**UNIVERSIDADE FEEVALE**

# UMA METODOLOGIA DE GESTÃO SOCIOAMBIENTAL PARA O SOCIOECOSSISTEMA BACIA HIDROGRÁFICA RIO DOS SINOS

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**Orientador: Dr. João Alcione Sganderla Figueiredo**

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**RODOLFO GONZÁLEZ ORTEGA**

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**Tese apresentada ao Programa de Pós-graduação em Qualidade Ambiental como requisito para a obtenção do título de Doutor em Qualidade Ambiental.**

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A minha família pela sua dedicação, seu sacrifício e pela incomensurável saudade nestes quatro longos anos.

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*"…cuando se ve que la intervención humana en la naturaleza acelera, cambia o detiene la obra de ésta, y que toda la Historia es solamente la narración del trabajo de ajuste, y los combates, entre la Naturaleza extrahumana y la Naturaleza humana…"*

*José Martí*

**RESUMO**

A bacia do Rio dos Sinos, teve um crescimento contínuo de assentamentos humanos e, sobretudo no último século, a pressão antrópica modificou a paisagem, passando de Mata Atlântica para terras agropecuárias, indústrias, cidades e uma grande rede de rodovias. Isto erodiu o ecossistema da bacia com poluição das águas superficiais e subterrâneas, com a perda de biodiversidade e uma diminuição na variabilidade genética das populações, o que também trouxe um efeito negativo sobre a sociedade. Assim, aumentaram os riscos, elevaram-se os danos e prolongaram-se os impactos no tecido social, econômico e no ecossistema. Nesta pesquisa foram estudadas abordagens implementadas no planeta para gestão integrada de bacias hidrográficas e seus componentes sociais e ambientais, o que permitiu identificar cinco metodologias socioambientais de gestão de bacias hidrográficas, as características que elas têm em comum e seus pontos fortes e fracos. Por meio da análise de fatores políticos, econômicos, sociais, tecnológicos, ecológicos e legais (PESTEL) identificaram-se variáveis que influenciam a gestão ambiental, sendo que cada uma delas tem subfatores. Criou-se então um modelo que permitiu medir e avaliar incertezas e indeterminações tendo em conta as interdependências entre eles. Ademais, criou-se um procedimento que, com a análise estática dos números neutrosóficos das interdependências entre os seus subfatores, a modelagem das incertezas e das indeterminações, permitiu demonstrar a sua aplicabilidade. Para modelar as interdependências dos subfatores e para a classificação de cenários através do método de decisão multicritério, foram utilizados Mapas Cognitivos Difusos e Mapas Cognitivos Neutrosóficos, assim como o processo analítico hierárquico neutrosófico (NAHP) combinado com a técnica para avaliar o desempenho de alternativas por meio de similaridade com a solução ideal (TOPSIS). Neste trabalho **foram agrupados em um suporte teórico um conjunto de teorias, métodos, abordagens e ferramentas que resultaram na concepção de um modelo teórico de gestão** e no desenvolvimento de uma **metodologia de gestão** socioambiental da bacia hidrográfica**,** os quais **constituem uma contribuição teórico-prática e** um **instrumento metodológico de gestão** a ser utilizado pelo comitê de bacia no planejamento das suas ações**. Esta metodologia é baseada** n**uma abordagem holística e integrada** qu**e reúne tecnologias e ferramentas de gestão**, dividida **em quatro etapas interativas e sequenciais**, **que** permitem atingir os obje**tivos técnicos e organizacionais da gestão integrada** da bacia **pelo comitê.**

**Palavras-chave:** bacia, gestão socioambiental, metodologia, tomada de decisões

## ABSTRACT

The Sinos River basin had a continuous growth of human settlements and, especially in the last century, anthropic pressure changed the landscape, changing it from Atlantic Forest to agricultural lands, industries, cities and a large network of highways. This eroded the basin's ecosystem with surface and groundwater pollution, loss of biodiversity and a decrease in the genetic variability of populations, which also had a negative effect on society. Thus, increased the risks, maximized the damages and went on impacts on the economic and social network and the ecosystem. In this research, approaches implemented in the planet for integrated watersheds management and their social and environmental components were studied, allowing the identification of five socio-environmental basin management methodologies, the characteristics they have in common and their strengths and weaknesses. Through the PESTEL analysis, the variables that influence environmental management were identified, each of them with their own subfactors. A model that allows the measurement and evaluation of the uncertainties and indeterminations was created, taking into account the interdependencies between them. In addition, a procedure was created where, with the static analysis of the interdependencies neutrosophic numbers among their subfactors and the uncertainties and indeterminations modeling, allowed to demonstrate its applicability. In order to model the subfactor interdependencies and the scenarios classification, using the multicriteria decision method, Diffuse Cognitive Maps and Neutrosophic Cognitive Maps were used, as well as the neutrosophic hierarchical analytical process (NAHP) combined with the technique to evaluate the performance of alternatives through similarity with the ideal solution (TOPSIS). In this work, a set of theories, methods, approaches and tools were grouped into a theoretical support. That resulted in the conception of a theoretical management model and in the development of a socioenvironmental management methodology of the hydrographic basin, which constitute a theoretical-practical contribution and a methodological management tool to be used by the basin committee in their actions planning. This methodology is based on a holistic and integrated approach that brings together management technologies and tools, divided into four sequential and interactive stages, that allows the technical and organizational objectives of the basin integrated management to be achieved by the committee.



**Keywords:** river basin, social environmental management, decision-making

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LISTA DE SIGLAS E ABREVIATURAS

| | |
|---|---|
| 4D | Discover, Dream, Design, and Destiny |
| AHP | Processo Analítico Hierárquico |
| AQI | Air Quality Index |
| CAPES | Coordenação de aperfeiçoamento de pessoal de nível superior – brasil |
| CER | Corporate environmental responsibility |
| COMITESINOS | Comitê gestor da bacia do rio dos sinos |
| CSER | Corporate social-environmental responsibility |
| CSR | Corporate social responsibility |
| DFWM-RBC | Decision framework for wetland management in a river basin context |
| ENVISION | Modelo de gestão hídrica usado na região dos grandes lagos nos Estados Unidos de América |
| FAO | Organização Mundial pela Agricultura e Alimentação |
| FCM | Fuzzy cognitive maps |
| FEEVALE | Universidade FEEVALE ( federação de estabelecimentos de ensino superior) |
| GDP | Gross domestic product |
| GIRH | Gestão integrada dos recursos hídricos |
| GWP | Global Water Partnership (associação mundial pela água) |
| IQA | Índice de qualidade da água |
| IWRM | Integrated water resources management |
| MSGM | Multi-stakeholder governance model |
| NAHP | Processo analítico hierárquico neutrosófico |
| NCM | Mapa cognitivo neutrosófico |
| NL | Neutrosophic logic |
| NS | Neutrosophic set |
| OD | Oxigenio disolvido |
| ONU | Organização das nações unidas |
| PEST | Political, economical, social, and technological aspects |
| PESTEL | Método de análise de fatores políticos, econômicos, sociais, tecnológicos, ecológicos e legais |
| PNRH | Plan nacional de recursos hídricos |
| R & D + I | Research & development + innovation |
| RIS | Arquivo do research information systems |
| SciMAT | Science mapping analysis software tool |
| SCOPUS | Base de dados científicos |
| SERH | Sistema estadual de recursos hídricos |
| SES | Sistema socioambiental |
| SRB | Sinos river basin |
| SRW | Sinos river watershed |
| TOPSIS | Método de análise desempenho de alternativas por meio de similaridade com a solução ideal |
| UNISINOS | Universidade do Vale do Rio dos Sinos |
| WFD 2000 | European water framework directive |
| WoS | Web of science |
| WTP | Wastewater treatment plant |

