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Comparison of Crisp and Fuzzy Logics on the Location of a Gauging Station

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COMPARISON OF CRISP AND FUZZY LOGICS ON THE LOCATION OF A GAUGING STATION

Strictly as per the compliance and regulations of :

Comparison of Crisp and Fuzzy Logics on the Location of a Gauging Station

Mônica de Aquino Galeano Massera da Hora [α], Olga Kelman Brocki Calhman [α] & Michely Libos [σ]

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Keywords : fuzzy logic, crisp logic, gauging station, hydrology.

I. Introduction

The traditional logic, called Aristotelian logic or Boolean, assumes a reality there only exists true and false, yes and no, [1]. However, humans function in a vague manner, using as often as possible words such as: warm, not so much, perhaps, more or less, and other words that belong to the infinite universe located among true and false, yes and no, [2]. To this logic, which treats the cloudiness present in many of the processes of daily life, it is given the name of fuzzy logic. With that in mind, we tried to address in this paper the application of crisp and fuzzy logic to a problem of locating a gauging site in a given river basin. Regarding the application of the crisp logic it was applied the COPPETEC-COSENZA model, [3]. Regarding the fuzzy logic, it was applied the operation with triangular numbers in an electronic worksheet.

II. How it Works

The human operators control very complex processes, based on inaccurate or approximate information or about what is being regarded. The manner how the human brain works in processing this information is also of imprecise nature and, in general, is able to be expressed in linguistic terms. The fuzzy logic, as its sets and its theories, can be used to translate imprecise information into mathematical terms expressed by a set of linguistic rules, [4].

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The fuzzy logic, as its sets and its theories, can be used to translate imprecise information into mathematical terms expressed by a set of linguistic rules, [4].

In this case, the variable is a linguistic variable. In order to illustrate, the values of the fuzzy temperature variable could be expressed as high, not high, quite high, very high, not very high, high but not too high. In this context, the temperature variable is a linguistic variable.

The main function of the linguistic variables is to provide a systematic manner to an approximate characterization of complex phenomena or badly defined. In essence, the use of the type of linguistic description taken on by humans, and not quantified variables, allows the treatment of very complex systems to be analyzed through conventional mathematical terms, [2].

III. Application to a Gauging Site

The implementation of a gauging site consists on the installation of a stage gauge or a water-level recorder that enables the knowledge of the water levels. Figure 1 presents a photo of a stage gauge installed on the Guandu river bank, located in Rio de Janeiro State, Brazil.

Fig. 1 : Gauging site on Guandu river

It is necessary to know the water levels and flow rates associated to support the management of water resources, highlighting the activities of planning, uses, reservoirs operation, navigation, recreation, flood risks, land use and occupation, erosion and environmental protection. Data on water levels, combined with the results of measurements of flow, allow the establishment of a relation called rating curve. Thus, the rating curve is a graphic representation of this relation, which involves geometric and hydraulic characteristics of the measuring sections and the considered section of the river.

For the present paper, a hypothetical basin was defined, as shown in Figure 2, where three river sections were selected with the following characteristics:

Section 1

- Section with waterfalls and no hydraulic control;
- Stable cross section;
- Difficult access;
- No interference on the upstream reach;
- No spatial scope;
- Existence of a bench-mark;
- Existence of an observer, however, far from the station.

Section 2

- Straight section with no hydraulic control;
- Stable cross section;
- Easy access;
- Interference on the upstream reach;
- Relative spatial scope;
- Absence of close bench-mark;
- Existence of an observer, nearby the site.

Section 3

- Straight section with hydraulic control;
- Stable cross section, subject to eventual flooding;
- Access is not permanent;
- No interference on the upstream reach;
- Spatial scope;
- Existence of a bench-mark;
- Existence of an observer, nearby the site.

It was assumed the same hydrometric team responsible for gauging site.

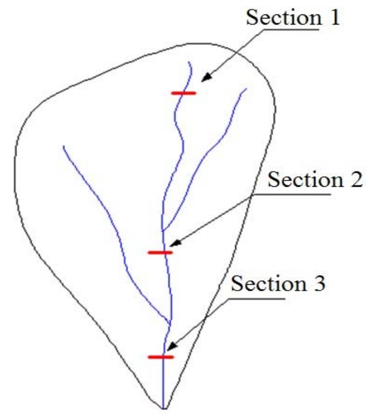


Fig. 2 : Gauging site on Guandu River

The general and specific factors of demand and offer, as well as its framework on a scale of linguistic terms were ranked based on information from experts in water resources. Thus, the factors to consider when locating a gauging site are:

General factors

- Access (A): should be permanent;
- Local observer (LO): the station should have an observer;
- Maintenance (M): the equipment and the site should be maintained by the hydrometric team;
- Bench-mark (BM): existence of references, in order to verify the position of the stage gauge.

