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Ecosystem Model for Environmental Applications

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***Abstract*—**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 model proposed provides new perspective for environmental assessment, and it can be used as a practical instrument for decision – making.

***Keywords*—**Ecosystem model, Environmental security, Fuzzy logic, Sustainability of habitable regions.

I. Introduction

THE human development through uncontrolled industrialization, especially in the twentieth century, represented an intrusion into the overall balance at fine ecosystems level. In the last decades, environmental issues have become more visible and compelling for the society, due to increased public interest for better understanding of ecosystems in order to efficiently intervene towards mitigating the human negative impact and improve the sustainability of habitable regions.

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.

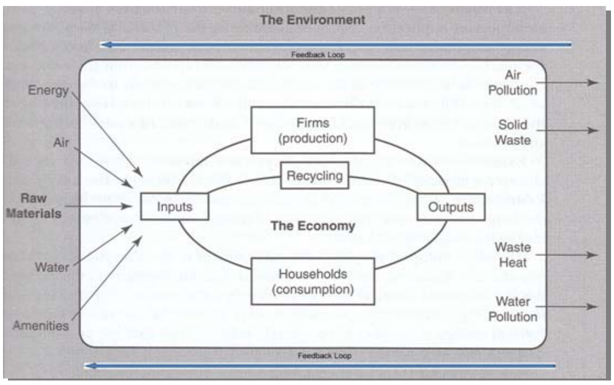

Fig. 1 The economical process

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To assess the performance of an ecosystem 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 region to region 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 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 [1].

Ability of fuzzy logic to represent uncertain data and to cope with vague situations where traditional mathematics is ineffective, makes it a worth trusty tool to use. Based on this approach it was 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.

II. Concept of Ecosystem Model

The fuzzy model is a layered-based structure including:

Geo-bio-physical knowledge:

- three environmental components,
- one component related to biodiversity,
- three strategic development issues and
- one related to cultural level;

Input membership functions

- minimum three Gaussian membership functions for environmental components and direct assignment functions for sustainability issues;
- Fuzzy rules, each connected to three input membership functions (PRESSURE, STATUS and RESPONSE);

Output membership functions;

- Aggregated output: each output membership function gets aggregated with the weight they carry;

The outcome based on computed fuzzy rules is represented by *environment sustainable development* (see Fig. 2).

Environmental performance assessment related to ecosystem 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.

The proposed concept of ecosystem model for environmental security is flexible in the sense that users can choose the set of indicators and adjust the rules at each knowledge level, according to their strategic plans and measurable characteristics of environmental system to be assessed. The model is based on fuzzy logic; a scientific tool that permits the modeling of a system by aggregating together detailed mathematical descriptions, quantitative measured data and qualitative attributes. 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 form the basis of answers to user queries.

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.

As shown in Fig. 2, environment sustainable rehabilitation strategy (ESRS) in the model encompasses two broad components, called primary indicators, ecological sustainability (BIO-ECOS1) and human sustainability (HUMAN-ECOS2). The ecological dimension of sustainability comprises four secondary indicators: air quality (AIR) land integrity (SOIL), water quality (WATER), and biodiversity (BIODIVERSITY). The human dimension of sustainability comprises another four secondary indicators: political aspects (POLITICAL), economic welfare (ECONOMICAL), health (HEALTH), and education (CULTURE).

Each secondary indicator is evaluated by means of three tertiary indicators: PRESSURE, STATE, and RESPONSE indicators. State is the present state of a component such as the size of forested land. Pressure is a force tending to change State such as the deforestation rate. Response is the reaction taken to bring Pressure to a level that will guarantee a better State as, for example, protecting a given area. The Pressure-State-Response approach was originally proposed by Organisation for Economic Co-operation and Development (1991) to assess the environmental component of sustainability.