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# INTRODUÇÃO

A gestão das bacias hidrográficas tornou-se um desafio para os homens desde os inícios da civilização. A necessidade de aproveitar os recursos destes ecossistemas, assim como mitigar os impactos de fenômenos cíclicos, como enchentes e estiagem que afetavam as sociedades primigênias, levaram à prática de ações modificadoras das bacias (HECHT, 1988; HADAS, 2012; LU et al., 2017; LUO et al., 2017).

Essas modificações graduais dos ecossistemas das bacias hidrográficas, no decorrer de longos períodos históricos, fizeram nascer uma relação entre os componentes das dimensões ambientais, sociais e econômicas das sociedades humanas, que cresciam e se desenvolviam nestes ecossistemas, dando lugar ao surgimento do conceito **socioecossistema**. Este conceito define-se como um sistema complexo com vínculos e interações dos sistemas ecológicos com os sistemas sociais, compostos pelos serviços e recursos ecossistêmicos, os usuários destes recursos e serviços, as infraestruturas construídas, os gestores destas infraestruturas, as instituições sociais e as regras destas instituições. Qualquer mudança ou modificação em um dos componentes deste sistema pode trazer mudanças inesperadas em outros componentes, inclusive os biofísicos da dimensão ambiental, o que torna o socioecossistema em um sistema bio-geo-físico com grande capacidade adaptativa e de resiliência (PARKES et al., 2010; CUMMING, 2011; SCHLÜTER; HERRFAHRDT-PÄHLE, 2011; BECKER, 2012; RATHWELL; PETERSON, 2012; CABELLO et al., 2015; OBIEDAT; SAMARASINGHE, 2016; VIRAPONGSE et al., 2016).

No Brasil, a Gestão Integrada dos Recursos Hídricos (GIRH) teve o seu início na década de 80 do século passado, implementando a política nacional da água no final dos anos 90 com a promulgação da lei 9.433/97. A legislação em questão estabelece a bacia como unidade territorial para a implantação da GIRH, a água como bem público e de valor econômico e determina, de forma geral, a gestão como descentralizada e o papel participativo da sociedade no processo. No ano seguinte foi criado o Conselho Nacional de Recursos Hídricos como órgão consultivo e deliberativo. Posteriormente, no ano 2000, foi constituída a Agência Nacional de Águas (ANA), com o objetivo de implementar a política nacional de recursos hídricos (SILVA; HERREROS; BORGES, 2017). Observa-se que o Brasil implementou um conjunto de normas jurídicas que permitiram organizar e efetivar, a nível federal e estadual, a GIRH. Estes comitês são integrados por representantes de instituições federais, estaduais e municipais e têm como competência: implementar os planos de bacia, dirimir os conflitos e estabelecer mecanismos de cobrança, entre outras funções (SILVA; HERREROS; BORGES, 2017).

No Brasil foi desenvolvida, em consonância com as práticas internacionais, uma estrutura legal e organizativa por meio da lei N° 9433/97 que institucionalizou a gestão dos recursos hídricos e estabeleceu o comitê de bacia como órgão gestor.

No caso específico da bacia hidrográfica do Rio dos Sinos (Figura 1), seu comitê de gerenciamento foi constituído pelo Decreto nº 32.774/1988, posterior ao Decreto nº 30.132/1981 que instituiu o sistema estadual dos recursos hídricos e seus objetivos. Posteriormente, o estado de Rio Grande do Sul institui a lei nº 10.350/1994 que define os objetivos e atribuições dos diferentes órgãos na gestão das bacias hidrográficas dentro da jurisdição do estado, antecipando-se, assim, à lei federal n° 9433/1997.


Figura 1 Bacia do rio dos Sinos

Fonte: http://olharcampobom.blogspot.com.br/2015/08/hidrografia-de-campo-bom.html

A história da gestão do Rio dos Sinos inicia-se com o assentamento de população de origem europeia e seu posterior desenvolvimento socioeconômico. Durante um período de aproximadamente 200 anos aconteceram inúmeras mudanças, tanto na componente ambiental, pelas pressões antrópicas, como nos componentes sociais e econômicos com o crescimento e desenvolvimento das populações. A maioria das mudanças aconteceram sem seguir um planejamento ambiental ou urbano que tivesse uma visão integral dos impactos no ambiente ou nas mudanças sociais (SPILKI; TUNDISI, 2010; FLORES GUZMÁN, 2016; PLANO SINOS, 2016). Isso gerou impactos negativos na flora, na fauna, alteração nos ciclos dos nutrientes, das chuvas e no microclima da região (BORDIN DA LUZ, 2014; RIBEIRO, 2016; SCHNEIDER HENRIQUE, 2016; LUCHETA, 2017). Além disso, trouxe consequências sanitárias para a poluição das águas superficiais e subterrâneas, como consequência de um limitado sistema de tratamento do esgoto doméstico e efluentes industriais (NASCIMENTO; NAIME, 2009; STAGGEMEIER, 2009; OLIVEIRA; HENKES, 2013; THIESEN BAUM, 2013; REIS DE OLIVEIRA, 2015; KONZEN; FIGUEIREDO; QUEVEDO, 2015). O crescimento das cidades sem um planejamento derivou em áreas de risco ante enchentes e deslizamento de terras. Se bem que esta bacia foi uma das primeiras a ter um comitê de bacia no Brasil, (GUTIÉRREZ, 2006), os problemas socioambientais continuam a acumular-se e agravam-se seus impactos neste socioecossistema.

Estes elementos justificam a presente investigação e suscitam o **problema científico**: Quais são as variáveis da gestão socioambiental do socioecossistema bacia Rio dos Sinos que influenciam nas dimensões ambiental, social e econômica, e determinam o desempenho dos processos da gestão?

