognizing this fact in our concern for the environment, but most of us are also reluctant to give up the profligate consumption of resources which characterizes the modern lifestyle [1].

Public concern about environmental issues has prompted activity to obtain a detailed understanding of ecosystems, to establish operative norms and ranges for typical environments and to remediate damaged environments. Environmental concerns are so deeply felt that they have become the basis for organized political activity on national levels. The range of issues which may need to be considered while preparing an environmental assessment is very large indeed. Some become relatively more important at one time than at another, while new problems arise constantly. It is for this reason, among others, that it is difficult to build into legislation or regulations a required set of items to be covered in every case. We present here some contemporary issues which are currently important, and suggest ways in which consideration of these problems enter into an assessment. There are certainly many other problem areas which may be more important in certain instances, but each of these has some history of being relevant to national and international decision making[1].The dynamics of any socio-environmental system cannot be described by the rules of traditional mathematics. Sustainability is difficult to define or measure because it is inherently vague and complex concept [2].

In this paper, a fuzzy model was developed, which uses data sampled from different environmental indicators that were then processed via fuzzy logic algorithms to derive measures for ecological sustainability of the region. Fuzzy logic is able of representing uncertain data, and handling vague situations where traditional mathematics is ineffective. Based on this approach we have developed a fuzzy model which uses basic indicators of environmental integrity, as inputs and employs fuzzy logic reasoning to provide sustainability measures on the local levels. A sensitivity analysis identifies the factors affecting sustainability. In this study, trials were made to identify those factors that influence the environment. About twenty indicators were tested and classified according to sensitivity as promoting, impeding, or having no effect on sustainability.

The method could become a useful tool to decision makers as they strive towards sustainability.

II. MODEL PRESENTATION

Environmental performance assessment related to a town region or a district is becoming a major issue worldwide and particularly in Europe. 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) and air quality (AIR). Fig. 1 illustrates the dependencies of sustainability components.

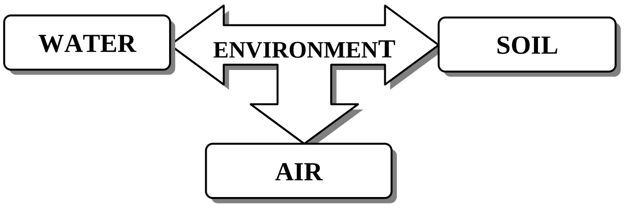

Figure 1. Dependencies of sustainability components.

The configuration of the model is shown in Fig.2. The model is composed from different sets of knowledge levels. The inputs of each knowledge level represent the parameters which can be provided by the user or composite indicators collected from other knowledge levels. By using fuzzy logic and IF-THEN rules, these inputs are combined to yield a composite indicator as output which represents an input for the subsequent knowledge level. For instance, the third order knowledge level that computes indicator AIR combines indicators TYPE 1, TYPE 2, and TYPE 3 indicators of air quality, which are outputs of fourth order knowledge level. Then, AIR is used in combination with SOIL and WATER as input for the first order knowledge level and so assesses ENVIRONMENT SUSTAINABILITY. The indicators from the third knowledge level were divided into three types of parameters because this way the analyze we believe would be is more accurate [2].

