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SPATIAL ASPECTS OF RISK MANAGEMENT: CASE OF STUDY OF AGRICULTURAL DROUGHT MITIGATION

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1. INTRODUCTION

Drought is a protracted period of deficient precipitation resulting in extensive damage to crops, resulting in loss of yield. Lack of rainfall for an extended period of time can bring farmers and major metropolitan areas to their knees.

Recently the methodology of management of agricultural drought mitigation was developed very quickly and is based on physical–statistical and statistical methodologies [12].

Statistical models of management of agricultural drought mitigation fit a set of equations to data derived from field experimentation. However in many cases, especially in a natural environment, information is inadequate to calculate probability standards. In other words, many elements that are part of management of agricultural drought mitigation can not always be expressed with probabilistic methodologies. The fuzzy set approach is an alternative procedure to characterise these processes.

The central concept of fuzzy set theory is the membership function, which represents the relationship of an element to a set. In classical sets theory, the membership of a set is defined as true or false, 1 or 0. The membership function of a fuzzy set, however, is expressed on a continuous scale from one (full membership) to zero (full non-membership). One of the principal benefits of the application of fuzzy set theory in real world planning situations is that most indices of the planning process can be estimated by using membership functions. In particular, by setting the membership function to one, we symbolise a maximum value of the indicator (or criterion) of the planning process, and setting membership function to zero, we represent a minimum of value of the indicator.

Fuzzy set theory has become of the utmost relevance in most engineering areas. In a broad sense, engineering applications involve goals to be achieved under technical, economical, and social constraints. Important advantages of the fuzzy set theory is its ability to deal with linguistic variables. Jager [1] states that *"the main motivation of fuzzy set theory is apparently the desire to build up a formal quantitative framework that captures the vagueness of human knowledge as it is expressed via natural languages"*. Decision-makers most often use linguistic constructs for expression of it-self perception of a problem.

Currently, the combination of geographical information system (GIS) with fuzzy set theory and deterministic models is a popular procedure that is used in many different fields to address a variety of questions and problems [9]. In this paper is discussed preliminary phase of research devoted to application of the approach for management of agricultural drought mitigation.

2. METHODOLOGY

A more appropriate way for drought mitigation management is the GIS fuzzy modelling approach (GISFM) [3 - 7]. GISFM is based on the combination of GIS with fuzzy set theory and crisp (conventional) models.

The four main steps used to realise a GISFM approach are as follows [8]:

- *Structuring phase*: perception of problem, identification of input and output data, obtaining of missed data using crisp models, definition of alternatives and criteria;
- *Fuzzy modelling phase*: building of membership functions, selection of fuzzy algorithm for integration in GIS environment;
- *Programming phase:* selection of suitable existed software or designing of a new one; and
- *Evaluation phase:* creation of thematic maps, which reflect evaluation criterion; perception of results obtained.

The distinguishing feature of the GISFM approach is the fact that indicators or criteria are defined using membership functions. The structuring phase includes the identification of criteria as membership functions. A membership function is selected for each indicator or criterion. The choice of a membership function is somewhat arbitrary and should mirror the subjective expert opinion.

GISFM software is built up in accordance with a special kind of interfacing. In the case of the integration of a fuzzy model into a GIS environment, the same programming language should be used for both GIS software and programming of the fuzzy model. For example, if it is assumed that GISFM approach will be carried out on the basis of MapInfo® software, then MapBasic® should be used as the language for programming of the fuzzy model. Let's to consider details of application of GISFM for study of drought mitigation.

2.1 Structuring Phase

Generally the drought mitigation management is defined on the basis of the spatial and temporal features of agricultural plots, on the one hand, and meteorological characteristics, on the other hand. In the case of study we can assign two indices: environmental and biological.

Environmental index can be defined by soil wilting moisture. It is well known that a protracted period of deficient precipitation tends to decrease soil moisture. As the result of it soil moisture reduces to wilting moisture. Let us to consider a soil water content indicator (*SWI*) denoted as follows

$$SWI = w_{wilt} / w, \qquad (1)$$

where w is current soil moisture and w_{wilt} is wilting moisture.

It is clear that if SWI is less than 1 then we have available moisture. In the case if *SWI* is more than 1 then soil moisture is equal to wilting moisture.