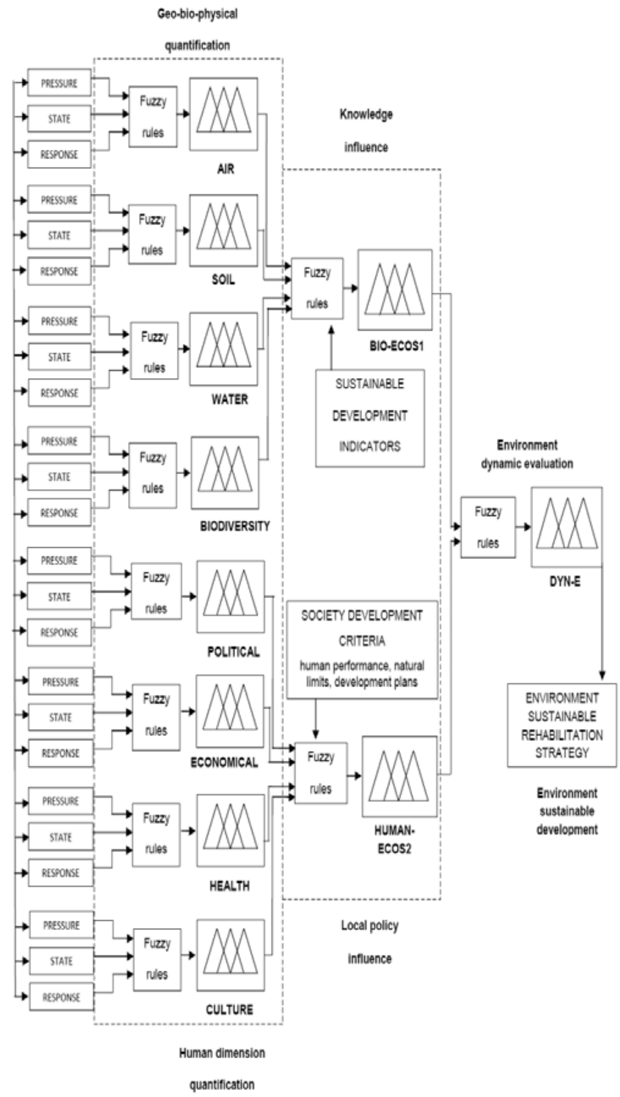

Fig. 2 Configuration of environment sustainable rehabilitation model

Finally, each tertiary indicator is a function of a number of more specialized indicators

For example, the state of biodiversity is an aggregate measure of the forest area and the numbers of plant, fish, and mammal species per square kilometer. We call these indicators basic because they are the starting point for computing all the composite indicators described above [2].

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. When the environmental impact of a certain region is assessed, the model to be used should be tuned to the particular realities of the eco-system.

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III. MATH

A. Fuzzy Logic Outlook

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]. 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 is represented 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 [6]. 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.

B. Methodology Application

Accordingly 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 sustainable development), 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 environmental sustainability. 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 Fig. 3.

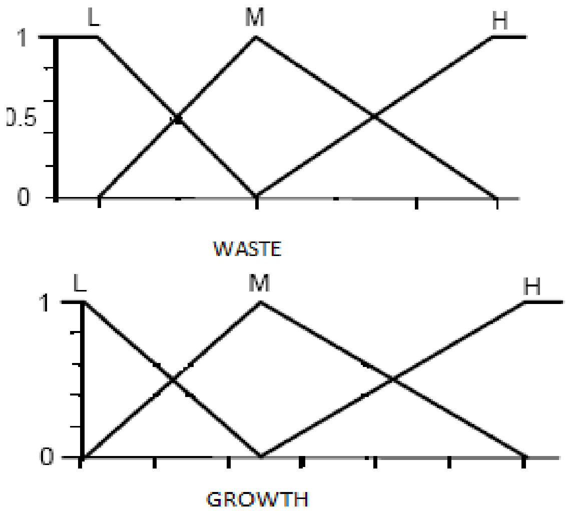

Fig. 3 Membership function for WASTE and GROWTH

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 [7].

IV. Case Studies

In order to apply the methodology for environmental assessment the city of Iasi located in the north-east of Romania, it was chosen. The town area is about 3770 hectares and a population of 340,000. By the mid '90s, the city was an important industrial center in Romania but since then, the economy went down, unfortunately, instead leaving high values of pollution levels (toxic solid and liquid waste). The components of environmental assessment (AIR, WATER, and SOIL) and their various characterizing indicators are presented in Table I.

TABLE I
INDICATORS USED FOR ENVIRONMENTAL ASSESSMENT

Component	PRESSURE	STATUS	RESPONSE
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. 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 [8] (Table II).

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

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 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;
- NO_2 emissions;
- Freshwater withdrawals;
- Solid and liquid waste generation;
- SO_2 emissions;

A very important thing is the indeterminate nature of human resources expert decisions. This is why a very high accuracy of classification cannot be expected. The same expert may easily make different decisions on the same data at different times. It is widely believed that different experts are also likely to make different decisions even under the same circumstances. Moreover environmental changes may have their own influence on decision making, so periodic training on as recent data as possible is required. Therefore, the reported values cannot give information about the quality of the decisions that the system makes, only about the performance of following the decisions launched by the surveyed expert. This problem is present in firm environmental organizations as well: they don't have a given model or formula to effectively evaluate expert performance.

V. Conclusion

In order to provide an explicit and comprehensive model able to cope with environmental sustainability concept a fuzzy based system was developed. The model outcome based on linguistic variables and linguistic rules turns out to be the strategy for sustainable environment rehabilitation model providing 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. Implementation of the model is intended to be a different approach based on computing techniques to environmental issues, establishing appropriate methods of action for reducing adverse effects on population and implicit the environment.

The hierarchical structure of the proposed ecosystem model is very useful for decomposing complex problems related to environmental sustainability. The 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 or human activity and policy, which must be balanced according to the polluted sites analysis to accurately account only for the factors that have the predominant role.

This system permits incorporation of all information which may be to hand, however ambiguous or subjective it may be, and cope with the lack of precision that is a concomitant of this sort of decision making process. Environment assessment for varying activities performed by organizations requires a coherent approach, which cannot be simplistic, to the information held.

Acknowledgment

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