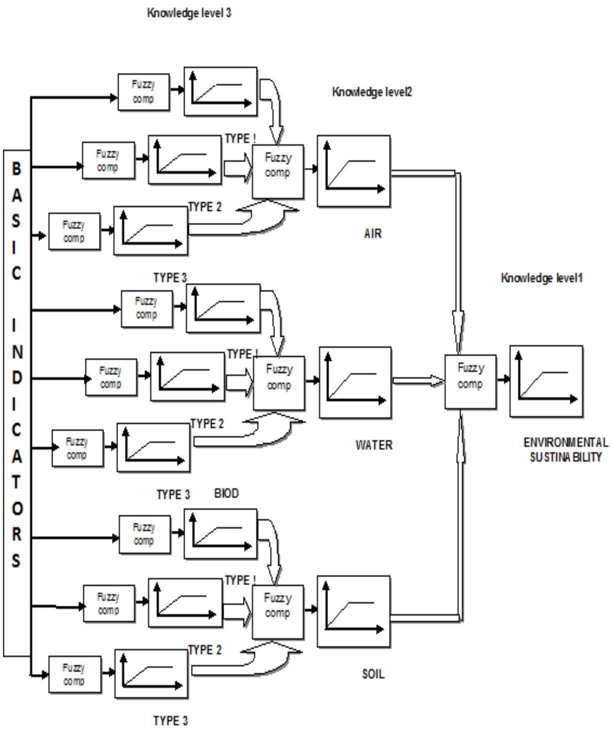

Figure 2. Configuration of environmental sustainability model

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.

III. Environment Assessment Methodology

A. Fuzzy logic overview

Fuzzy logic was introduced by Zadeh [3] as an extension of the classical two-valued logic, in which a proposition is either true or false and an object either belongs or does not belong to a set. Zadeh studied the concept of vagueness by assuming that propositions and set memberships are true with degrees ranging from 0 (100% false) to 1 (100% true). This method can handle incomplete knowledge and inexact or vague data in a systematic way.

Fuzzy logic is often referred to as a way of "reasoning with uncertainty." It provides a well-defined mechanism to deal with uncertain and incompletely defined data, so that one can make precise deductions from imprecise data. The fuzzy theory provides a mechanism for representing linguistic constructs such as "many," "low," "medium," "often," "few." In general, the fuzzy logic provides an inference structure that enables appropriate human reasoning capabilities [4].

Fuzzy sets are commonly used to express the way humans extract qualitative information from numerical, categorical or linguistic data, and the way they rate, summarize, and process this information to make decisions and assessments. To this end, a fundamental concept of fuzzy logic is the notion of linguistic variable introduced by Zadeh [5],[6]. Loosely speaking, a linguistic variable is a variable "whose values are words or sentences in a natural or artificial language," as Zadeh has put it. More precisely, a linguistic variable is a fuzzy partition of some physical domain X into possibly overlapping regions. Each region isrepresented with a fuzzy set in X called linguistic value.

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. The user supplies facts or other information to the expert system and receives expert advice for his queries. The internal organization of an expert system consists of a knowledge-base and an inference engine. The knowledge –base contains the knowledge with which the inference engine draws conclusions. The inference engine is a control structure which helps in generating various hypotheses leading to conclusions that from the basis of answers to user queries [7]. Fuzzy logic introduced by Zadeh permits the notion of nuance. It presumes that this condition could be anything from almost true/false to hardly true/false. Generally, a fuzzy set F in a universe of discourse X is described by a membership function μ_F , which maps the set X to the membershis space M∈ [0,1]. The membership function μ_F (x) represents the grade of membership of x in F. The closer the value of μ_F (x) is to 1, the more x belongs to F [8].

The membership function that was used in the problem of environmental sustainability is shown in Fig. 3.

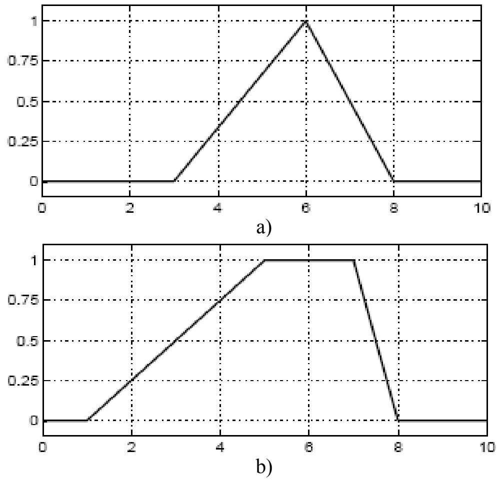

Figure 3. Membership function: a) triangular, b) trapezoidal

In order to combine evaluation criteria two methods were used: weighted average and weighted product described in (1) and(2):

$$V_i = \sum_{j=1}^{n} w_j * v_{ij} \tag{1}$$

$$V_i = \prod_{j=1}^{n} v_{ij} \cdot w_j \tag{2}$$

where V_i - represents the final grade of area *i*, w_j - represents the relative importance weight of criterion *j*; v_{ij} - represents the grading value of area *i* under criterion *j* and *n* represents total number of criteria.

