Sinos River basin social-environmental prospective assessment of water quality management using fuzzy cognitive maps and neutrosophic AHP-TOPSIS

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Abstract.The Sinos River basin (SRB) is one of the most polluted river basins in Brazil, leading to considerable efforts to mitigate the impacts and achieve their recovery, is possible through adequate integral management. Aiming at the need for water quality management through the analysis of the interrelationships among the different factors, which can be difficult given the multiple connections between the variables involved. In this article, the authors presented a tool of multi-criteria decision method using Neutrosophic elements in AHP-TOPSIS models and linked to Fuzzy Cognitive Maps, which can contribute to better environmental management to be carried out by the Basin Management Committee of the Sino River. This method, it is possible for modeling the complex system and variables involved inthe determination of water quality, according to the Water Quality IndexandusingNeutrosophic Analytical Hierarchical Process (NAHP) with Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) for ranking scenarios. The methodology exposed in this research shows an improved method to be used by the SRB Committee when planning decisions. The applicability of the framework has been demonstrated during the case study presented.

Keywords:FCM, Neutrosophic AHP, TOPSIS,Sino River Basin, Scenario Analysis

1 Introduction

The complexity of socio-environmental management in a water basin, strongly impacted by anthropic actions, is manifested in a considerable number of environmental problems that affect the health and well-being of the populations of the region. Additionally,altered the biological diversity the abiotic components of the ecosystem are eroded [1].

The present work focuses on the managing of water quality through the analysis of the interrelations between the different factors. Considering the variables that compose the Water Quality Index (WQI) on the SinosRiver basin(SRB)[2] and how they are influenced by actions such asincrease of industrial and domestic wastewater treatment, improve legal systems and law enforcement, conservation or recovery of the gallery forest, wetlands and swamplands areas. Moreover, the degree of the impacts to the biota, the people health,and the regional economy is determined.

The proposal consistsusingtheFuzzy Cognitive Maps (FCM) [3] as a tool to understand the complex nature of environmental management, making easier the analysis of existent interrelations, the discussion, and understanding of the problems complexity by the stakeholders, contributing to making the basin management process more democratic. Additionally, the combination with the Neutrosophic Analytical Hierarchical Process(NAHP)[4-6] and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) [7] multi-criteria method allows making prospective management when analyzing and ranking of different scenarios.

Most noteworthy, this is the first study, to our knowledge, that integrates FCM with Neutrosophic NAHP-TOPSIS for water management. All these factsallow the analysis of different alternatives, ranking them and selecting the best one, optimizing the decision-making processes into the social-environmental management by the SRB Committee.

The paper continues as follows: Section 2 is about the SRB and his environmental issue and some important concepts about fuzzy cognitive maps, AHP and TOPSIS. Methodological aspects are detailed in section 3. A case studyisdiscussed and presented insection 4. Thisarticle ends with inferences and some recommendation for future work.

2 Preliminary

In this section the SRB and its environmental problems are presented then FCM fundamentals are discussed. Additionally necessary concepts about neutrosophic AHP and TOPSIS are presented.

2.1 The SRB social-environmental water problems

The SRB is one of the most polluted water basins in Brazil [8] which leads to tremendous efforts for its recovery through adequate integral management. The SRB Committee is responsible for the environmental management but, due to the complex nature of the interrelations between the different factors involved in environmental quality management becomes intricate and therefore requires the use of tools that facilitate decision making.

The SRB (Fig. 1),positioned in the eastern portion of the Rio Grande do Sul State. It has an area of approximately 3.696 km², equivalent to 1.3% of the total area of the Rio Grande do Sul State and 4.4% of the Guaíba Hydrographic Region [9], providing fresh water to nearly 1.3 million people in 32 municipalities [10].

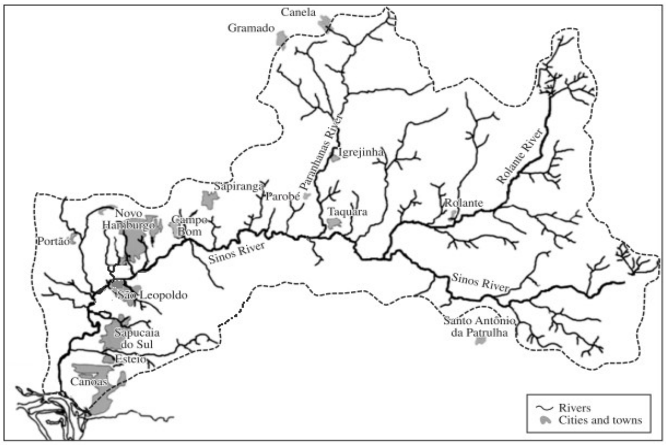

Figure 1: Sinos Rivers Basin

The SRBis frequentlycited as a highly degraded watershed due to the process of substantial economic development disjoined from environmental conservation concerns [11]. The deficiency of urban planning proper zoning hasstrong consequent in urbanization observed for the municipalities within the water basins [11].

