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Applications of Fuzzy Logic in Geographic Information Systems for Multiple Criteria Decision Making

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1 ABSTRACT

This work will present some of problems in making spatial analyses, study done as part of making Spatial Plan of Tuzla Canton. This procedure in classic GIS is very demanding in time and it is unsuitable for decision making in real time. Limitations of multi criteria analyses in standard GIS are necessity to define all steps in advance and inability to simple change criteria or thresholds later.

Here will be shown how incorporation of fuzzy set into GIS is improving system's level of intelligence and have useful implications for spatial data handling.

Contrary to classic method, where was everything done graphically, this methodology moves whole process to database side. This approach put time demand part in preparation of process and delaying defining criteria to time of creating queries. This makes possible doing such multiple criteria decision making in real-time. Also, very important issue is that results could be ordered according to its importance for decision makers.

2 INTRODUCTION

Geographic Information Systems (GIS) are computer based systems designed to support the capture, management, manipulation, analysis, modeling and display of spatially referenced data at different points in time. Today, GIS are widely used in many government business and private activities, which fall into three major categories:

socio-economic applications (urban and regional planning, cadastral registration, archaeology, natural resources)

environmental applications (forestry, fire and epidemic control) and

management applications (organization of pipeline networks and other services such as electricity and telephones, real-time navigation for vessels, planes and cars).

In these applications GIS provide decision makers with effective tools for solving the complex and usually not-at-all or semi-structured spatial problems.

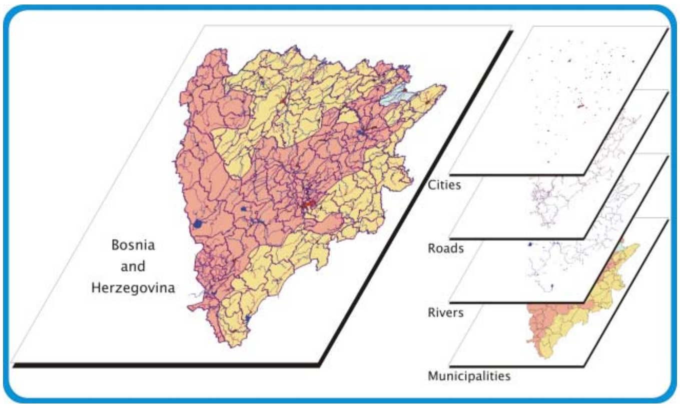


Figure 1: Map of Bosnia and Herzegovina made from layers

GIS contains various interrelated information for urban planners: cadastre maps, altitudes, urban plans, land use, economic development information, demographic information and various statistical analyses. GIS maps are layered, with each layer consisting of information related to the area contained in the map, such as spatial objects (roads, rivers, lakes, etc.), population distribution, land division, etc. Regarding spatial objects, the GIS contain a special feature that allows their illustration in either vector form or with abrupt fields (grid and raster).

GIS also has capability to show different kinds of objects (houses, lakes, plots of land) by using simple geometric forms to represent them: dots, lines and polygons. For example, polygons can be used to represent objects big enough to be shown with borders (lakes, parks, municipalities), lines can be used to draw linear objects such as rivers and roads, and dots are useful for illustrating small objects such as trees and other abutments.

The primary function of GIS includes: geoprocessing, 3D visualization, interoperability, cartography and infrastructure. GIS provides a mechanism for data integration, management and analysis, and generates concise reports on spatial environment. This tool assists planners and decision-makers with their urban analysis and planning.

One of the main benefits of GIS is improvements to the management of the organization and its resources by allowing for the sharing of data between various departments. A shared database allows one department to benefit from the work of another; data can be collected once and used many times.

GIS, at present, has several limitations which make them inefficient tools for decision-making. Biggest limitation is that current commercial systems are based on an inappropriate logical foundation. Current GIS are predominantly based on Boolean logic.

Fuzzy logic is an alternative logical foundation coming from artificial intelligence (AI) technology with several useful implications for spatial data handling. Contrary to traditional logic, fuzzy logic accommodates the imprecision in information, human cognition, perception and thought. This is more suitable for dealing with real world problems, because most human reasoning is imprecise.

Major advantage of this fuzzy logic theory is that it allows the natural description, in linguistic terms, of problems that should be solved rather than in terms of relationships between precise numerical values. This advantage, dealing with the complex systems in simple way, is the main reason why fuzzy logic theory is widely applied in technique.

Fuzzy logic appears to be instrumental in the design of efficient tools for spatial decision making. Fuzzy set theory is an extension of the classical set theory. A fuzzy set A is defined mathematically as follows:

IF X = {x} denotes a space of objects, THEN the fuzzy set A in X is the set of ordered pairs: $A = \{x, \mu A(x)\}$, $x \in X$,

where the membership function $\mu A(x)$ is known as the "degree of membership (d.o.m.) of x in A". Usually, $\mu A(x)$ is a real number in the range [0, 1], where 0 indicates no-membership and 1 indicates full membership. Here $\mu A(x)$ of x in A specifies the extent to which x can be regarded as belonging to set A.