Refletir sobre as ações desenvolvidas durante o período de funcionamento do comitê de bacia do Rio dos Sinos; identificar os problemas que dificultam a gestão integrada do socioecossistema; identificar as variáveis de gestão socioambiental que influenciam as dimensões social, econômica e ambiental do ecossistema social; integrar conceitos, abordagens, modelos e teorias em uma proposta teórico-metodológica para melhorar a gestão socioambiental da bacia do Rio dos Sinos formam o núcleo das atividades desenvolvidas para a criação e formulação desta tese, cujos objetivos são:

## 1. Objetivos

### 1.1. Objetivo geral

Compreender as interações entre as dimensões ambiental, social e econômica e como determinam o desempenho dos processos de gestão socioambiental.

### 1.2. Objetivos específicos:

–Estudar as características e a evolução da gestão nas bacias hidrográficas ao nível internacional e nacional.

–Descrever a gestão na bacia do Rio Sinos, avanços e desafios.

–Identificar as variáveis da gestão socioambiental do socioecossistema bacia hidrográfica que influenciam as dimensões ambiental, social, econômica, política e legal e que determinam o desempenho dos processos de gestão.

–Desenvolver ferramentas de auxílio na tomada de decisões pelas estruturas de gestão.

–Desenvolver uma metodologia para a gestão socioambiental no socioecossistema bacia Rio Dos Sinos.

Partindo dos objetivos específicos apresentados acima, expõe-se as seguintes **perguntas de pesquisa:**

1- Qual é o aporte teórico-metodológico da evolução histórica da gestão socioambiental de diferentes bacias hidrográficas, a nível internacional e nacional, na gestão socioambiental do socioecosistema Bacia do Rio Sinos?
2- Que variáveis do entorno influenciam na gestão socioambiental do socioecosistema Bacia do Rio do Sinos?
3- Quais são os avanços e desafios que apresenta a gestão socioambiental do socioecosistema Bacia do Rio do Sinos?
4- Que ferramentas de análise muil-ticriteria podem auxiliar na tomada de decisões na gestão socioambiental da bacia.
5- Que características deve ter uma metodologia de gestão socioambiental para que contribua para mitigar ou remediar os danos dos impactos antrópicos causados ao socioecosistema Bacia do Rio do Sinos?

Para alcançar os objetivos propostos na presente tese e dar resposta as perguntas ora mencionadas, estruturou-se este trabalho em cinco capítulos em que cada um busca responder as respectivas perguntas de pesquisa e objetivo:

O primeiro capítulo faz uma revisão da literatura consultando bases de dados internacionais, percorrendo os conceitos de gestão socioambiental de bacia, o que permitiu identificar o conceito de Sistema Socioambiental (SES) e cinco das metodologias mais usadas na gestão integrada de bacias hidrográficas no mundo. Também buscou-se abordar o conceito de Serviços Ecossistêmicos e a participação de *stakeholders* na gestão. Estas metodologias são a Gestão Integrada dos Recursos Hídricos e o Nexo água – Energia – Alimentos, as duas promovidas pela Associação Mundial pela Água (GWP) e pela Organização Mundial pela Agricultura e Alimentação (FAO), ambas as organizações membros da Organização das Nações Unidas (ONU) e com uma abrangência de alcance global; o Marco Diretivo da Água, promovido pela União Europeia para ser empregado nos países membros; O modelo ENVISION usado nos Estados Unidos na gestão de bacias hidrográficas na região dos grandes lagos e o Marco de decisão para a gestão de regiões alagadas na bacia do rio Guayas, no Equador. Estas metodologias realizam diferentes aproximações em relação às soluções de problemas sociais e ambientais, apresentando caraterísticas que as distinguem, mas também semelhanças, pois tratam de dar soluções a problemas análogos. Esta análise bibliográfica permitiu trazer aproximações e fazer analogias com a gestão socioambiental da bacia do Rio dos Sinos.

O segundo capítulo trata dos avanços e desafios da Gestão Integrada dos Recursos Hídricos na bacia do Rio dos Sinos. A gestão integrada dos recursos hídricos foi o modelo adotado pelo Brasil desde meados dos anos 70 do século passado e, portanto, utilizado na gestão da bacia do Rio dos Sinos pelo seu comitê de bacia. Este modelo propõe a gestão coordenada de recursos hídricos, do solo e de outros recursos naturais sob uma abordagem social, econômica e ambiental.

No terceiro capítulo realizou-se a análise PESTEL da gestão da bacia do Rio dos Sinos, que trata da identificação das variáveis externas que têm influência na eficiência da gestão e dos problemas encontrados na avaliação e medição, levando em consideração as suas interdependências e incertezas. Para solucionar estas dificuldades foi realizada a modelagem dos subfatores usando um Mapa Cognitivo Neutrosófico (NCM). Um exercício com os atores permitiu identificar trinta e três subfatores externos, que a critério deles, tinham relevância no desempenho da gestão, considerando-os da seguinte forma: da variável política identificaram-se cinco subfatores; das variáveis econômicas e socioeconômicas apontaram-se sete; da variável social nomearam-se três; da variável sociocultural diferenciaram-se outras três; da variável tecnológica também foi possível indicar três; da variável ecológica classificaram-se seis e essa mesma quantidade de subfatores foi indicada na variável legal. Modelaram-se as interdependências destes subfatores e as suas incertezas com números neutrosóficos para determinar o conhecimento causal e as complexidades destas relações.

No quarto capítulo, buscou-se fazer uma avaliação socioambiental prospectiva da gestão da qualidade da água na bacia do rio Sinos, utilizando mapas cognitivos difusos e AHP-TOPSIS neutrosóficos; apresenta uma ferramenta baseada em um método de decisão multicritério que utiliza elementos neutrosóficos em modelos AHP-TOPSIS e ligados a Mapas Cognitivos Fuzzy, que podem contribuir para uma melhor gestão ambiental a ser realizada pelo Comitê gestor do Rio dos Sinos. Nas visitas às reuniões do COMITESINOS em que se apresentavam estudos técnicos, e nas entrevistas a gestores participantes na elaboração destes estudos, detectou-se que na maioria das ocasiões eram proporcionadas aos membros do COMITESINOS soluções com pouca ou nenhuma análise de alternativas. Não se levada em consideração as restrições de diferentes naturezas que poderiam surgir, incertezas ou as interligações complexas entre os diferentes fatores envolvidos. Para solucionar tal questão, propôs-se fornecer um método que contribua na análise prospectiva de alternativas. Tomou-se como exemplo prático, num exercício realizado com um grupo de atores, o modelo das relações dos fatores envolvidos na determinação do Índice de Qualidade da Água (IQA), em que se usam mapas cognitivos difusos, por meio do Processo Analítico Hierárquico Neutrosófico (NAHP), para auxiliar os gestores na classificação das diferentes alternativas, através da comparação de diferentes cenários, pela Técnica para a Ordem de Preferência por Similitude com Solução Ideal (TOPSIS), o que vai permitir uma fácil tomada de decisões e supre sólidos argumentos para justificá-las.