The growth of towns and villages without following the guidelines of urban and territorial planning threaten the basin ecosystem biota. Another factor threatening isthe occupation of flooding areas by people, the riparian forest deforestation. Additionally,the domestic sewage with inadequate treatment threw into the water body, contributes to the surface and ground waters degradation. However, the city grew along the river also brought about an increase of industrial facilities, which pour, since the beginning until today, their rubbish into the streams of the river basin. So the primary sources of pollution of the SRB are two: the industrial wastewater and the domestic sewage [12].

The insufficient capacity of domestic wastewater and industrial effluents treatment has a negative influence on the ecosystem life, increasing the concentrations of pollutants in the water, killing thousands of fish and other types of life. [12, 13] .It is also responsible for waterborne diseases such as hepatitis, enteritis,and diarrhea[14], [15].

The industrial waste pumped into the streams of the basin is the source of illness due to many substances like chrome, nickel, iron, mercury, lead,and cyanide. These materials were found with values beyond the limits accepted by Brazilian legislation[16, 17]. Furthermore, organic compounds were found, such asDiethyl phthalate; Fluorene; Dibenzofuran; Nitrobenzene; 4-Bromodiphenyl ether; Hexachlorobenzene; Phenanthrene; Carbazole; Di-n- butyl phthalate e Benzyl butyl phthalate[18].

Another pollution source of the SRB is the diffused pollution linked with the increasing vehicular traffics, industrial air pollution and soil pollution by agricultural runoff [19]. The current situation shows the deficiencies and the inability of the watershed committee to reach the goals and have a proactive action into the social-environmental management. The SRB Committee need for new analysis tools that support decision making in this situation.

2.2 Fuzzy Cognitive Maps Fundamental

Cognitive maps were firstintroduced by Axelrod [20], where arcs indicate either positive or negative causal relations between nodes. fuzzy cognitive map (FCM)[3] extends cognitive maps with fuzzy values in arcs in the [-1,1] interval. Recently FCMs have gained considerable research interest and are mainly to analyze causal systems especially in system control and decision making [21-23]. When neutrosophic is included in arcs weights a neutrosophic cognitive is obtained [24].

In FCM there are three types of causal relations between nodes in the matrix: negative, positive and-none. The matrix representation of FCM allows the making of causal inferences. In FCM the dynamic analysis begins with the design of the initial vector state, which represents the initial value of each node. The value of a concept is calculated in each simulation step using the following calculation rule:

$$A_i^{(t+1)} = f\left(A_i^t + \Sigma_{j=1,\, j\neq i}^{n} A_i^t \times W_{ji}\right) \qquad (1)$$

Where $A_i^{(t+1)}$ is the state of the node i at the instant t+1 , W_{ji} is the weight of the influence of j node over the i node, and f(x) is the activation function. The hyperbolic tangent activation function is defined as follows [25]:

$$S_i(C_{it}) = \tanh(\lambda C_{it}) \qquad (2)$$

The calculation halts if an equilibrium state is reached. The final vector reflects the state of the FCM nodes after the system intervention [26, 27].

The interestin the use of FCM iscrescent, in the most recent years, as a participatory method for understanding social-ecological systems [28]. FCM has been used in a different set of contexts reaching from invasive species management [29] to agricultural policy design and communication [30]. The FCM is due mainly to its transparent graphical models of complex systems useful for decision making, the ability to illuminate the core presumptions of environmental stakeholders and to structure environmental problems for scenario development.

2.3Neutrosophic AHP

Smarandache[31] suggested the concept of a neutrosophic set, which usesthe truth-membership function, indeterminacy-membership function,and falsity-membership function. Neutrosophic set theory should be utilized to rationalize uncertainty associated with ambiguity in a manner analogous to a human in the decision-making process [32]. A single value neutrosophic number $\tilde{a} = \langle (a_1, a_2, a_3); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}} \rangle$ express a quantity approximately equal to a[33].

In this paper with the calculation of the weights through the analytical hierarchal process (AHP) using triangular neutrosophic numbers[34].

In AHP the relative priorities are assigned to different criteria using a scale for comparison by pairs (Table 1).

Saaty Scale	Explication	Neutrosophic Triangular Scale
1	Equally influential	$\tilde{1} = \langle (1, 1, 1); 0.50, 0.50, 0.50 \rangle$
3	Slightly influential	$\tilde{3} == \langle (2, 3, 4); 0.30, 0.75, 0.70 \rangle$
5	Strongly influential	$\tilde{5} = \langle (4, 5, 6); 0.80, 0.15, 0.20 \rangle$
7	Very strongly influential	$\tilde{7} = \langle (6, 7, 8); 0.90, 0.10, 0.10 \rangle$
9	Influential	$\tilde{9} = \langle (9, 9, 9); 1.00, 0.00, 0.00 \rangle$

Table 1. Priority scale of AHP criteria for pairwise comparison using triangular neutrosophic numbers [4].