B. Methodology application

According to Fig. 2, the hierarchical structure of the evaluation problem consists of 4 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 and the fourth level represents evaluation sub 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 or soil integrity. Of course there are many factors that can influence the environment as biodiversity but this fact represent the object of another study more complex and more elaborate, and for the moment we consider that these three factors have the predominant role. These parameters are represented by the decision criteria; in the present paper the decision criteria are classified into three main categories namely AIR (air quality), WATER (water quality) and SOIL (soil integrity). In order to create the decision criteria several other parameters that affect the criteria are considered. 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 the expert system.

For example SOIL is a component of environmentl sustainabiliy. Type 1 for short, is an aggregate measure of the changing forces human activities exert on land. To compute this parameter we use several inputs but, for simplicity, here we consider only two of them: Solid and liquid waste generation (WASTE) and population growth rate as percentage of the current population of a country (GROWTH). The inputs are represented by three linguistic values, L (low), M (medium), and H (high). Although we use the same term set for both inputs, the linguistic variables have different universes of discourse, as shown in Figure 4.

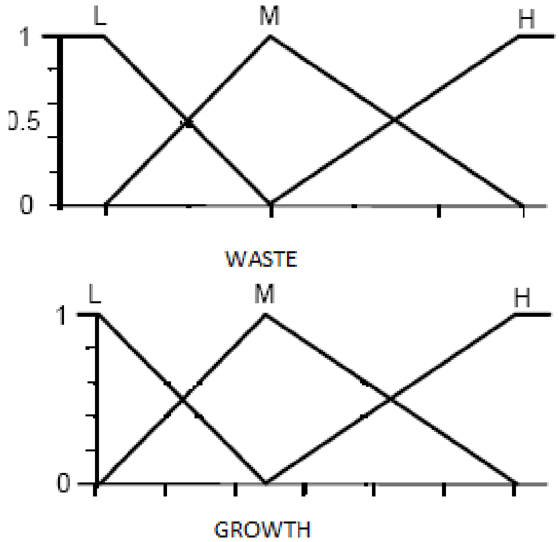

Figure 4. Membership function for WASTE and GROWTH

The rules and inputs/outputs of each knowledge level are expressed symbolically in the form of words or phrases of a natural language and mathematically as linguistic variables and fuzzy sets. Examples of IF-THEN rules used in the model are:

-IF AIR is good AND WATER is bad, AND SOIL is good THEN QUALITY MANAGEMENT EVALUATION is average;

By using fuzzy logic and IF-THEN rules, these inputs are combined to yield a composite indicator as output, which is then passed on to subsequent knowledge levels [9].

IV. CASE STUDIES

To test the environmental assessment methodology the model has been applied to 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 center in Romania. Since then, the economy is unfortunately decreasing, but pollution with solid and liquid waste, toxic waste has reached high values.

The primary components of environmental sustainability (AIR; WATER, and SOIL) and their sensitivities to various input indicators were computed are presented in Table I.

TABLE I. INDICATORS USED IN SUSTAINABILITY MODEL

Component	Type 1	Type2	Type 3
AIR	SO_2 emissions, CO_2 emissions CH_4 emissions	Atmospheric concentration of greenhouse and ozone depleting gases: CO_2 , NO_2 SO_2 CH_4 CFC-12	Fossil fuel use, (Primary electricity production Public transportation
WATER	(Water pollution Urban per capia water use Freshwater withdrawals	Annual internal renewable water sources	Percent of urban wastewater treated
SOIL	Solid and liquid waste generation Population density Growth rate Commercial energy use	Net energy imports Domesticated land Forest and wood-land area	Primary energy production Nationally protected area Urban households with garbage collection

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. 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. A derivative 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[10] (Table II).