O quinto capítulo trata a Metodologia para a gestão socioambiental do socioecosistema Rio dos Sinos. Realiza-se, assim, uma análise a partir da observação não participante dos processos de gestão, de entrevistas aos membros do COMITESINOS e do estudo dos documentos normativos e gerenciais da organização, identificando os principais problemas de gestão que apresenta o COMITESINOS e enquadrando-os em quatro grupos: Problemas organizacionais e de gestão; econômicos; de planejamento e controle de ações; estruturais e funcionais da organização, os quais limitam o desempenho da gestão do COMITESINOS.

Para propor uma solução buscou-se analisar o modelo GIRH, se indagou no conceito de gestão e suas múltiplas interpretações aderindo a uma delas. Analisaram-se os conceitos de gestão social e gestão socioambiental. Todas estas ações permitiram descrever o modelo de gestão socioambiental da bacia do Rio dos Sinos por meio de um mapeamento de processos, as suas entradas e suas saídas, suas bordas funcionais e espaciais, assim como as abordagens, tecnologias e teorias integradas em uma metodologia. Esta metodologia é descrita por meio de um diagrama de fluxo que permite mostrar cada uma das etapas, os processos para sua concreção e apresenta características como: sistémica, adaptativa, flexível, proativa, democrática, participativa, colaborativa e cooperativa. Esta é sustentada pelo método sistêmico e integra um conjunto de teorias, métodos, abordagens, ferramentas e conceitos como: as teorias gerais da direção e das restrições, a abordagem de processos, o método da indagação apreciativa, o modelo de governança *multistakeholders*, os conceitos de responsabilidade social corporativa e ecoeficiência, assim como um amplo uso dos mapas cognitivos difusos para uma melhor compreensão da complexidade inerente à gestão socioambiental de um socioecosistema. Esta metodologia precisa se incorporar à prática, pois é um construto teórico nestas áreas do conhecimento.

A presente tese enquadra-se na linha de pesquisa: Tecnologia e Intervenção Ambiental, do programa de doutorado em qualidade ambiental da Universidade Feevale.

CAPÍTULO 1**:**

**The Social-Ecological Management of Watershed Ecosystem: a Literature Review**

**ARTIGO 1 SUBMETIDO**

Este manuscrito foi submetido à avaliação pelo **Journal of Environmental Management,** (Anexo 2).

CAPÍTULO 1:

# The Social-Ecological Management of Watershed Ecosystem: a Literature Review

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**Abstract:** This article treaties with the concept of socio-environmental management of the watershed and the increasing importance of its treatment in recent years. The approaches to socio-environmental management of the watershed concept and the methodologies implemented to put it into practice around the world were studied. They were also processed by the SciMat bibliometric software, which allowed the identification of common characteristics among them, which were later subjected to a method of qualitative content analysis. Of these 49 papers, 28 were case studies and 20 theoretical approaches. This classification allowed distinguishing between five methodologies of socio-environmental management of basins, according to the characteristics they have in common, and allowed identifying strengths and weaknesses when comparing five common attributes. As well as determining that the Water Framework Directive is the most comprehensive, although it has weaknesses that can be improved.

**Keywords:** Social-ecological; social-environmental management; watershed; river basin; stakeholders; social networks

## 1. Introduction

The term socio-ecological also referred to as socio-environmental or socio-ecological, is related to the indissoluble connection between the social system and the biological ecosystem, these interconnections forming a complex and open system, with numerous connections to subsystems such as political, economic, biological among others (MUSTERS; DE GRAAF; TER KEURS, 1998). Both terms, social and environmental, were separated to study by biologists and social scientists researchers among others scientists, but "the delineation between social and natural systems is artificial and arbitrary"(BERKES; COLDING; FOLKE, 2003). Within the global socio-environmental term, were searched in the database Scopus, articles on the concept of the socio-environmental system of the river basin, where it was observed that its publication was slowly but steadily increasing over the years. (Figure 1)

Figure 1 Papers published by years (source Scopus)


Socio-environmental management is a dynamic and adaptable model for managing environmental and social responsibility issues that an organization can implement (TACHIZAWA; ANDRADE, 2011). It is also the interconnection of the environmental variable with the organizational management process variables, such as economic, technological, competitive, cultural, demographic, sociocultural and political-ideological variables (BERTÉ, 2012). The socio-environmental management provides multidisciplinary concepts and approaches about human and ecological relationship systems that are unable to be a dissociated part of complex and multi-scale systems (VIRAPONGSE et al., 2016).

The watershed (also known as river basin or catchment) needs a complex and multi-scale analysis method capable of solving environmental problems as well as social system development challenges (CABELLO et al., 2015b).

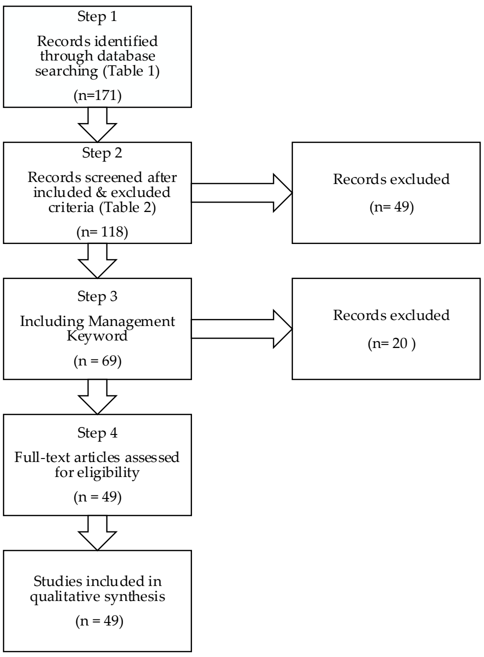
In general, there is a consensus among researchers on the holistic nature of the socio-environmental management of the basin given the infinite and complex interconnections between its multiple subsystems (CUMMING, 2011; SANTELMANN et al., 2012; CABELLO et al., 2015a; WOHLFART et al., 2016). Therefore, during the approach of the solution to the different problems, management tools must be adopted with a marked holistic and multidisciplinary character and identifying some of these tools and how different approaches are applied as part of this research.

## 2. Materials and Methods

Scopus database provides more coverage for environmental research (BURNHAM, 2006; FALAGAS et al., 2007), that´s why, it was used to find the information needed to the literature review on the Social-ecological system (SES) of watersheds, selected because of the coverage it offers within the environmental, social and natural sciences. This database provides 20% more coverage than Web of Science (WoS) for citation analysis, and it is more consistent than Google Scholar (BURNHAM, 2006; FALAGAS et al., 2007; SALISBURY, 2009; AGHAEI CHADEGANI et al., 2013). The research was focused only on electronic journal papers, written in English, Portuguese and Spanish, since 2011, were publications have grown, to June 2017, the final date of the research, excluding other publications like books, book chapters, conferences or grey literature.