Let be $\tilde{a} = \langle(a_1,\ a_2,\ a_3);\ \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}}\rangle$ the neutrosophic comparison matrix it converted to its crisp form by using score degree of ã[4]:

$$S(\tilde{a}) = 1/8\,[a_1 + a_2 + a_3] \times (2 + \alpha_{\tilde{a}} - \theta_{\tilde{a}} - \beta_{\tilde{a}}) \quad (3)$$

and the accuracy degree of ã[4]:

$$A(\tilde{a}) = 1/8\,[a_1 + a_2 + a_3] \times (2 + \alpha_{\tilde{a}} - \theta_{\tilde{a}} + \beta_{\tilde{a}}) \quad (4)$$

NAHP has the same advantages of classical AHP for example user with a richer structure framework than the classical AHP, fuzzy AHP,and intuitionistic fuzzy AHP. Describe the preference judgment values of the decision maker efficiently handling vagueness and uncertainty over fuzzy AHP and intuitionistic fuzzy AHP because it considers three different grades “membership degree, indeterminacy degree and non-membership degree [33, 35].

2.4 TOPSIS

Decision-making at environmental projects requires consideration of trade-offs between sociopolitical, environmental and economic impacts, making multi-criteria decision analysis (MCDA) a valuable methodology in this situations.TOPSIS is MCDA method to do rank alternative from a finite set of one’s [36]. The chosen alternative should have the farthest distance from the negative ideal solution and the shortest distance from the positive ideal solution [37]. Some extensions for TOPSIS have been developed based on neutrosophic[38].

The algorithm for TOPSIS is as follows

Step 1: Determine the normalized decision matrix (R). The raw decision matrix (D) is normalized for criteria comparability:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\Sigma_{i=1}^{m} x_{ij}^2}} \quad (5)$$

Step 2: Compute the weighted normalized decision matrix (V) with weights obtained from Neutrosophic-AHP. The weighted normalized value of can be computed by

$$v_{ij} = r_{ij} \cdot w_j \quad (6)$$

where w_j is the weight of the jth criterion and $\Sigma_{j=1}^{m} w_j = 1$.

Step 3: State the positive-ideal (A^+) and negative-ideal (A^-) alternatives. The values of the criteria in the positive-ideal and the negative-ideal alternative correspond to bethe best level and the worst level respectively [39]:

$$A^+ = \{(\max_{i=1}^{n} | j \in I^+ |), (\min_{i=1}^{n} | j \in I^- |)\} = [v_1^+, v_2^+, \ldots, v_n^+],$$

and

$$A^- = \{(\min_{i=1}^{n} | j \in I^+ |), (\max_{i=1}^{n} | j \in I^- |)\} = [v_1^-, v_2^-, \ldots, v_n^-],$$

where I^+ and I^- are the criteria sets of benefit and cost type, respectively.

Step 4: Compute the distance measures with the Euclidean distance. The separation to the positive-ideal alternative is:

$$d_i^+ = \sqrt{\Sigma_{j=1}^{m} (v_{ij} - v_j^+)},\ i = 1, \ldots, n \quad (7)$$

Additionally, the distance to the negative-ideal alternative is denoted as:

$d_i^- = \sqrt{\Sigma_{j=1}^m \left(v_{ij} - v_j^-\right)}, \; i = 1, \dots, n$ (8)

Step 5: Compute the relative closeness to the ideal alternative and rank the preference order. The relative closeness of the ith to the ideal alternative concerning the ideal alternative is as follows:

$C_i^+ = \frac{d_i^-}{d_i^+ + d_i^-}$ (9)

A set of alternatives that can be preference ranked according to the descending order of C_i^+ ; then larger means a better alternative.

3Proposed Method

We propose an approach to support decision making in water management, made of some steps that range from indicator selection to scenario comparison and ranking support decision making.

1. Select relevant indicators

Relevant indicators are selected, and the FCM representing causality is modeled. The data source or expert(s) could be used in this step. Several methodologies could be used in order to reach a consensus within a group of participant experts [40].

2. Static Analysis

The concept in which the model can be categorized into one of three ways based on analysis: as driving components, receiving components or ordinary components [41].

The following measures are calculated with the absolute values of the FCM adjacency matrix:

Outdegree $od(v_i)$ is sum the of absolute values in the row of a variable in the adjacency matrix. It shows the cumulative strengths of connections (a_{ij}) departing the variable.

Indegree $id(v_i)$ is the sum of the absolute values in the colum of a variable. It shows the cumulative strength of variables incoming the variable.

The centrality measureof a variable is the summation of its indegree and outdegree

$td(v_i) = od(v_i) + id(v_i)$ (10)

Later variables could be classified according to the following rules and be selected in scenario development[42]:

a) Transmitter variables have a positive or indeterminacy outdegree, and zero indegrees.

b) Receiver variables have a positive indegree or indeterminacy and zero outdegree.

c) Ordinary variables can be more or less a receiver or transmitter variables, based on the relation of theiroutdegrees and indegrees measures.

3- Identify future scenarios

Scenarios are identified,and initial stimuli vector for each one are defined. A Stimulus vector is designed for each scenario representing the initial value of each node. The simulation of the scenarios with the FCM is run with the outcome in the form of concepts being 'activated' at different levels after reaching equilibrium [38].