Operations of fuzzy set theory provide the counterpart operations to those of classical set theory. Logical operations with fuzzy sets are more generalized forms of usual Boolean algebra applied to observations that have partial membership of more than one set. The standard operations of union, intersection, and complement of fuzzy sets A and B, defined in domain X, create a new fuzzy set whose membership function is defined as:

Union: $\mu A\ B(x) = \max\{\mu A(x), \mu B(x)\}$, $x \in X$ (1)

Intersection: $\mu A\ B(x) = \min\{\mu A(x), \mu B(x)\}$, $x \in X$ (2)

Complement: $\mu{\sim}A(x) = 1 - \mu A(x)$, $x \in X$ (3)

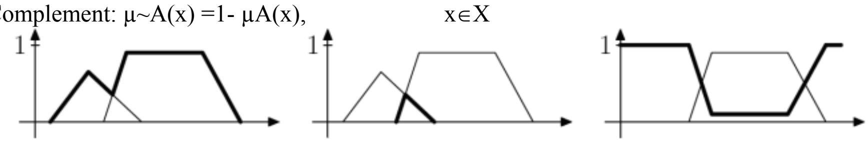


Figure 2: Standard fuzzy operations

Considering the classification of individual locations on a layer based on the slope values with linguistic values [level, gentle, moderate, steep] and a second classification based on the land moisture with linguistic values: [dry, moderate, wet, water].

For each individual location l (e.g., d.o.m. for level = 0.8 and d.o.m. for dry = 0.4) the d.o.m. value which provides an overall measure regarding:

level ground and dry land is derived by: $\min\{\mu level(l), \mu dry(l)\}$, (e.g., $\min\{0.8,0.4\}=0.4$);

level ground or dry land is derived by: $\max\{\mu level(l), \mu dry(l)\}$,(e.g., $\max\{0.8,0.4\}=0.8$); and

non-level ground is derived by: $1-\mu level(l)$, (e.g., $1-0.8=0.2$).

3 LIMITATIONS OF GIS

Uncertainty in GIS means the imperfect and inexact information. The uncertainty is an inherent feature of geographic data. Currently used methods for the representation and analysis of geographic information are inadequate, because they do not tolerate uncertainty. This is mostly due to the applied membership concept of the classical set theory, where a set has precisely defined boundaries and an element has either full or no membership in the set (Boolean logic).

The representation of geographic data based on the classical set theory affects on reasoning and analysis procedures, adding in all problems of an "early and precisely classification". Final decision is made after steps which drastically reduce the intermediate results. Any constraint is accompanied with an absolute threshold value and no exception is allowed. For instance, if the threshold for a flat land is slope = 10%, a location with slope equal to 9.9% is characterized as level, while a second location with slope equal to 10.1% is characterized as non-level (steep). Moreover, for decisions based on multiple criteria, it is usually the case that an entity (i.e., an individual location), which satisfies quite well the majority of constraints and is marginally rejected in one of them, to be selected as valid by decision-makers.

However, based on Boolean logic, a location with slope 10.1% will be rejected (as non-level), even if it satisfies quite well all other constraints posed by decision-makers. In addition, decision-makers are obliged to express their constraints through arithmetical terms and mathematical symbols in crisp relationships (e.g., slope < 10%), since they are not allowed to use natural language linguistic terms (e.g., flat land). Finally, another effect of classical set theory is that the selection result is flat, in the sense that there is no overall ordering of the valid entities as regard to the degree they fulfill the set of constraints. For instance, dry-level layer highlights all locations which satisfy the constraints: dry land (threshold 20%) and flat land (threshold 10%). However, there is no clear distinction between a location with moisture = 10% and slope = 3% and another with moisture = 15% and slope = 7%. These impediments call for a more general and sound logical foundation for GIS.

3.1 Overlay operation

The polygon overlay is used to calculate the common (or different) area between two overlapping objects.

The overlay operation is analogous to join operation in conventional database systems, and is defined as the assignment of new attribute values to individual locations resulting from the combination of two or more layers.

It could be additive or subtractive overlay operation. The additive overlay creates one or more polygons from the intersection between the polygons on layers A and B. The subtractive overlay subtracts the polygons on layer 2 from the polygons on layer 1. Fig. 3. a) shows two layers: layer A (no hatch pattern) and layer B (diagonal hatch). The result of additive overlay on layer C is displayed in solid black on b). The result of a subtractive overlay on layer C is displayed in solid black on c). Overlay operation is most used of all vector analysis in GIS.