In this section it was analyzed the pertinent literature about Social-ecological management of watersheds, providing differences between the previously published papers and laying out the author´s contribution to this theme. This procedure had been created to develop this study.

Figure 2. Search process.



The objective of the first search was to select many papers like the theoretical reference.

| | |
|---|---|
| Keywords used for search | TITLE-ABS-KEY ( socioambiental OR socioenvironmental OR socio-environmental OR socio-ambiental OR socio-ecological OR socioecological OR social-ecological ) AND river* AND basin* OR watershed ) |

Table 1. Searched terms, in English, Portuguese and Spanish, into Scopus

The second step was the reading and evaluation of the papers based on a set of inclusion and exclusion criteria (Table 2), and actualized keyword search (Table *2. Inclusion and exclusion criteria.*
).

| Inclusion criteria | Exclusion criteria |
|---|---|
| Literature published from Jan/2011 to Jun/2017.<br>Index in Scopus database.<br>Content relevant to the search.<br>Peer-reviewed paper. | Literature published before 2011 and after Jun 2017<br>Not available in the Scopus database.<br>Irrelevant content.<br>Reviews, proceeding papers, conferences, book chapters, and editorial material. |

Table 2. Inclusion and exclusion criteria.

| | |
|---|---|
| Keywords used for search | TITLE-ABS-KEY ( ( socioambiental OR socioenvironmental OR socio-environmental OR socio-ambiental OR socio-ecological OR socioecological OR social-ecological ) AND management AND ( river* AND basin* OR watershed ) ) AND ( LIMIT-TO ( PUBYEAR , 2017 ) OR LIMIT-TO ( PUBYEAR , 2016 ) OR LIMIT-TO ( PUBYEAR , 2015 ) OR LIMIT-TO ( PUBYEAR , 2014 ) OR LIMIT-TO ( PUBYEAR , 2013 ) OR LIMIT-TO ( PUBYEAR , 2012 ) OR LIMIT-TO ( PUBYEAR , 2011 ) ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) ) |

Table 3 Keywords actualized with exclusion criteria

This search resulted in 118 papers. The third phase was the addition of the term “management” in the keywords search of step two. That inclusion had as objective the identification of methods, models or procedures of social-environmental management in the watershed. The search result was 69 papers, analyzed by year of publication.

Moreover, Science Mapping Analysis Software Tool (SciMAT), a bibliometric procedure, was used to process all of the 69 papers. The science mapping has procedures to data analysis, to do: data recovery, preprocessing, network mining, normalization, mapping, analysis, visualization and results from interpretation, focusing on the scientific field and allowing to delineate areas of research (COBO et al., 2013). The SciMAT can read RIS format files so after the creation of the project was added the RIS file previously exported by the SCOPUS database. On the knowledge menu was checked and normalized parameters like authors, documents, journals, references, and words. In the same menu were selected the periods for analysis. Subsequently, the authors and words were grouped by similarity (COBO; HERRERA, 2013). In the next step, the analysis was done. For this analysis, the period parameter was modified including all the years sought. Words were the chosen unit for analysis with author´s word, source´s word and added keywords marked too. After this chosen, data reduction was the next option, setting the unit named “frequency reduction value” at three, like the minimum threshold. The next step was to select co-occurrences like kind of matrix. From this time, it was necessary a network filtering using two as a minimum edge value reduction.

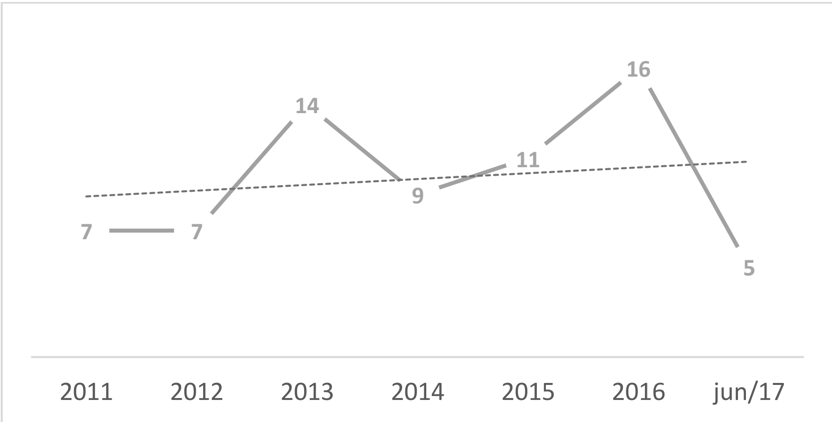
Once finished, there was required the normalization measures and selection of the clustering algorithm. For the normalization, it was chosen the equivalence index like similarity measures and simple center algorithm to make the cluster. Clustering was set as fifteen the maximum network size value and three the minimum one. Afterward, the document mapper option was selected and was activated the core mapper and secondary mapper options. Later, the performance and the quality bibliometric measure were selected. Then, the h-index and the sum citation options clicking on the checkbox were selected. The penultimate step before doing the complete analysis, the measures for longitudinal maps were selected together with the Jaccard´s index for evolution map and inclusion index for overlapping map. When all these steps were completed, click finish and generate the analysis. In the end, about twenty works were excluded, leaving 49 papers selected for exhaustive reading.

For the literature review process, it was used the qualitative content analysis method. This method intrinsically combines data observation and production or data analysis and interpretation following the scientific method, so it is systematic, objective, replicable, and valid (ANDREÚ, 2002).

## 3. Results

The initial evaluation of the sample was planned to identify similarities, points in common, shared characteristics, topics addressed and other relevant issues. The graphic shows the publications behavior by years of the collections stored in the Scopus database (Figure 2). They were cataloged as a case study, theoretical approach and others, being the other a comparative analysis of nine big river basins, exploring the resilience in complex SES (CUMMING, 2011). In general, there is a slight growth trend of related papers in this research.

Figure 3.Research papers by publication years.




After reviewing each paper**,** Table 4 was constructed, showing the distribution according to the type of research.

| Type of research | Quantity of papers |
|---|---|
| Case study | 28 |
| Theoretical approach | 20 |
| Others | 1 |

**T**able 4. Distribution according to the type of research.**¡Error! No se encuentra el origen de la referencia.** shows the number of papers by journals, order by the impact factor of these journals. The “Ecology and Society” journal had the most representative with eight papers. Although, the Journal of Applied Ecology, which as the highest value of the impact factor, have only published two papers.

| Journals | Publications | Impact factor 15/16 |
|---|---|---|
| Ecology and Society | 8 | 4,55 |
| Environmental Science and Policy | 4 | 4,51 |
| Environmental Management | 3 | 1,83 |
| International Journal of River Basin Management | 3 | 3,88 |
| Ecological Indicators | 2 | 5,37 |
| Ecosystem Services | 2 | 2,48 |
| Water (Switzerland) | 2 | 2,14 |
| Water Alternatives | 2 | 2,57 |
| Journal of Applied Ecology | 2 | 6,02 |
| Science of the Total Environment | 2 | 4,42 |
| Others journals with only one. | 39 | ----- |

**T**able 5. Showing the relationship of publications by Journals.

This research focused on the conceptual aspects of the area of scientific research utilizing a bibliometric network, using the co-word parameter to detect the most critical issues, with higher quality and significant impact within the selected sample.