5- Rank and evaluate the different scenarios.

The Neutrosophic AHP-TOPSIS method is a combination of the NAHP method with the TOPSIS method. In this case, the weights are calculated in the NAHP. At the first stage, NAHP is used to weight the relative importance of NODES when compared to each other. According to this, the positive-ideal scenario (PIS) and the negative-ideal one (NIS) are defined. Moreover, alternatives are ranked according to the TOPSIS algorithm [43].

4Results

Understanding the complexity of water pollution sources and their mitigation using the fuzzy cognitive maps modeling to supporting decision making.

In Step 1 relevant indicators are selected (Table 2).

Concept	Description
WQI	The WQI was created to assess the quality of raw water in the public supply treatment systems. This indicator has limitations because not analyzeessential parameters such as toxic substances, pathogenic viruses and protozoa,and others substances.
OD	This indicator shows the level of free oxygen present in the water body. It iscrucial for all life in the water.
Coliforms T	The quantity of Thermotolerant Coliform bacteria is an indicator of domestic sewage pollu-

	tion in the water body.
pH	pH is a measurement of water acidity or alkalinity, determined by hydrogen ions in the water
Water Temp	This indicator is determined by solar radiation,orphysical-chemical processes and the variability of the indicator could modify many water parameters such as surface tension or viscosity,which can affect the growth, reproduction or life of aquatic organisms?
Nitrogen Total	This indicator reflects the total quantity of nitrogen existing in the water from different sources.
Phosphorus Total	This indicator reflects the total amount of phosphorus present in the water from various sources. High phosphorus levels in water are the leading causes of eutrophication.
Turbidity	Turbidity indicates the degree of attenuation caused by the particles in suspension undergoing a ray of light passing through the water
Total Solids	The total residue is the remaining material after evaporation, calcination or drying of the water sample for a determine time and temperature.
DBO5	The BDO5 is the total of oxygen necessary to oxidize the organic substance present in the water through aerobic microbial decomposition for five days.
Domestic Wastewater	This concept is wastewater from residential towns and services, such as houses, restaurants, hotels; and which come up from toilets, bathrooms,and kitchens.
Industrial Liquid Water	This wastewater can be the result of any process, industrial activity or commercial activity, of the transformation of any natural resource or of operations with animals, such as feedlots, chicken coops or dairies.
Diffuse Pollution	Is the nonpoint source pollution, this term refers to the difficulty of adequately determining the origin of the pollutant.
Health Impact	It is the combination of methods, procedures,and tools through which can determine the relationship of certain phenomena and their effects on the health of people or animals, as well as the spatial or temporal distribution of these effects.
Economic Impact	It is the combination of methods, procedures,and tools with which can determine the relationship of certain phenomena and their effects on the economy of a region, as well as the distribution over time of these effects.
Biota impact	It is the combination of methods, procedures,and tools with which can determine the relationship of certain phenomena and their effects on the life of an ecosystem, as well as the spatial or temporal distribution of these effects.
Wastewater Treatment Plant	It is a process of elimination of pollutants from industrial and domestic wastewater. The physical, chemical and biological processes are included that make it easier to eliminate these pollutants and produce a safer discharge for the environment.
Law enforcement	This indicator reflects as the system using which the members of society act in an organized way to enforce the law, dissuading, rehabilitating or punishing people who violate the rules and regulations that govern that society.
wetlands conservation	The objective of this indicator is to measure the degree of protection and preservation of areas such as swamps, marshes,and wetlands.
Riparian forest conservation	This indicator measures the conservation of riparian forests, given their importance for forming a complex ecosystem and the occurrence of interrelationships between species of terrestrial and aquatic organisms, as well as the relationships between the biotic and abiotic components.

Table 2.CFM Relevant indicators (Nodes) and their meanings.

In Step 1 an FCM based on expert is developed. Figure 2 shows an FCM model with obtained with 20 nodes and 63 edges.

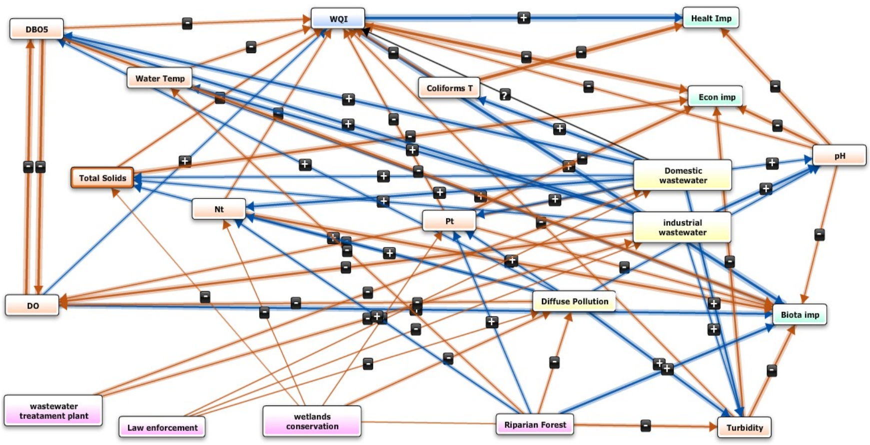

Figure 2: FCM model

FCM Model of the WQI relationships. Blue lines show positive relationships and red lines point to negative relationships and the fatness of the line represents the strength of the relationship.