Specific factors

- Hydraulic control (HC): the river section should be straight and, if possible, have a downstream hydraulic control;
- Stable cross section (CS): the river margins must be stable and high enough to prevent river overflows;
- Absence of interference in the upstream river reach (AI): it is recommended to avoid reaches where existing river sand mining, derivations or effluent discharges, which may interfere and / or modify the hydraulic section;
- Spatial scope (SS): it is recommended that the station is representative of the drainage area to the gauging site.

The demand factors were classified by the following attributes:

- Critical (Cr): strongly demanded;
- Conditioning (C): demanded;
- Little conditioning (PC): little demanded;
- Irrelevant (I): no effect on demand.

The offer factors were classified by the following attributes:

- Great (Gt): offered in excess;
- Good (G): offered;
- Regular (R): little offered;
- Weak (W): not offered.

IV. Simulation Through Electronic Worksheet

The triangular fuzzy numbers representing each attribute of demand and offer are presented in Tables 1 and 2 and their graphical representations in Figures 3 and 4.

Table 1 : Triangular fuzzy numbers of demand attributes

Attribute	Demand		
	L	M	R
Cr	2	3	3
C	1	2	3
PC	0	1	2
I	0	0	1

Table 2 : Triangular fuzzy numbers of offer attributes

Attribute	Demand		
	L	M	R
Gt	2	3	3
G	1	2	3
R	0	1	2
W	0	0	1

Note that the letters L, M and R represent the left, medium and right values of the fuzzy triangle.

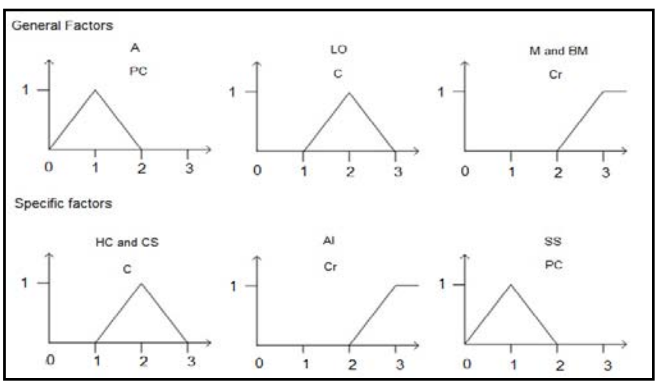


Fig. 3 : Graphic representation of the linguistic variables of demand

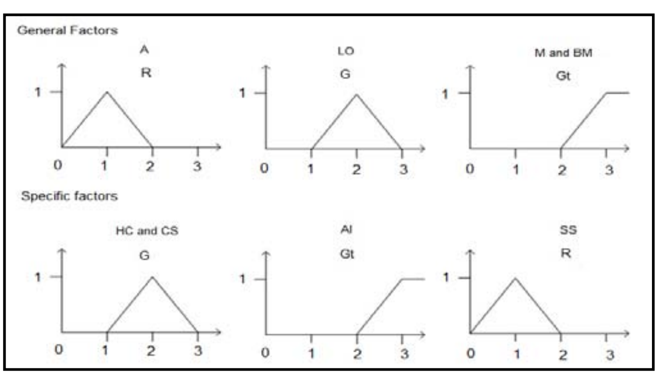


Fig. 4 : Graphic representation of the linguistic variables of offer

The resulting matrix was obtained by considering two calculation criteria. The first, called Crisp-Fuzzy (CF) admits that the matrix of demand is represented by a crisp number equal to the sum of the medium value of the triangular fuzzy number. The second criterion, named Fuzzy-Fuzzy (FF) admits that the matrix of demand is represented by the triangular fuzzy numbers.

The weighed equation adopted is given by:

$$i_K = \frac{\sum a_i \cdot b_i}{\sum a_i} \qquad (1)$$

Where i_k is the support value; a_i the demand matrix and b_i the offer matrix.

The calculation worksheets by the two criteria are shown in Tables 3 and 4, and the graphic representation of the fuzzy numbers in Figure 5.