Figure 4. Cluster´s network generated by SciMat).

Figure 4. Cluster´s network generated by SciMat

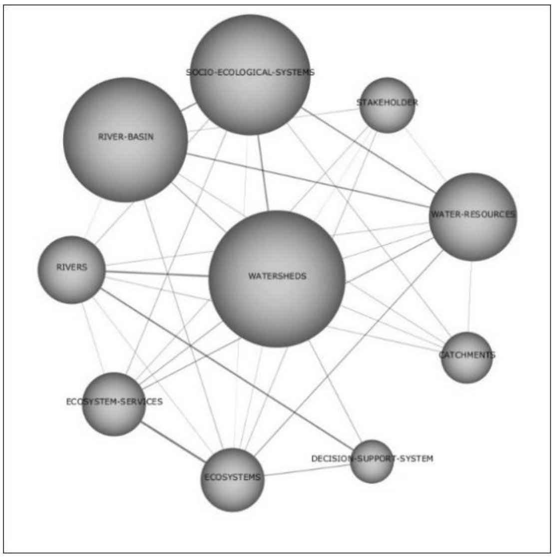


Table 6 shows that the terms of greater weight and significance were watersheds, river basins, and SES.

| Node´s name | Number of documents by node |
|---|---|
| Watersheds | 27 |
| River basins | 24 |
| Social-ecological system | 23 |
| Water resources | 15 |
| Rivers | 10 |
| Ecosystem | 9 |
| Ecosystem services | 9 |
| Stakeholders | 7 |
| Catchments | 6 |
| Decision support system | 4 |

**T**able 6. Nodes generated by SciMAT.

These papers have a wide geographical distribution, but North America and Asia have significant numbers, this is exposed in Table 7.

| Geographic region | No. Papers |
|---|---|
| North America | 14 |
| South America | 8 |
| Europa | 8 |
| Africa | 2 |
| Asia | 10 |
| Australia | 1 |

Table 7 Papers by geographic distribution.

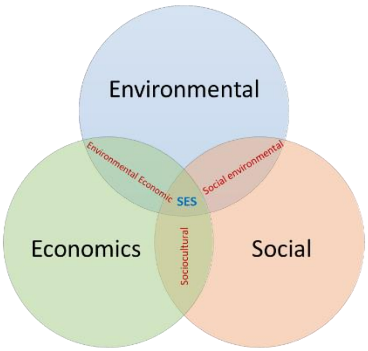
The above described allowed to identify several issues related to the socio-environmental management of a water basin, such as: the definition of the social environmental system and its characterization; its resilience and adaptive capacity; the ecosystem services offered by the basin; the importance of stakeholders and social networks in the managing processes of the SES. Different methodologies and tools were also identified to help in the decision-making processes in the SES management. The identification was made using the definition and procedures for qualitative content analysis method proposed by Mayring (MAYRING, 2014).

## 4. Discussion

### *4.1. Social Environmental Systems (SES)*

A water basin is a complex ecosystem divided into different subsystems for better study and understanding. Various authors, (GOHAR; WARD, 2010; CUMMING, 2011; MWENGE KAHINDA; MEISSNER; ENGELBRECHT, 2016; SAPOUNTZAKI; DASKALAKIS, 2016), call this set of subsystems as the SES for including different names such as complex ecosystem, hydrological system, agro-ecosystem or social-system among others, which reaffirms the holistic nature of the concept and the intrinsic interrelation indissoluble between society and ecosystem. The SES has distinct components such as ecological, hydrological, social, economic, socio-cultural and political, all in constant interaction with their feedback and gradual evolution (CUMMING, 2011; MOLLE; MAMANPOUSH, 2012; GAIN et al., 2013; GARRICK et al., 2013; SANCHEZ et al., 2014; CABELLO et al., 2015b; DIFRANCESCO; TULLOS, 2015; MWENGE KAHINDA; MEISSNER; ENGELBRECHT, 2016; VILLAMAYOR-TOMAS et al., 2016). These components should be merged_into three dimensions, separated for study in social, economic and environmental dimensions with each of their integration factors (Figure *5*).

Figure 5 SES Dimensions (made by the authors)




Thereby, an SES can also be represented in four subsystems, the system of resources, the system of governance, the system of actors and resources units (GARRICK et al., 2013).

An SES has borders that can be classified into two types, one determined by the orography and the demography of the basin, which have a natural or physical origin. The other is a diffuse and artificial boundary created by human activities such as economic, social or political activities (SAPOUNTZAKI; DASKALAKIS, 2016).

Several authors refer to the inherent resiliency characteristic of SES. The resilience is the aptitude of a system to soak up the commotions and reorganize while changing, to still retain substantially the same functions, structure, identity, and feedbacks (SAPOUNTZAKI; DASKALAKIS, 2016). This characteristic should not be taken into account separately for each of the dimensions as environmental, economic or social, but should be analyzed with a holistic approach, with particular emphasis on the links between each of the dimensions and on the different scales expressed (POLHILL et al., 2016). This characteristic should not be taken into account separately for each of the dimensions, environmental, economic and social, but should be evaluated with a holistic approach, with particular emphasis on its links in the different scales that are manifested. Besides, the SES can cushion and reorganize once suffered natural or anthropic impacts (CUMMING, 2011; POLHILL et al., 2016). Another of the SES's capabilities is that of adaptation, which is based on the ability to identify change modifiers or transformation drivers at different scales of time and space. The components of the social dimension have their ability to adopt measures that allow adaptation to these changes and contribute in decreasing the effect of the impacts and thus the resilience of the SES (WELSH et al., 2013; DOWNARD; ENDTER-WADA; KETTENRING, 2014; GIVENTAL; MEREDITH, 2016). Also, like the ability to adapt to settle disputes by the stakeholders in a collective, participatory and collaborative manner. These conflicts derive from the contradictions in the use of the ecosystem services of the SES (WELSH et al., 2013).