In step 2 a static analysis is performed on centered on studying the features of the weighted directed graph that represent the model, using graph theory metrics (Figure 3).

Concept	Indegree	Outdegree	Centrality
WQI	2.91	2.86	5.77
OD	2.44	2.03	4.47
Coliforms T	0.81	1.36	2.17
pH	1.26	1.89	3.15
Water Temp	0.78	0.59	1.37
Nitrogen Total	1.39	1	2.39
Phosphorus Total	1.9	1.06	2.15
Turbidity	2.25	1.5	3.75
Total Solids	1.38	1.16	2.64
DBO5	2.69	1.86	4.55
Domestic Wastewater	0.34	4.53	4.87
Industrial Liquid Water	0.26	3.04	3.3
Diffuse Pollution	0.43	3.19	3.62
Health Impact	2.81	0	2.81
Economic Impact	3.39	0	3.39
Biota impact	4.7	0	4.7
Wastewater Treatment Plant	0	0.58	0.58
Law enforcement	0	0.03	0.03
Wetlands con-	0	0.45	0.45

servation			
Riparian forest conservation	0	1.8	1.8

Table 3: Static Analysis

The most central nodes are WQI, Domestic Wastewater,and Biota impact. Receiver variables are Health Impact, Economic Impact,and Biota impact. Transmitter variables are Law enforcement, Wetlands conservation, Riparian forest conservation.Scenarios are identified and simulated (Table 4).

In step 3 scenarios are identified,and initial stimuli vector for each one are defined.

Scenario	Description	Initial Stimulation
S1	The actual capacity of wastewater treatment in the basin of Sinos River	WTP 5%
S2	increase the quantity and capacity of the wastewater treatment system	WTP 35%
S3	Increasing of natural or artificial Wetlands areas	Wetlands 35%
S4	Increase the law enforcement	Law Enforcement 35%
S5	Increasing Wetlands areas and Law enforcement	Wetland 25% Law 30%
S6	Increasing of wastewater treatment plant, Wetlands areas,and Law enforcement	WTP 45% Law 25% Wetland 30%d

Table 4..Scenarios identification and stimulated.

Scenario planners calculate the FCM model for different input vectors that represent probable or desirable combinations of concept states.[44] In this case, the hyperbolic tangent activation function is used[25].

The scenarios are further investigated the next step (Step 4) for ranking.Ending scenarios are exemplified graphically in Figure 4.