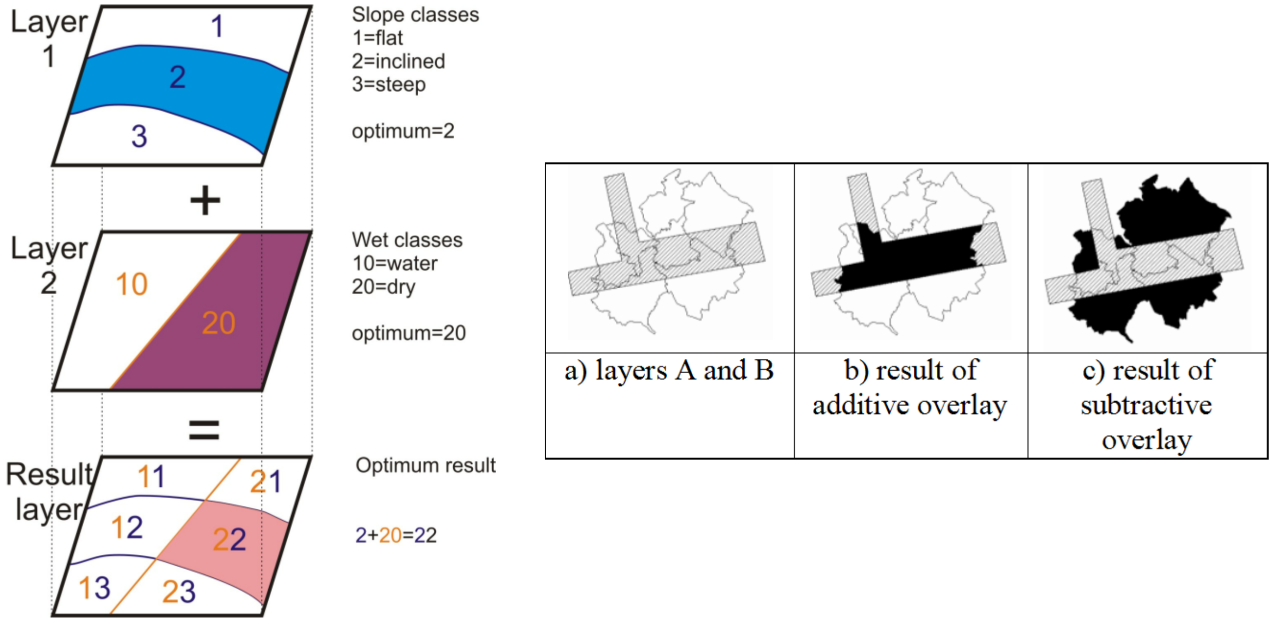


Figure3: Schema of polygon overlay operation

3.2 Site selection in classic GIS

Here will be presented example of searching for relevant location, study done as part of making Spatial Plan of Tuzla Canton. In this situation, the set of constraints and opportunities consists of: level and smooth site (slope < 20%), not-north-facing slope, not agriculture land (usability) class 1, not close to garbage depot, vacant area (no development), not close to exploiting area, not close to sliding-land area, not reserved for special purpose, not close to mine contaminated area (MCA), nearness to the existing road network, nearness to the existing electrical network, dry land.

Figure4: a) Constraint: development area b) Opportunity: agricultural area not class 1 c) Result: selected area

In addition all candidate sites should have an adequate size to satisfy the needs of the planning activity (more then 2 sq km). The whole task requires as input five themes (layers) of the region under examination: hypsography theme (3D surface of the region or altitude values), development theme (existing infrastructure of the region like roads or buildings), vegetation theme (area covered with vegetation like forest or usability areas), moisture theme (soil moisture of the region like lakes, wet-lands, dry-lands) and MCA theme.

The procedure of site selection, based on the sets of constraints and opportunities determined above, may consist of the sequence of operations. First, from this 5 themes it is necessary to extrude 12 layers one by one. Some of the layers should be buffered (roads are usually presented as lines, buffer operation will make areas of them; MCA or sliding area are very dangerous, so it should be buffered to wider protective band). After that, using overlay operation (additive and subtractive) of all layers will produce a result layer with only areas that satisfy all criteria. Then, it should be checked if candidate sites satisfy condition of minimal area and exclude which not. Here was created a set of constraints (e.g. development area on Fig. 4.a), which restrict the planned activity, and a set of opportunities (e.g. agricultural area on Fig. 4.b), which are suitable for the activity. The combination of this two is considered in order to find the best locations (result on Fig. 4.c).

This procedure was very demanding in time and it was unsuitable for decision making in real time. It produced useful results but it also emphasis some of limitations. The biggest problem was that all criteria have to be given in advance and every change requires repeating many steps of the procedure (time demanding). Second problem was mathematical precision of data, which is in such real case unnecessary high and require additional user's effort to define precise constraints.

4 FUZZY LOGIC IN SPATIAL MULTIPLE CRITERIA DECISION MAKING

In classic model each theme is described through a set of attribute values and each individual location on it is assigned by only one of these values. The assignment of an attribute value to an individual location indicates its full membership regarding this feature in the corresponding layer.

In fuzzy set theory the concept of full membership is replaced by concept of partial membership and consequently the representation of individual locations should change. The incorporation of fuzziness into the spatial data model forces the redefinition of the components forming the hierarchical data model.

Specifically, while in conventional set theory the individual locations in a layer are assigned the attribute values (soil, grass, fruit-trees, forest) characterizing a theme (vegetation), in fuzzy set theory they are assigned d.o.m. values regarding each attribute value (0.1 for soil, 0.6 for grass, 0.3 for fruit-trees and 0 for forest). These values are derived by applying both the appropriate membership functions chosen by decision-makers and the knowledge provided by the experts.

Field measurements and results derived from sampling techniques are processed and transformed into d.o.m. values for the predefined attribute (linguistic) values characterizing a theme. Apparently, the number of layers increases, since each theme is represented by as many layers as the number of attribute values associated to it.