### *4.2. SES Ecosystem Services*

Some of the authors define ecosystem services (ES) as the benefits obtained from a given ecosystem by the human population (BERBÉS-BLÁZQUEZ, 2011; WOLLHEIM et al., 2013; MWENGE KAHINDA; MEISSNER; ENGELBRECHT, 2016; JUJNOVSKY et al., 2017). The ES is subdivided into provisioning services such as wood, minerals, fish, water, fuels, and natural fibers, among others. There are also services to regulate natural processes such as climate regulation, natural water purification, and disease regulation among others. Moreover, cultural services are intangible services that humans can appreciate from their natural environment such as recreational and scenic use, spiritual realization, educational. Finally, support services, which are ecological functions that support all other services such as the nutrient cycle, pollination, the water cycle and others (BERBÉS-BLÁZQUEZ, 2011; NORMAN et al., 2013). The health of the SES, according to some of the authors, is determined by the health of the ES, mainly the provisioning service, although all are closely related. To determine the health of the SES, they propose methods to monitor various parameters that allow evaluating the changes that occur in ES as well as the impact of these changes on economic and social factors that affect well-being (EZEJI; SMOUT; BOSHER, 2013; JORDA-CAPDEVILA; RODRÍGUEZ-LABAJOS; BARDINA, 2016). Besides, they highlight the need for stakeholder participation in the identification of ES of the SES of the basin in a way that allows shaping management models by analyzing multiple scenarios and determining their preferences (JORDA-CAPDEVILA; RODRÍGUEZ-LABAJOS; BARDINA, 2016). Other authors consulted refer to the problems that persist due to the rapid growth of economic activities without an analysis of the impacts on ES that affect the balance of the SES and its capacity for resilience and adaptation. These impacts are not only examined from the environmental point of view, but also socially and economically with the growth of phenomena such as poverty, food insecurity, health and education problems, and some countries the violation of fundamental human rights (QUEIROZ et al., 2013; WOLLHEIM et al., 2013)**.**

### *4.3. Stakeholders and social networks*

Approaches for participation and collaboration of stakeholders are perceived as fundamental in the management of the SES. The social system and stakeholder networks are crucial for the identification of socio-environmental issues, identification of risks and the monitoring of possible impacts on ecosystem services by anthropic activities or natural phenomena. The participation of stakeholders with and without formal power contributes to balance power inequalities and increase collaborative governance and co-management of the SES. The inclusion of new decision-making approaches that involve civil society groups, private companies, and public and governmental institutions help with better performance. The benefits of collaboration and cooperation from stakeholder networks contribute to accessing solutions, knowledge, technologies, social and human capital, and financial funds for the SES management, unreachable in another context (CAREY; FRENCH; O'BRIEN, 2012; ONAINDIA et al., 2013; GAIN; GIUPPONI, 2015; HILL et al., 2015; PLUMMER et al., 2016; JUJNOVSKY et al., 2017)**.**

A set of criteria was identified and grouped, summarizing the attributes that a socio-environmental management system of a water basin should have.

| Criteria | attributes |
|---|---|
| Governance | - Democratic, cooperative, collaborative and transparent decision-making method<br>- Holistic Planning<br>- Adaptive monitoring |
| Economic | - Economics, financial and social environmental viability projects |
| Social | - Social and cultural issues<br>- Stakeholders Networks participations<br>- Social-ecological approach |
| Environmental | - Sustainability development<br>- Resiliency and dative<br>- Holistic phenomenal compression |

Table 8 Criteria of SES Management, (Adapted from Shah (SHAH; GIBSON, 2013)).

*4.4. The Social-ecological management*

The Social-ecological management of an organization deals with the insertion of the socio-environmental variable throughout the process of planning, organizing, directing and controlling; using the functions that compose this process, as well as the interrelationships that occur in the ecosystem, aiming to reach its objectives and goals in the most sustainable way possible. It must be understood that there are interrelationships between economic, social and environmental impacts (NASCIMENTO; LEMOS; MELLO, 2008).

Furthermore, the social-ecological management interconnects the environmental variable with the organizational management process variables, giving as an example the economic, technological, competitive, cultural, demographic, sociocultural and political-ideological variables (BERTÉ, 2012). Also, the socio-ecological management must go through strategic, tactical and operational planning becoming part of the activities development, alternative scenarios discussions and, consequently, the generation of policies, goals and action plans. The organization is concerned not only with their economic performance but also with their ethical values. Other authors (TACHIZAWA; ANDRADE, 2011), mention that Social-ecological management is a dynamic and adaptable model of environmental and social responsibility management that an organization can implement. Therefore, Social-ecological management is a participatory and democratic process, free of coercion actions, where every member has equal rights of expression and access to information. These actions are coordinated between the public power and the society in favor of social, political, economic and cultural well-being in a territory (TENÓRIO, 1998, 2005; RAMOS; MATOS, 2009; OLIVEIRA; CANÇADO; PEREIRA, 2010; MONJE-REYES, 2011). Other authors also determine different variables to define social-ecological management, such as participatory, collaborative, communicative process and joint learning, developed through coordinated actions and inter-institutional relationship spaces, with an inclusive approach to environmental variables (SIQUEIRA, 2009).

The bibliometric analysis was able to identify relevant methodologies used to the management of the SES and methods of helping in decision-making or theoretical approach. Among the methodologies identified, the following stands out: The integrated water resources management (IWRM) (ROPERO; AGUILERA; RUMÍ, 2015; NEWIG; SCHULZ; JAGER, 2016); the European Water Framework Directive (WFD 2000)(MOSS, 2012; CABELLO VILLAREJO; MADRID LOPEZ, 2014; NEWIG; SCHULZ; JAGER, 2016); FAO Water – Energy – Foods Nexus (MDEE, 2017);Envision (SANTELMANN et al., 2011; BLESH; WOLF, 2014); Decision framework for wetland management in a river basin context (DFWM-RBC) (ARIAS-HIDALGO et al., 2013). Table 9

| | **IWRM** | **FAO Water – Energy – Foods Nexus** | **WFD 2000** | **Envision** | **DFWM-RBC** |
|---|---|---|---|---|---|
| Integration level | Other policies and objectives are integrated into water policy. | Integration of water and energy policies and objectives - Food Security | Integrates solution policies and institutions at multiple levels | Integration of hydrological, ecological and socioeconomic factors | Integration of hydrological, ecological and socioeconomic factors |
| Governance | It integrates policies for basin-level solutions under the principle of | Integrates solution policies and institutions at multiple levels | High level of integration, EU multinational and EU policies | Integrates solution policies and institutions at multiple levels | Integrates solution policies at the local level |

| | | | | | |
|---|---|---|---|---|---|
| | "Good Governance." | | | | |
| Scale | Water Basin scale | Multiple scales | Multiple scales | Water Basin scale | Water Basin scale |
| Participation of the Stakeholders | Stakeholders involved in decisions in the basin | Multiple participation levels. Extensive use of collaborative tools encouraging public-private partnerships | Multiple participation levels, stakeholders with broad decision-making capabilities | Multiple Levels of Participation | Participation at the basin scale |
| Use of resources | Efficient use of local resources, recoverable costs, equitable access to stakeholders | Decision-making based on economic factors and cost recovery | Efficient use of local, national and multinational cooperation resources | Efficient use of local resources, multifactorial decision making | Efficient use of local resources, recoverable costs, equitable access to stakeholders |
| Sustainable development | Medium, on-demand monitoring, and management of stakeholders | Low, Securitization of resources and dependence on the market value | High, ambitious goals and well-defined goals for sustainability | High, ambitious objectives and well-defined goals | Medium, on-demand monitoring, and management of stakeholders |

**T**able 9 Comparison of methodologies (partially **taken** of Mdee (MDEE, 2017) and improved by the authors).

Table 9 shows the different methodologies identified in this study. It is not defined, which is the better one to manage one watershed although it is possible to find similarities and accentuated differences at different levels: integration level, governance, scale, stakeholders, use of resources, sustainable development impact.