The soil water content indicator can be characterised by two threshold values. Using the upper threshold value (th_{up}) it is possible to describe boundary of permanent wilting. By the use of low threshold value (th_{low}) we can define the initial point of drought.

Crop water demand depends on prevailing weather conditions, biological characteristics of the specific plant, its stage of growth, and the physical and biological properties of the soil. Therefore the biological index of the drought mitigation management is defined as an integrated indicator taking into account impacts of these characteristics.

2.2 Fuzzy modelling phase

Environmental index. In this study environmental index is described mathematically by appropriate membership function $\boldsymbol{\mu}(SWI)$ as follows:

$$\mu(SWI) = \begin{cases} 0; & SWI < th_{low} \\ f(SWI); & th_{low} \le SWI \le th_{up} \\ 1 & SWI > th_{up} \end{cases} \qquad (2)$$

It is easy to see that $\mu(SWI)$ has grades in the interval [0,1]. $f(SWI)$ can be described by different mathematical expressions. In this study it is selected linear function as follows:

$$f(SWI) = (th_{up} - SWI)/(th_{up} - th_{low}) \qquad (3)$$

The membership function in graphical form is shown in Figure 1 and one can see that if *SWI* is below the lower threshold, the soil water is available, but if *SWI* is above the upper threshold the situation is fully classified as permanent wilting.

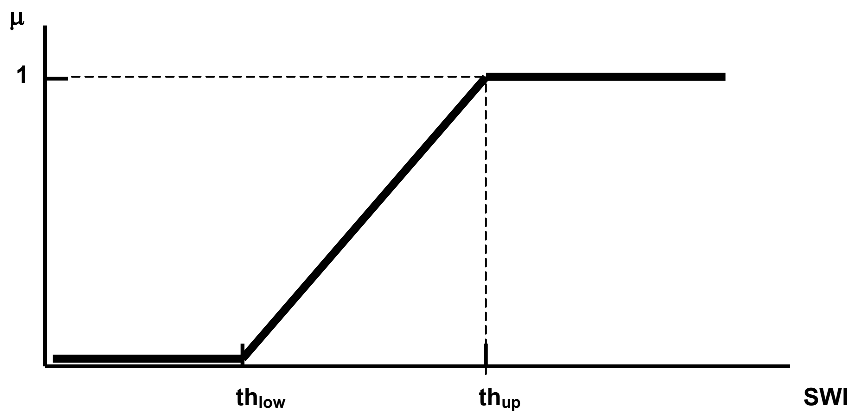

Fig. 1 The fuzzy linear membership function.

Biological index. Problem of description of this index for the drought mitigation management is connection with development of the knowledge-based subsystem.

In computer science and engineering, the term "knowledge" means the information (Pedrycz and Gomide, 1998). Because knowledge is important for intelligent behaviour, the representation of knowledge is a central issue. Knowledge representation embraces all faculties aimed at organising pieces of evidence necessary to capture domain knowledge.

For computation the knowledge has to have a manipulable representation. One useful way for manipulable representations of knowledge is the rule-based knowledge representation**.**

Rules provide a formal way of representing directives and are often appropriate when domain knowledge results from empirical associations or experience. Generally, knowledge may be viewed as a collection of propositions in a language. The basic information unit is a proposition of the type

The (attribute) of (object) is (value) (4)

Rules are conditioned propositions. The *if* parts of *if-then* rules are generically called antecedents, whereas the *then* parts are their consequents. The syntax and semantics of rules are described by several kind of scheme [11].

Current analysis of the state of the art of existing knowledge-based systems show that FuzzyCLIPS [10] is an appropriate basis for design of algorithm for computation of biological index. This is due to the fact that main factors are characterised by uncertainty or fuzziness. Uncertainty occurs when one is not absolutely certain about a given factor affecting on biological index. The degree of uncertainty is usually represented by a crisp numerical value on a scale from 0 to 1. Fuzziness occurs when the boundary of a piece of information is not clear-cut. Fuzziness is taken into account by fuzzy sets.

Uncertainty and fuzziness can take into account using three types of simple rules: crisp simple rules, fuzzy_crisp simple rules, and fuzzy_fuzzy simple rules [10]. Crisp simple rule is regulation, which does not contain a fuzzy object. Fuzzy_crisp rule is precept, in which the antecedent contains only a fuzzy fact. Fuzzy_fuzzy rule is order, in which both antecedent and consequent contain fuzzy facts.