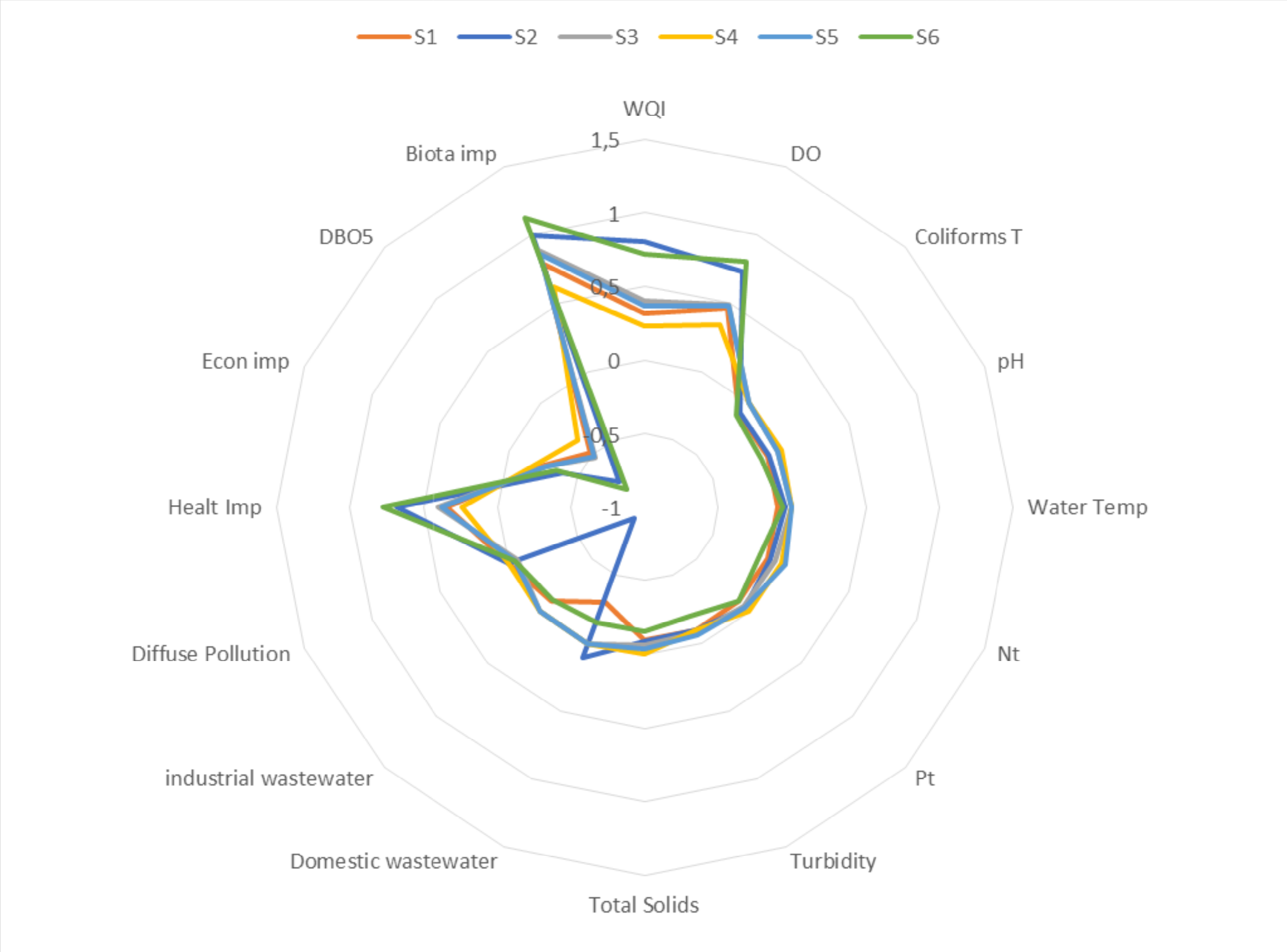

Figure 4: Scenarios' results

Scenarios ranked with NAHP-TOPSIS. Pairwise comparison matrix was obtained using triangular neutrosophic numbers. Nodes are weightedaccordingto the AHP method as follows, see table 4.

Indicators	Weights
WQI	0,15
OD	0,10
Coliforms T	0,08
Ph	0,08
Water Temp	0,07
Nt	0,06
Pt	0,06
Turbidity	0,06
Total Solids	0,06
Domestic Wastewater	0,05
Industrial Wastewater	0,05
Diffuse Pollution	0,04

Health Imp	0,02
Economic Imp	0,02
DBO5	0,05
Biota Imp	0,01
Wastewater treatment plant	0,02
Law enforcement	0,02
Wetlands Conservation	0,01
Riparian Forest	0,01

Table 5: Weights results

WQI and OD are the most important nodes. Theyjointly comprisethe 25% of the total weights. Additionally the least important are Biota Imp,Wetlands Conservation and Riparian Forest comprising only 3% of the total weights.

Then the weighted normalized decision matrix (V) is computed. The authorsadopt that all the nodes are classified as benefit (higher scores are better). After TOPSIS procedureoutcomesare displayed,and the scenarios are ranked (Table 5).

Scenario	Distance to Ideal	Distance to Anti-Ideal	Relative Degree Closeness	Rank
S1	0.96	0,93	0,49	5
S2	1.04	1,01	0,49	5
S3	0.72	1,11	0,61	2
S4	1.05	1,13	0,52	4
S5	0.75	1,11	0,60	3
S6	0.67	1,29	0,66	1

Table 6: TOPSIS results

S6 rank as the best scenario and S1 is the less desirable scenario. Increasing of wastewater treatment plant, Wetlands areas,and Law enforcement id the best scenario according to the method.The final ranking of scenarios is as follows: $S6 \succ S3 \succ S5 \succ S4 \succ S1$ ≈S2.This result coincide with experts opinions consulted.

In this study, we presented a methodology based in FCM to obtain a better comprehension about the complex relation of variables involved in water quality. The representation of relationships variables by FCM allows the SRB Committee do participation exercisesand all of the stakeholders gain in knowledge aboutthe challenges of social-environmental management and the water management specifically. Additionally scenarios are ranked taking into account importance of the factor involved with the NAHP and the TOPSIS methods.

Conclusion

In this paper, the authors present a Neutrosophic AHP TOPSIS multi-criteria decision method tool that can contribute for a better choice of environmental management in the watershed by the Basin Management Committee. With this technique, it is possible to use FCM to model the complex system of variables involved in the determination of water quality, according to the WQI and TOPSIS for ranking scenarios. The methodology exposed in this research shows an improved method to be used by the SRB Committee when planning decisions. The applicability of the framework has been demonstrated during the case study presented above.

The originality of the approach shown in this document is to use the built scenarios, their evaluation and their classification for water quality management. Future work should focus on extending the auxiliary proposal into a neutrosophic decision map to work out the decision-making dependency of multiple criteria and feedback problems. The development of a full neutrosophic proposal is another area of future research.

References

1. Santelmann, M., J. McDonnell, J. Bolte, S. Chan, A. Morzillo, and D. Hulse, *Willamette water 2100: river basins as complex social-ecological systems.* WIT Transactions on Ecology and the Environment, 2012. **155**: p. 575-586.