The Fuzzy Logic Toolbox in MATLAB provides tools for building Fuzzy Inference System (FIS), as show on Fig. 5. Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The process of fuzzy inference involves: membership functions, fuzzy logic operators and if-then rules. There are two types of fuzzy inference systems that can be implemented in the Fuzzy Logic Toolbox: Mamdani-type and Sugeno-type.

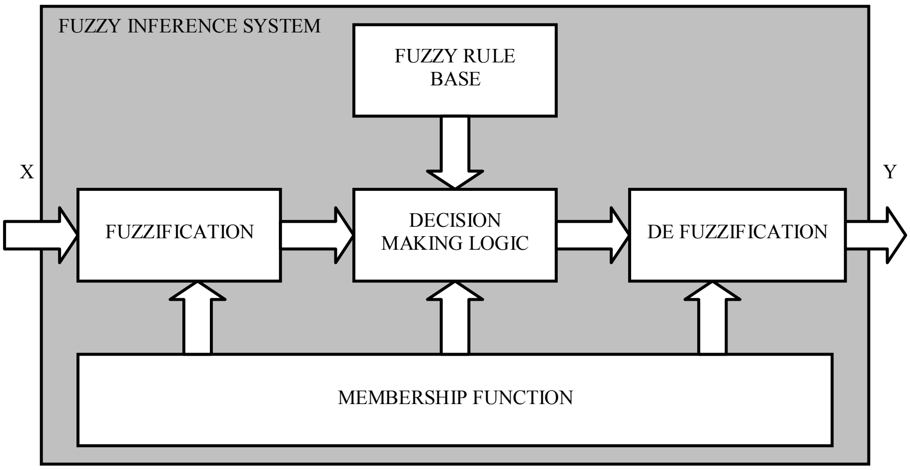


Figure5: Block structure of Fuzzy system

Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology and it expects the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification.

There are five parts of the fuzzy inference process: fuzzification of the input variables, choosing membership functions, constructing rules, making decision and defuzzification.

4.1 Fuzzification

It is chosen 6 main criteria for analyze: spatial accessibility (from centers of settlements, with consider of natural barriers), slope (level or slope), relative altitudes, aspect (orientation to the sun), usability (for forestry and agriculture) and ecological value (land Use got from satellite images).

Classes of slopes	Klase nagiba	from	to
flat (level)	ravno	0	2
small inclination (gentle)	mali nagib	2	4
inclined (moderate)	nagib	4	10
steep	strmo	10	20
very steep	vrlo strmo	20	30

Table 1: Fuzzifucation of slopes

Also there are some constraints like areas under water (lakes and bigger rivers), sliding-land areas, forest, mining areas, construction areas, MCA etc.

An important issue for decision making is reasoning based on linguistic values assigned to physical entities (e.g. inclined is slope between 4% and 10%). A set of linguistic values should be assumed to classify entities and measurements in categories. Each linguistic value corresponds to a range of physical values. Every input criterion should be fuzzified. For example, slopes are classified in five categories, what is shown in Table 1.

Based on this classification, it is made a thematic map of slopes in GIS shown on Figure 6.

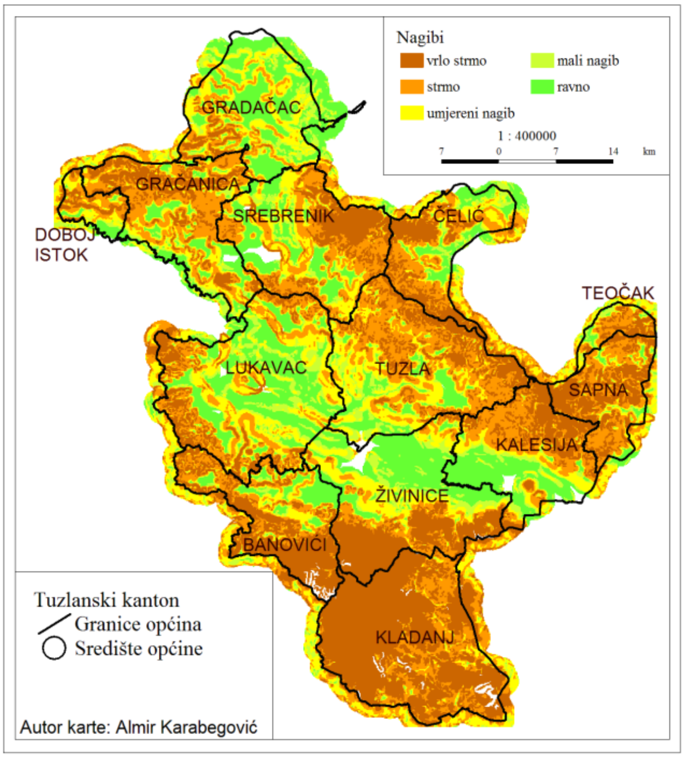


Figure6: Thematic map of slopes

4.2 Choosing membership functions

A fuzzy membership function is a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. The input space is sometimes referred to as the universe of discourse. The choice of the membership function, its shape and form, is crucial and strongly affects the results derived by the decision-making process.