A suitable way of taking into account the measure of trust to these rules was developed in FuzzyCLIPS [10]. In this study we applied this approach. The measure of trust is evaluated by the certainty factor.

For crisp simple rules and fuzzy_fuzzy simple rules certainty factor is determined as

$$CFc = CFr * CFf \quad (5)$$

where CFr is the certainty factor of the rule, *CFf* is the certainty factor of the fact, *CFc* is the certainty factor of the conclusion.

For fuzzy_crisp simple rules certainty factor is defined as

$$CF_c = CF_r * CF_f * S \quad (6)$$

where *S* is a measure of similarity between the fuzzy.

2.3 Programming phase

Algorithm for computation of the environmental index contains two main components: commercial GIS software and decision support subsystem (DSS). GIS is realised by MapInfo software. DSS is designed on the basis of mathematical relations (1) - (3), the knowledge-based subsystem and the soil water balance model [6]. All components are linked by file exchange mechanism.

2.4 Evaluation phase

In the preliminary phase of this research a GIS algorithm intended for computation of soil moisture and based on the use of the soil water balance model [6] was studied. With this aim in mind a GIS database describing the agricultural area located in the suburbs of Saint Petersburg was developed. The selected area consists of 104 homogeneous agricultural fields. These fields differed in soil type, field cultivation (fig. 2A), soil hydrology, microclimate, soil acidity, etc.

Information of this GIS database was used as input for calculation of soil moisture. The first result of computation of soil moisture showed suitability of the GIS algorithm (fig. 2B). Currently this research is being continued.

3. CONCLUSION

Preliminary phase of research devoted to application of the GIS fuzzy modelling approach for management of agricultural drought mitigation was carried out. In particular, main indices of drought mitigation were defined on the basis of fuzzy set concept. The soil water balance model, which is necessary to calculate soil moisture, was selected. The first result is shown that the GIS fuzzy modelling approach is the appropriate way for development of methodology of agricultural drought mitigation.

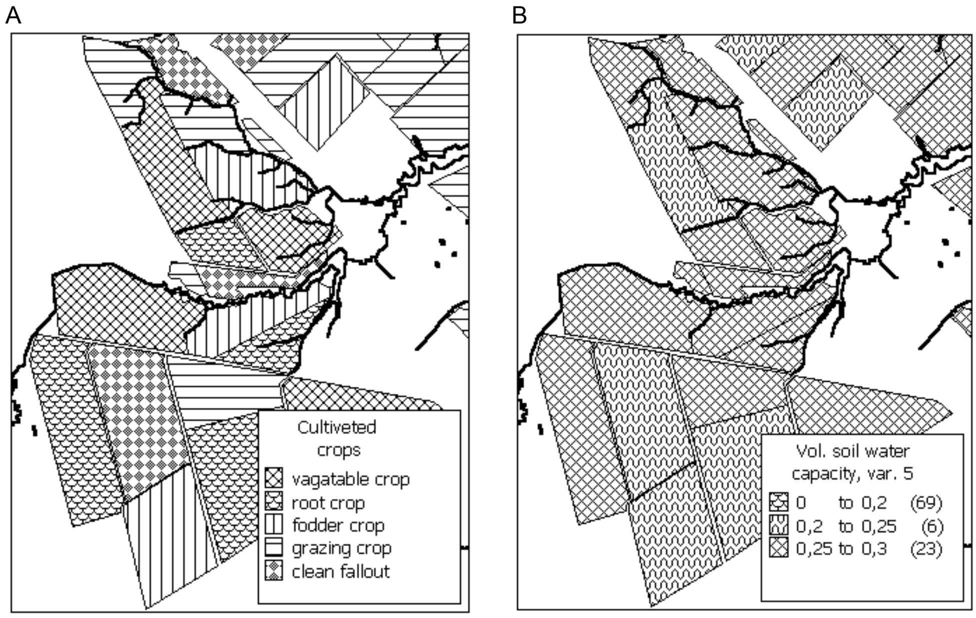

Fig. 2 Distribution of cultivated crops (A) and mean values of the volumetric soil water content (B).

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