2. Konzen, G., J. Figueiredo, and D. Quevedo, *History of water quality parameters–a study on the Sinos River/Brazil.* Brazilian Journal of Biology, 2015. **75**(2): p. 1-10.
3. Kosko, B., *Fuzzy cognitive maps.* International journal of man-machine studies, 1986. **24**(1): p. 65-75.
4. Abdel-Basset, M., M. Mohamed, and F. Smarandache, *An Extension of Neutrosophic AHP–SWOT Analysis for Strategic Planning and Decision-Making.* Symmetry, 2018. **10**(4): p. 116.
5. Abdel-Basset, M., G. Manogaran, M. Mohamed, and N. Chilamkurti, *Three-way decisions based on neutrosophic sets and AHP-QFD framework for supplier selection problem.* Future Generation Computer Systems, 2018. **89**: p. 19-30.
6. Abdel-Basset, M., G. Manogaran, and M. Mohamed, *Internet of Things (IoT) and its impact on supply chain: A framework for building smart, secure and efficient systems.* Future Generation Computer Systems, 2018. **86**: p. 614-628.
7. Li, C. *Water resources renewability assessment based on TOPSIS*. in *Artificial Intelligence and Computational Intelligence, 2009. AICI'09. International Conference on*. 2009. IEEE.
8. Figueiredo, J., E. Drumm, M. Rodrigues, and F. Spilki, *The Rio dos Sinos watershed: an economic and social space and its interface with environmental status.* Brazilian Journal of Biology, 2010. **70**(4): p. 1131-1136.
9. Plano Sinos. *Plano de Gerenciamento da Bacia Hidrográfica do Rio dos Sinos. Síntese da Situação Atual dos Recursos Hídricos*. 2016 [cited 2018 August 20]; Available from: http://www.prosinos.rs.gov.br/downloads/PBHSINOS-R10-Volume%20%C3%9Anico.pdf.
10. Blume, K.K., J.C. Macedo, A. Meneguzzi, L.B.d. Silva, D.M.d. Quevedo, and M.A.S. Rodrigues, *Water quality assessment of the Sinos River, southern Brazil.* Brazilian Journal of Biology, 2010. **70**(4): p. 1185-1193.
11. Spilki, F. and J. Tundisi, *Priority targets for environmental research in the Sinos River basin.* Brazilian Journal of Biology, 2010. **70**(4): p. 1245-1247.
12. Guzmán, R.A.F., *A Manchester Brasileira não tem esgoto: Análise histórica da gestão das águas na bacia hidrográfica do Rio dos Sinos.* 2016, UNIVERSIDADE FEEVALE
13. Nascimento, C.d. and R. Naime, *Panorama do uso, distribuição e contaminação das águas superficiais no Arroio Pampa na bacia do Rio dos Sinos.* Estudos Tecnológicos, 2009. **5**(1): p. 101-120.
14. Staggemeier, R., *Vírus Entéricos Humanos em Sedimento e Água Superficial de Áreas Urbanas da Região do Vale do Rio dos Sinos*. 2016, Universidade Feevale
15. Rodrigues, M.T., *Efeitos do clima sobre a dispersão de vírus entéricos e a incidência de viroses de veiculação hídrica na região do Vale do Rio dos Sinos, Brasil,*. 2012, Feevale University
16. de Oliveira, L.A. and J.A. Henkes, *Poluição hídrica: poluição industrial no Rio dos Sinos-RS.* Revista Gestão & Sustentabilidade Ambiental, 2013. **2**(1): p. 186-221.
17. Oliveira, C.R.d., *Avaliação da qualidade da água do rio dos sinos*. 2015, FEEVALE
18. Ribeiro, A.G., *A Qualidade Ambiental Do Rio Dos Sinos: Poluentes Orgânicos, Metais Tóxicos, Parâmetros Físico-Químicos E Toxicidade No Sedimento E Águas Superficiais*. 2016, Feevale
19. Dorneles, M.B., *Monitoramento da genotoxicidade do ar atmosférico com o uso de Tradescantia e avaliação da estrutura comunitária de epífitos vasculares em áreas com diferentes graus de antropização na Bacia do Rio dos Sinos, Rio Grande do Sul,*. 2012, Feevale
20. Axelrod, R., *Structure of decision: The cognitive maps of political elites*. 2015: Princeton university press.
21. Pérez, Y.F., C.C. Corona, and J.L. Verdegay, *Modelling the interrelation among software quality criteria using Computational Intelligence techniques.* International Journal of Computational Intelligence Systems, 2018. **11**: p. 1170-1178.
22. LEYVA, M., J. HECHAVARRIA, N. BATISTA, J.A. ALARCON, and O. GOMEZ, *A framework for PEST analysis based on fuzzy decision maps.* Revista ESPACIOS, 2018. **39**(16).
23. Kyriakarakos, G., A.I. Dounis, K.G. Arvanitis, and G. Papadakis, *Design of a Fuzzy Cognitive Maps variable-load energy management system for autonomous PV-reverse osmosis desalination systems: A simulation survey.* Applied Energy, 2017. **187**: p. 575-584.
24. Pramanik, S. and S. Chackrabarti, *A study on problems of construction workers in West Bengal based on neutrosophic cognitive maps.* International Journal of Innovative Research in Science, Engineering and Technology, 2013. **2**(11): p. 6387-6394.
25. Bueno, S. and J.L. Salmeron, *Benchmarking main activation functions in fuzzy cognitive maps.* Expert Syst. Appl., 2009. **36**(3): p. 5221-5229.
26. Arroyave, M.R.M., M.L. Vazquez, and A.F. Estrada, *Modelado y análisis de indicadores ciencia y tecnología mediante mapas cognitivos difusos.* Ciencias de la Información, 2016. **47**(1): p. 17-24.