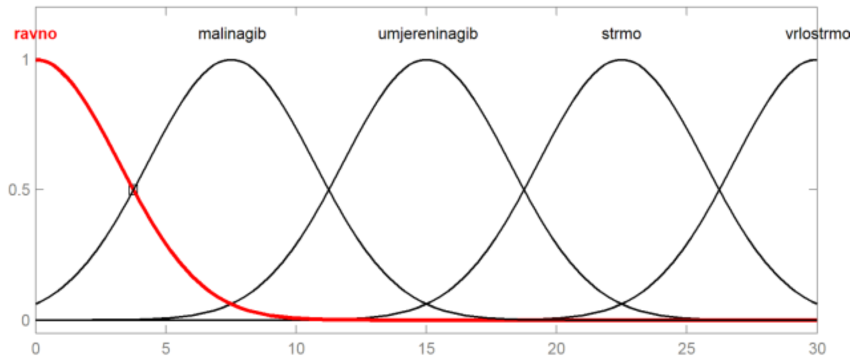


Figure7: Membership function for slopes

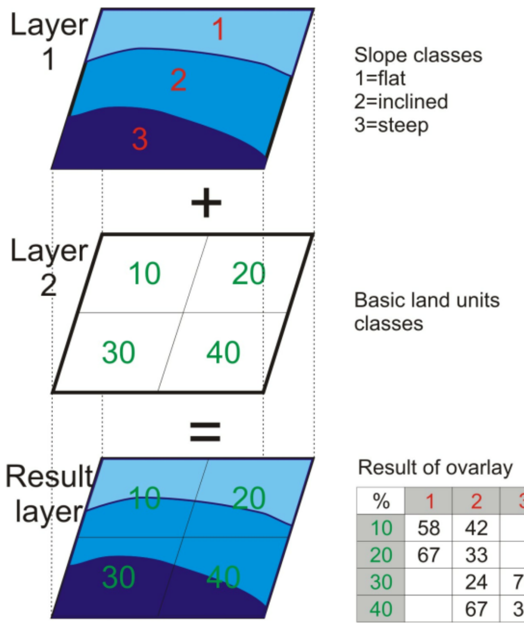
There are several membership function mostly used for geographically phenomena, but especially triangular and Gaussian. A Gaussian membership function is built on the Gaussian distribution curve and is defined as following formula.

$$f(x_1) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-1}{2\sigma^2}(x-\mu)^2} \tag{4}$$

where μ is the mean and σ is the standard deviation, the two parameters for the Gaussian membership function.

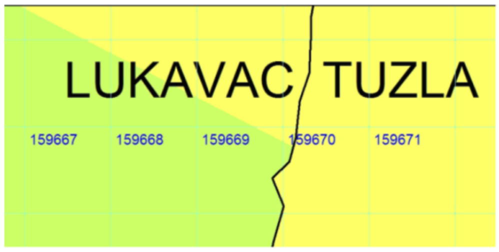
Because of its smoothness and concise notation, Gaussian membership function is popular method for specifying fuzzy sets. This curve has the advantage of being smooth and nonzero at all points.

In this work, Gaussian membership function is used form in most of criteria, like is shown for slopes on Fig. 7. There is one transformation function associated to each linguistic value, what means that number of functions is equal to the number of linguistic values assumed.



Result of ovarlay

%	1	2	3
10	58	42	
20	67	33	
30		24	76
40		67	33



ID	Municipality	Accessibility	Area [ha]
159667	Lukavac	Near	1
159668	Lukavac	Near	1
159669	Tuzla	Moderate	0,000326
159669	Tuzla	Moderate	0,02652
159669	Lukavac	Near	0,943643
159669	Lukavac	Moderate	0,029511
159670	Tuzla	Moderate	0,945568
159670	Lukavac	Moderate	0,031038
159670	Lukavac	Near	0,023182
159670	Lukavac	Near	0,000206
159671	Tuzla	Moderate	1

Figure 8: Overlaying, a) schematically and b) example

4.3 Spatial representation

General spatial data model is here presented in space as two-dimensional grid of cells, or land units. This grid is created in GIS, every cell is one entity connected with one record in the database. Schematically, it is shown on Fig. 8. a).

Most important feature of grid is its resolution, because accuracy of results is dependent on it. In isometric analysis for every municipality is used grid resolution of 30x30 m2. But, for whole Tuzla Canton area (around 2700 km2), as optimal resolution, is chosen grid 100x100 m, or 1 ha, which satisfy level of regional planning. This produced layer of basic land units (grid layer) with 281 526 entities and same number of records in database.

This layer is overlaid with every theme (layer). This operation add linguistic values (classes) of overlaid layer as new attributes to table of basic land units, and fill in values as size of area which cover that class in that cell. An example is overlaying layer of accessibility with layer of basic land units. Results are shown on Fig. 8. b). As a result it is produced a big table connected to layer of basic land units with all classes of all input criteria as attributes and with their parts in area as values. This table of fuzzified values for one record is presented on Fig. 9.