Table 3 : Matrix resulting from weighing between the demand and offer CF solution

Factors	Demand			Weighted Offer								
				Section 1			Section 2			Section 3		
	L	M	R	L	M	R	L	M	R	L	M	R
A	0	1	2	0	0	1	2	3	3	0	0	1
LO	1	2	3	0	2	4	4	6	6	4	6	6
M	2	3	3	6	9	9	6	9	9	6	9	9
BM	2	3	3	6	9	9	0	0	3	6	9	9
HC	1	2	3	0	0	2	2	4	6	4	6	6
CS	1	2	3	4	6	6	4	6	6	0	2	4
AI	2	3	3	6	9	9	0	0	3	6	9	9
SS	0	1	2	0	0	1	0	1	2	2	3	3
Sum		17		22	35	41	18	29	38	28	44	47
Support Value				1,3	2,1	2,4	1,1	1,7	2,2	1,6	2,6	2,8

Table 4 : Matrix resulting from weighing between the demand and offer FF solution

Factors	Demand			Weighted Offer								
				Section 1			Section 2			Section 3		
	L	M	R	L	M	R	L	M	R	L	M	R
A	0	1	2	0	0	2	0	3	6	0	0	2
LO	1	2	3	0	2	6	2	6	9	2	6	9
M	2	3	3	4	9	9	4	9	9	4	9	9
BM	2	3	3	4	9	9	0	0	3	4	9	9
HC	1	2	3	0	0	3	1	4	9	2	6	9
CS	1	2	3	2	6	9	2	6	9	0	2	6
AI	2	3	3	4	9	9	0	0	3	4	9	9
SS	0	1	2	0	0	2	0	1	4	0	3	6
Sum	9	17	22	14	35	49	9	29	52	16	44	59
Support Value				0,6	2,1	5,4	0,4	1,7	5,8	0,7	2,6	6,6

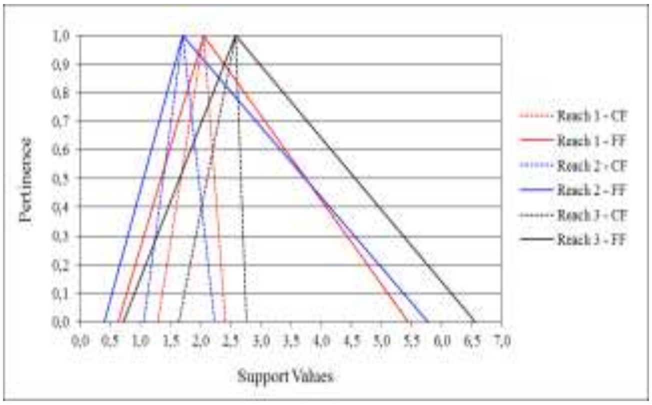


Fig. 5 : Representation of fuzzy numbers resulting from CF and FF simulations

V. Simulation Through Coppetec-Cosenza Location Model

The success expected with respect to the COPPETEC COSENZA location model concerns: (a) careful conceptualization of the attributes that will be considered in each case of study, and (b) mechanisms to evaluate the level in each attribute will be offered or demanded [5]. According to the model, the specific factors are those essential to the establishment of an industry: the absence of any of these factors implies the impracticability of this industry on the evaluated site.

They are classified into:

- Present in satisfactory amounts to meet industrial demand = 1;
- Missing or unsatisfactory amounts = 0.

The general factors are those common to many types of industries, usually infrastructure. They are classified, both for offer and demand in:

- Critical (Cr)
- Conditioning (C)
- Little conditioning (PC)
- Lrrelevant (I)

The values to be considered in the matrices of offer and demand are:

- Offer matrix: present = 1; absent = 0
- Demand matrix: critical (Cr) = 1; conditioning (C) = 1; little conditioning (PC) = 0; irrelevant (I) = 0

Being n the number of general and specific factors:

a) $n \cdot C > n \cdot PC + n \cdot I$
b) $n \cdot PC > n \cdot I$
c) If there is a critical factor or an insufficient amount, the region should be disregarded in the process of decision making.

From the classifications made, offer matrices are constructed of specific and general factors of each elementary area to be analyzed and demand ones for these same factors of industries to be evaluated.

Matrices of Demand and Offer of General Factors

Demand Matrix: $A = \lfloor a_{ij} \rfloor_{mxs}$

Where m is the number of industries and s is the number of general factors.

Offer Matrix: $B = \lfloor b_{jk} \rfloor_{sxr}$

Where r is the number of elementary regions.

Priority Matrix in Relation to General Factors

Being matrix $C = [c_{ik}]_{mxr} = A \Theta C$, where the operation of multiplication is given by the matrix below:

b_{jk} / a_{ij}	0	1
0	1/n!	1/n
1	0	1

So that n is the amount of general location factors. This comparison is made to determine the location advantages with respect to these factors.

Matrices of Demand and Offer of Specific Factors

Demand Matrix: $A^* = \lfloor a^*_{ij} \rfloor_{mxs'}$

Where s' is the number of specific factors.