TABLE II. INDICATORS USED IN SUSTAINABILITY MODEL

Description of indicator		Gradients of environmental sustainability
SOIL		
1	Solid and liquid waste generation	-0,00125
2	Population density	-0,00064
3	Growth rate	0,0000
4	Domesticated land	0,0000
5	Forest and wood-land area	0,00250
WATER		
6	Urban per capia water use	-0,00265
7	Freshwater withdrawals	-0,00249
8	Phosporus concentration	-0,00479
9	Water pollution	-0,00415
10	Percent of urban wastewater treated	0,00257
AIR		
11	Atmospheric concentration of greenhouse and ozone depleting gases: CO_2 , NO_2 SO_2 CH_4 CFC-12	-0,00219
12	NO2 emissions	-0,00513
13	SO2 emissions	-0,00514

According to the sensitivity analysis projects can be proposed to improve promoting indicators, and taking measures to correct impeding factors.

According to the sensitivity results, a sustainable environment is dependent on enhancing the following factors in order of importance:

- Percent of urban wastewater treated;
- Forest and wood-land area;

and decreasing the following impeding factors

- Water pollution;
- NO2 emissions;
- Freshwater withdrawals;
- Solid and liquid waste generation;
- SO2 emissions;

V. CONCLUSIONS

This paper aims to build a system based on fuzzy models that can be implemented in the assessment of ecological systems, to determine appropriate methods of action for reducing adverse effects on environmental and implicit the population. The developed model, represent an attempt to provide an explicit and comprehensive description of the concept of environmental sustainability. Using linguistic variables and linguistic rules, the model gives quantitative measures of ecological sustainability. Then, the problem of sustainable decision-making becomes one of specifying priorities among basic indicators and designing appropriate policies that will guarantee sustainable progress.

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.

In the future we will try to extend this system by incorporating more representative environmental parameters after discussions with specialists. Thus the system will be able to provide a more concrete analysis of a studied ecosystem.

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REFERENCES

[1] R. Jain, L.V. Urban, G.S. Stacey, H. Balbach, Environmental assessment, 2nd ed., Digital Engineering Library @ McGraw-Hill, www.digitalengineeringlibrary.com

[2] Y.A. Phillis, L.A. Andriantiatsaholiniaina, "Sustainability: an ill-defined concept and its assessment using fuzzy logic", Ecol. Econ., 37, 2001, pp.435-456 .

[3] L.A. Zadeh "Fuzzy sets," Information and Control, Vol 8, pp. 338–353,1965.

[4] G. J. Klir and B. Yuan, Fuzzy Sets and Fuzzy Logic, Prentice-Hall, New Jersey, 1995.

[5] L.A. Zadeh "Outline of a new approach to the analysis of complex systems and decision processes," IEEE Transactions on Systems, Man and Cybernetics, Vol. SMC-3, 28–44. (1973)

[6] Zadeh LA "The concept of a linguistic variable and its application to approximate reasoning–I, –II, –III," Information Sciences, Vol. 8, pp. 199–249 (a); Vol.b8, pp. 301–357 (b); Vol. 9, pp. 43–80 (c),1975.

[7] L.A. Zadeh "The role of fuzzy logic in the management of uncertainty in expert systems", Fuzzy Sets and Systems, Vol. 11, 1983, pp. 199–227.

[8] K. Tanaka, An Introduction to Fuzzy Logic for Practical Applications, Springer-Verlag, New York, 1997.

[9] Y.A. Phillis, V.S. Kouikoglou, "Fuzzy measurement of sustainability" Nova Science Publishers, Inc. New York, 2009

[10] R Prescot-Allen. "Barometer of Sustainability: A Method of Assessing Progress towards Sustainable Societies", PADATA, Victoria Canada, IUCN, Gland, Switzerland, 1996.

[11] L.Andriantiatsaholiniaina, V.S Kouikoglou, Y.A. Phillis, "Evaluating strategies for sustainable development: fuzzy logic reasoning and sensitivity analysis", Ecological Economics, Vol. 48, No 2, 2004, pp. 149–172