Basic information

ID	Number	Municipality
1000554913	188342	Tuzla

Slope classes

Flat	Small inclination	Inclined	Steep	Very steep
0,036906179	0,251406435	0,479215376	0,211899903	0,020572108

Aspect classes

Horizontal	North	East	South	West
		0,71126	0,28874	

Accessability classes

Close	Near	Moderate far	Far	Very far
			1	

Altitudes classes

Lawland	Hill	Mountain
	1	

Agriculture classes

Agrozone1	Agrozone2	Agrozone3
	0,0333171	

Biological values classes

NoBioVal	SmallBioVal	MedBioVal	HighBioVal	VeryHighBioVal
0,30296106		0,69703894		

Development classes and wet

Development	Economic	Water
0,9415659		

Figure 9: Table of fuzzified values

4.4 Constructing rules

Fuzzy sets and fuzzy operators are the subjects and verbs of fuzzy logic. These if-then rule statements are used to formulate the conditional statements that comprise fuzzy logic. A single fuzzy if-then rule assumes the form:

IF x IS A THEN y IS B (5)

where A and B are linguistic values defined by fuzzy sets on the ranges (universes of discourse) X and Y, respectively. The if-part of the rule "x is A" is called the antecedent or premise, while the then-part of the rule "y is B" is called the consequent or conclusion. An example of such a rule might be

IF slope IS inclined THEN area IS suitable (6)

The input to an if-then rule is the current value for the input variable (slope) and the output is an entire fuzzy set (suitable). This set will later be defuzzified, assigning one value to the output.

Interpreting an if-then rule involves distinct parts: first evaluating the antecedent (which involves fuzzifying the input and applying any necessary fuzzy operators) and second applying that result to the consequent (known as implication). In the case of two-valued or binary logic, if-then rules don't present much difficulty. If the premise is true, then the conclusion is true. If the antecedent is true to some degree of membership, then the consequent is also true to that same degree. The antecedent of a rule can have multiple parts.

IF (slope IS flat) AND (aspect IS south) AND (accessibility IS close) AND (altitudes IS low) AND (usability IS agrozona3) THEN area IS suitable (1)

in which case all parts of the antecedent are calculated simultaneously and resolved to a single number using the logical operators. Number in brackets is weight of that rule. Every rule has a weight (a number between 0 and 1), which is applied to the number given by the antecedent. Generally this weight is 1 and so it has no effect at all on the implication process.

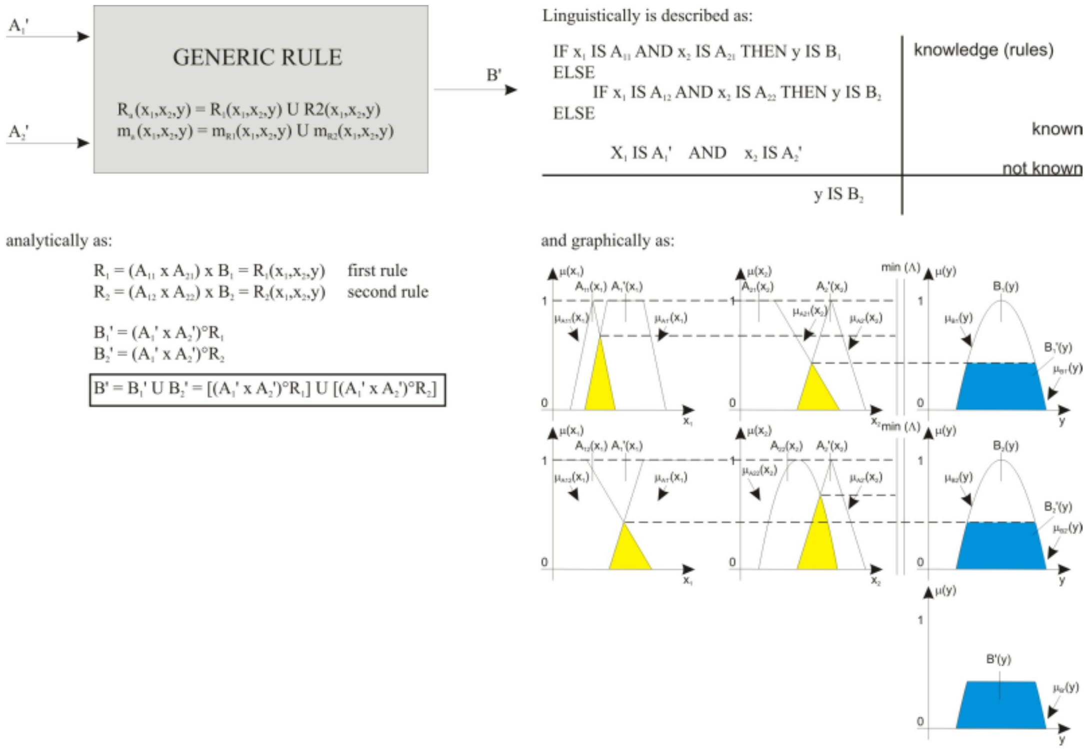


Figure10: GMP with many inputs and many rules

Apparently, number of rules is equal to number of combination for all membership functions (classes, linguistic values). Using knowledge base, some of combination are excluded, so final number of rules for solving this problem is 432.

The consequent specifies a fuzzy set that will be assigned to the output. After that, the implication function modifies that fuzzy set to the degree specified by the antecedent. The most common ways to modify the output fuzzy set are truncation using the min function.