Offer Matrix: $B^* = \lfloor b^*_{jk} \rfloor_{s'xr}$

Priority Matrix in Relation to Specific Factors

Consider the matrix $C^* = [c^*_{ik}]_{mxr} = A^* \Theta B^*$ of m industries by elementary regions, being its elements indicators to establish an order of priority in decision making with respect to the specific factors. The formation of this matrix is defined by the following criterion:

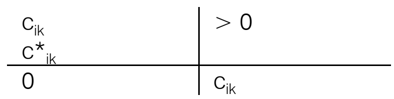
B^*_{jk} / a^*_{ij}	0	1
0	0	0
1	0	1

Priority Matrix in Relation to General and Specific Factors

Consider $P = [p_{ik}]_{mxr} = C \oplus C^*$, such that the special sum operation meets the following matrix:

c_{ik} / c^*_{ik}	> 0	0
0	0	0
> 0	$c^*_{ik} + c_{ik}$	c^*_{ik}

The elements of P represent the location advantages with respect to the general and specific factors. One may observe that the impossibility of location in relation to the specific factors automatically annuls the location advantage, however, if the project does not depend on the specific factor the operation must be:



Simulation with the COPPETEC-Cosenza model

The critical and conditioning factors have been adopted as being equal to 1, i.e., important, therefore the little conditioning and irrelevant factors are equal to 0, i.e. not significant. Thus, the demand matrix for the general factors can be completed as Table 5.

Table 5 : General factors demand matrix

General factors	Variable	
	Linguistics	Numerical
A	PC	0
LO	C	1
M	Cr	1
BM	Cr	1

Following the same procedure, the demand matrix for specific factors can be completed as Table 6.

Table 6 : Specific factors demand matrix

Specific factors	Variable	
	Linguistics	Numerical
HC	C	1
CS	C	1
AI	Cr	1
SS	PC	0

For the construction of the offer matrix, it was considered that the general and specific factors will assume 0 and 1 values, in case of absence and presence, respectively, in the considered sections. Thus, the offer matrix of general factors in the considered sections can be completed as Table 7.

Table 7 : General factors offer matrix

General factors	Section		
	1	2	3
A	0	0	1
LO	0	1	1
M	1	1	1
BM	1	0	1

The offer matrix of specific factors in the considered sections can be completed as Table 8.

Table 8 : General factors offer matrix

Specific factors	Section		
	1	2	3
HC	0	0	1
CS	1	1	0
AI	1	0	1
SS	0	1	1

The priority matrix resulting from the decision making in relation to the general factors is shown in Table 9.

Table 9 : General factors priority matrix

Gauging Site	Section 1	Section 2	Section 3	Sum
A	0.04	0.25	0.04	0.33
LO	0.00	1.00	1.00	2.00
M	1.00	1.00	1.00	3.00
BM	1.00	0.00	1.00	2.00
Sum	2.04	2.25	3.04	

The priority matrix resulting from decision making in relation to the specific factors is shown in Table 10.

Table 10 : Specific factors priority matrix

Gauging Site	Section 1	Section 2	Section 3	Sum
HC	0.00	0.00	1.00	1.00
CS	1.00	1.00	0.00	2.00
AI	1.00	0.00	1.00	2.00
SS	0.00	0.00	0.00	0.00
Sum	2.00	1.00	2.00	

The priority matrix resulting from decision making in relation to the general and specific factors is shown in Table 11.

Table 11 : General and specific factors priority matrix

General and specific factors	Gauging Site
HC	1
CS	1
AI	1
SS	0
A	0
LO	1
M	1
BM	1

The final results to the gauging site by the three sections are shown in Table 12.

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Table 12 : Final results

Section	1	2	3
Gauging site	4.04	3.25	5.04

VI. Conclusion

The results of the simulations performed with the use of the electronic worksheet and displayed in Figure 5 allows to deduce that in the Crisp-Fuzzy criterion, the triangles resulting from the operation of fuzzy numbers are not superimposed, sequentially following, in ascending order of section 1 to 3, with respect to the suitability for the gauging site. With respect to the Fuzzy-Fuzzy criterion, section 3 remains to be the best candidate for the gauging site, but the resulting triangles of sections 1 and 2 are superimposed, indicating certain "cloudiness" about the hierarchy between them.

The simulations carried out using the COPPETEC-COSENZA model allowed to infer that, with respect to the general factors section 3 showed superior results compared to the other sections. With respect to the specific factors, sections 1 and 3 presented result equal and superior to that of section 2. In conclusion, section 3 is the most suitable for the implantation of the gauging site and section 2 is not appropriate for such. Based on the above, section 3 is the one that provides the best conditions for meeting the factors of general and specific demand of the project in question.

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