27. Leyva-Vázquez, M., K. Pérez-Teruel, and R.I. John. *A model for enterprise architecture scenario analysis based on fuzzy cognitive maps and OWA operators*. in *Electronics, Communications and Computers (CONIELECOMP), 2014 International Conference on*. 2014. IEEE.
28. Gray, S.A., S. Gray, J.L. De Kok, A.E. Helfgott, B. O'Dwyer, R. Jordan, and A. Nyaki, *Using fuzzy cognitive mapping as a participatory approach to analyze change, preferred states, and perceived resilience of social-ecological systems.* Ecology and Society, 2015. **20**(2).
29. Baker, C.M., M.H. Holden, M. Plein, M.A. McCarthy, and H.P. Possingham, *Informing network management using fuzzy cognitive maps.* Biological Conservation, 2018. **224**: p. 122-128.
30. Christen, B., C. Kjeldsen, T. Dalgaard, and J. Martin-Ortega, *Can fuzzy cognitive mapping help in agricultural policy design and communication?* Land Use Policy, 2015. **45**: p. 64-75.
31. Smarandache, F., *Neutrosophic set-a generalization of the intuitionistic fuzzy set.* Journal of Defense Resources Management, 2010. **1**(1): p. 107.
32. Henríquez Antepara, E.J., A. Arzube, O. Omar, C. Arroyave, J. Arturo, E.A. Alvarado Unamuno, and M. Leyva Vazquez, *Competencies evaluation based on single valued neutrosophic numbers and decision analysis schema.* Neutrosophic Sets & Systems, 2017.
33. Abdel-Basset, M., M. Mohamed, Y. Zhou, and I. Hezam, *Multi-criteria group decision making based on neutrosophic analytic hierarchy process.* Journal of Intelligent & Fuzzy Systems, 2017. **33**(6): p. 4055-4066.
34. Abdel-Basset, M., M. Mohamed, A.-N. Hussien, and A.K. Sangaiah, *A novel group decision-making model based on triangular neutrosophic numbers.* Soft Computing, 2017: p. 1-15.
35. Pramanik, S., P. Biswas, and B.C. Giri, *Hybrid vector similarity measures and their applications to multi-attribute decision making under neutrosophic environment.* Neural computing and Applications, 2017. **28**(5): p. 1163-1176.
36. Hwang, C.-L. and K. Yoon, *Methods for multiple attribute decision making*. in *Multiple attribute decision making (pp. 58-191), (*1981), Springer
37. Biswas, P., S. Pramanik, and B.C. Giri, *TOPSIS method for multi-attribute group decision-making under single-valued neutrosophic environment.* Neural computing and Applications, 2016. **27**(3): p. 727-737.
38. Biswas, P., S. Pramanik, and B.C. Giri, *Neutrosophic TOPSIS with Group Decision Making*, C. Kahraman and İ. Otay, Editors. in *Fuzzy Multi-criteria Decision-Making Using Neutrosophic Sets (pp. 543-585), (*2019), Springer International Publishing: Cham.10.1007/978-3-030-00045-5_21.
39. Ritha, W. and W.L. Merline, *Risk Factors of Meningitis in Adults-An Analysis Using Fuzzy Cognitive Map with TOPSIS.* International Journal of Scientific and Innovative Mathematical Research, 2014. **2**(4): p. 418-425.
40. Pérez-Teruel, K., M. Leyva-Vázquez, and V. Estrada-Sentí, *Mental models consensus process using fuzzy cognitive maps and computing with words.* Ingeniería y Universidad, 2015. **19**(1): p. 173-188.
41. Gray, S., R. Jordan, A. Crall, G. Newman, C. Hmelo-Silver, J. Huang, W. Novak, D. Mellor, T. Frensley, and M. Prysby, *Combining participatory modelling and citizen science to support volunteer conservation action.* Biological conservation, 2017. **208**: p. 76-86.
42. Pérez-Teruel, K. and M. Leyva-Vázquez, *Neutrosophic Logic for Mental Model Elicitation and Analysis.* Neutrosophic Sets and Systems, 2014. **2**(unknown): p. 31-33.
43. Salmeron, J.L., R. Vidal, and A. Mena, *Ranking fuzzy cognitive map based scenarios with TOPSIS.* Expert Systems with Applications, 2012. **39**(3): p. 2443-2450.
44. Jetter, A. and W. Schweinfort, *Building scenarios with Fuzzy Cognitive Maps: An exploratory study of solar energy.* Futures, 2011. **43**(1): p. 52-66.

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