Consider the rule (5). If it is observed that x is A', it uses fuzzy implication to reason that y is B'. Mathematically written, the implication form is

$$R = \int_{(x,y)} \mu(x,y)/(x,y) \quad \text{or} \quad R = \sum_{(x_i,y_i)} \mu(x_i,y_i)/(x_i,y_i) \tag{7}$$

There are 40 implication operators, but most important are Zadeh Max-Min, Mamdani Min and Larsen. In this work is used Mamdani Min implication operator, defined as:

$$\Phi m\,[\mu A(x), \mu B(y)] \equiv \mu A(x) \wedge \mu B(y) \rightarrow \mu(x, y) \tag{8}$$

where Φ is implication operator which take as input membership function of antecedent μA(x) and consequent μB(y).

4.5 Making decision

Fuzzy algorithms are evaluated using generalized modus ponens (GMP). GMP is a data-driven inferencing procedure that analytically involves the composition of fuzzy relations, usually max-min composition. Max-min composition under a given implication operator affects right side of rule in a specific manner (by clipping with Mamdani or scaling with Larsen implication operator). In general, GMP is a transformation of the right side of the rule by a degree commensurate with the degree of fulfillment

(DOF) of the rule and in a manner dictated by the chosen implication operator. As far as the entire algorithm is concerned, the connective ELSE is analytically modeled as either OR ($\wedge$) or AND ($\vee$), depending on the used implication operator for the individual if-then rules (when the Mamdani min implication is used, the connective ELSE is interpreted as OR). In this work is used GMP with many inputs and many rules. It is described as on Fig. 10.

From table of fuzzified values, using given rules is now possible to make multiple criteria analysis or multiple criteria decision making. The easiest way of manipulation data in tables is with SQL statements. So, in this work it is suggested to transfer if-then rules to SQL statement. Last if-then rule could be present in database as:

```
SELECT
ID, Municipality
FROM
TK
WHERE
Slope Is Not Null AND South Is Not Null AND Close Is Not Null AND Low Is Not Null AND [Agrozona 3] Is Not Null;
```

Based on such query in GIS are selected all basic land units which satisfy this condition and calculated total area. The result is same as it was got in classical method of overlaying and there no any ranging of data.

A problem that arises in this case is that only one of the participating d.o.m. values dominates by assigning its value to the whole decision criterion. In this way the contribution of the other d.o.m. values is eliminated.

For decision criteria which combine more than one layer and linguistic value e.g. level ground and dry land an overall measure should be computed and assigned to individual locations. This measure is derived from the consideration of d.o.m. on two or more layers. For a fuzzy set $A \in X$ with d.o.m. $\mu A(x) \in [X]$ the overall measure can be provided by an exponential function, which is given by the following commonly used formula:

$$\mu E(x) = \sum_{i=1}^{k} \left[\mu_{A_i}(x)\right]^q \tag{9}$$

By applying this equation (e.g. for q = 2, quadratic measure) the big weight values (d.o.m.) are amplified, while the small values are nearly eliminated. Assuming the previous example, the overall measure characterizing each individual location (l) of a region, regarding level ground and dry land using the energy function, is given by:

$$\mu_{level\text{-}dry}(l) = [\mu_{level}(l)]^2 + [\mu_{dry}(l)]^2 \tag{10}$$

Results derived by the previous formula should be normalized in the fuzzy domain [0, 1]. Using formula (10) it is produced new SQL statement which add new result field to express degree of membership of every basic land unit.

```
SELECT
ID, Municipality, ([Flat]^2 + [South]^2 + [Close]^2 + [Low]^2 + [Agrozone 3]^2) AS Result
FROM
TK
WHERE
Flat Is Not Null AND South Is Not Null AND Close Is Not Null AND Low Is Not Null AND [Agrozone 3] Is Not Null;
```

Here is chosen exponent 2 which provides order of qualified locations. This feature of exponent is very beneficial for decision criteria which combine multiple sets and linguistic values and make order of results for decision maker.

In GIS, process of visualization such data is process of making thematic maps, which gives decision maker a clear picture of his decision.

$$y^* = \frac{\sum_{i=1}^{N} y_i * \mu_{B'}(y_i)}{\sum_{i=1}^{N} \mu_{B'}(y_i)} \quad \text{or} \quad y^* = \frac{\int_y \mu_{B'}(y_i) * y * d(y)}{\int_y \mu_{B'}(y_i) * d(y)} \tag{11}$$

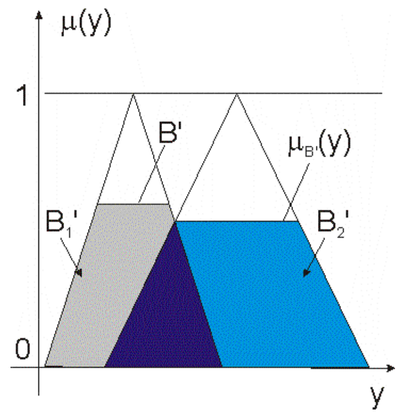


Figure11: Defuzification scheme: COA

4.6 Defuzzification

The output of fuzzy system is a fuzzy value. There is an option of using this value without any modification (leaving the final crisp action to the human operator) or to use a defuzzification scheme and generate a crisp output.

Commonly used defuzzification schemes include Tsukamoto's, Center of Area (COA) and Mean of Maximum (MOM) methods. In case of COA the defuzzified output y is given by an equation (11) or graphically as on Fig. 11.

Fuzzy output was defined in four classes as in Table 2. These linguistic values are from real world, and there are terms that the decision makers normally use in their work. So, even without any modification (leaving fuzzy values) results are appropriate.

Category classes	Klase kategorizacije	from	to
extraordinarily suitable	izvanredno podobna	75	100
very suitable	vrlo podobna	50	75
suitable	podobna	25	50
unsuitable	nepodobna	0	25

Table 2: Fuzzification output

4.7 Results

Final query for multiple criteria decision making did land valorization for every of 13 municipalities in Tuzla Canton, which final result for municipality Tuzla is on Fig. 12. It is also produced a table of areas balances for all municipalities, where decision makers can see, for every class of quality, how big area it covers. Combined with thematic maps, it makes the base for any analyses.

```
SELECT
ID,
Municipality,
[flat]+[small_inclination]+[inclined] AS Slope,
[east]+[south]+[west] AS Aspect,
[close]+[near]+[moderate_far] AS Accessibility,
[lawland]+[hill] AS Altitude,
[agrozone2]+[agrozone3] AS Usability,
[nobioval]+[smallbioval]+[medbioval] AS BioValue,
([slope]^2+[aspect]^2+[accessibility]^2+[altitude]^2+
[usability]^2+[biological_value]^2)/6 AS Result
FROM
TK
WHERE
[flat]+[small_inclination]+[inclined])>0) AND
(([east]+[south]+[west])>0) AND
(([close]+[near]+[moderate_far])>0) AND
(([lawland]+[hill])>0) AND
 (([agrozone2]+[agrozone3])>0) AND
(([nobioval]+[smallbioval]+[medbioval])>0) AND
((ALL CONSTRAINTS)=0));
```

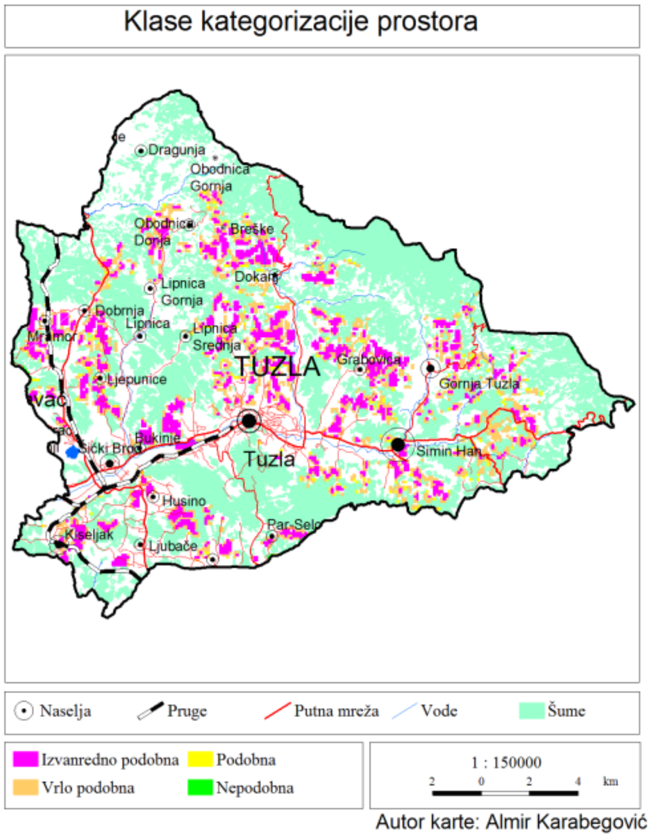


Figure 12: Land valorization for municipality Tuzla, SQL query and graphic result

Getting results with such procedures is only matter of database and GIS is now just a tool for making spatial presentation of results. Contrary to classic method, where was everything done graphically (in database data were only copied), this methodology employs database, which enables to put time demand part in preparation and defining criteria delaying to time of creating queries.

Every change of input data, now, requires only checking its influents to information (classic UPDATE statement in database). Also, data are ordered according to its impoertance for decision makers.

5 CONCLUSION

In spatial multi criteria analyses geographic information systems are used to identify alternatives, present them and give information to decision makers for evaluating, comparing and ordering of alternatives. Limitations of multi criteria analyses in standard GIS are necessity to define all steps in advance and inability to simple change criteria or thresholds later.

Fuzzy set methodologies could be excellent for designing efficient tools to support the spatial decision making process. Here is examined the incorporation of these methodologies into a DBMS repository for the application domain of GIS. It is shown how the useful concepts of fuzzy set theory may be adopted for the representation and analysis of geographic data, whose uncertainty is an inherent characteristic.

It is presented example of a real world situation involving spatial decision making and shown that using fuzzy logic makes the process simpler and faster enabling the possibility of ordering results.

Future research includes choice of the appropriate membership functions to simulate physical phenomena and fuzzy operations for the set of constraints posed by decision-makers (experts).

Also, this work is a solid logic base for solving spatial optimization problems in multiple criteria analysis using genetic algorithm.

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