IWRM methodology has different objectives for water use, such as Agriculture and irrigation, transportation, energy, fishing and aquaculture, tourism and recreation, and at last but not less important, potable water distribution to people and animals (ROCKSTRÖM et al., 2014; STEWART; BENNETT, 2016; BISCHOFF-MATTSON; LYNCH, 2017; SILVA; HERREROS; BORGES, 2017). For being more far-reaching, it needs adequate policies and precise synergy between each necessary action to reach the goals. Integration between governmental and non-governmental institutions is fundamental to participation, collaboration, and cooperation of all actors (VILLAMAYOR-TOMAS et al., 2016; JUJNOVSKY et al., 2017).

Regarding IWRM, the difference of FAO methodology (Water – Energy – Food) is that it has a minor complex integration level, focusing only in three objectives, population water supply, agriculture irrigation, and hydroelectric energy production. This methodology is mainly implemented in water scarcity environments, decreasing conflicts by putting in execution public-private ventures with government intervention at different levels and small stakeholder's participation. The integration processes occur in an economic framework (CABELLO VILLAREJO; MADRID LOPEZ, 2014; FLAMMINI et al., 2014; YANG; GOODRICH, 2014; CABELLO et al., 2015a; MDEE, 2017).

European Water Framework Directive (WFD 2000) is an implantation policy for the bloc common rules that allows governmental organizations integration between the several European Union members that share watersheds and activities implementation to reach common goals. That facilitates integration not only for national governments but also for municipalities of membership countries, enabling institutional interrelationships between them (GARRICK et al., 2013; LEBEL et al., 2013; CABELLO VILLAREJO; MADRID LOPEZ, 2014; NEWIG; SCHULZ; JAGER, 2016).

The Envision has an integrated multi-agent-based modeling component that can represent the impact of decision-making. The agents are defined as entities with authority, such as federal land managers, agricultural producers, or homeowner. It is useful for decision-making and the study of resilience in SES, because of its capability of incorporating output from social, economic, hydrologic, and ecological models as feedback that results from specific scenarios (SANTELMANN et al., 2012). This model could be used to calibrate responses of the social ecosystem in situations of water scarcity since integration and feedback of hydrological, ecological and socio-economic factors are included itself.

The decision framework for wetland management in a river basin context (DFWM-RBC) is a methodology for analysis, handle and make-decision in swamplands or floodplains environments. This methodology integrates a rainfall simulation, hydrodynamic models, water allocation model, and other tools. The criteria of the experts and the opinion of the stakeholders to take the necessary decisions are also taken into account (ARIAS-HIDALGO et al., 2013).

The participation of the interested parties is recognized as necessary in the decision-making process in the five methodologies identified in this research, showing that to find a balance in the socio-ecosystem, the active participation of all the interested parties is of vital importance. All the impacts of the anthropogenic activity on the ecosystem and its effects are challenging to predict, so only by working with common objectives can these impacts be mitigated (ONAINDIA et al., 2013; SANCHEZ et al., 2014; VERKERK et al., 2017). The multiple problems that hinder the proper management of water in a socio-ecosystem make it necessary to improve the water management system based on the participation of stakeholders, the public and private sectors working together (TUNDISI, 2008; TUNDISI; TUNDISI, 2016).

As it was possible to appreciate, these five methodologies present many points in common and significant differences in their main characteristics. The level of integration is one of the most different features, with WFD2000 standing out as the most comprehensive when integrating the multiple levels from the multinational government strata to the inter-municipal levels and also at inter-institutional levels, which favors better governance processes and high stakeholder participation in making decisions. However, its weakness lies in setting very ambitious and comprehensive objectives, which makes it difficult to adequately monitor the goals achieved by each of the participating governments, agencies, institutions, and stakeholders. The strengths and weaknesses identified contribute to the development of future methodologies that incorporate the best practices of these methodologies and improve the deficiencies identified.

### *4.5. Study cases*

Some case studies were selected for each of the methodologies analyzed. The first one presents the development and implementation of a decision support system framework for the management of wetland areas in the Guayas river basin in Ecuador (ARIAS-HIDALGO et al., 2013). The second case study was the execution of the water-energy-food nexus methodology in the Wami- Ruvu River Basin in Tanzania (MDEE, 2017). The third case study was the implementation of the Envision methodology in the Willamette River Basin (Oregon, USA) (SANTELMANN et al., 2012). The fourth case study was the putting into practice of water integrated resource management methodology in the Magdalena River Watershed in Mexico (JUJNOVSKY et al., 2017). The fifth case study was the application of the European Water Framework Directive methodology in two rivers watersheds, in the Hase sub-basin and Wupper sub-basin, located in the north-western part of Germany (NEWIG; SCHULZ; JAGER, 2016).

## 5. Conclusions

In the search conducted in the Scopus database it was evident that there is a wide geographic distribution in the subject of research in question, but a low frequency in most of the countries, except the United States and China. These two countries have a significant number of publications in the period consulted. This research allowed the identification of five methodologies of socio-environmental management of watersheds, some of them having a broad implementation in many countries. In some countries to be part of intergovernmental agreements and in others because these methodologies are supported by international organizations that are part of the United Nations. The analysis of concepts such as Level of integration, Governance, Scale, Participation of stakeholders, Use of resources and Sustainable Development, allowed identifying the advantages and disadvantages of each of the methodologies.

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CAPÍTULO 2:
Gestión integrada en la cuenca del Río dos Sinos. Avances y desafíos
**ARTIGO 2 SUBMETIDO**

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CAPÍTULO 2:

# Gestión integrada en la cuenca del Río dos Sinos. Avances y desafíos

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## Resumen

Este artículo aborda los avances y desafíos de la gestión de recursos hídricos en la cuenca del Río dos Sinos. El manejo integrado de cuencas hidrográficas, sin duda alguna juega un rol importante, porque promueve la gestión coordinada del agua, suelo, y otros recursos naturales bajo un enfoque social, económico y ambiental. La cuenca del Rio dos Sinos durante los últimos doscientos años ha visto en sus tres cuartas partes de existencia un proceso predatorio de sus recursos naturales, que ha provocado la contaminación del agua. El objetivo del estudio fue develar los aportes e insuficiencias del COMITESINOS en la gestión integrada de la cuenca del Río dos Sinos, para ello se realizó una investigación cualitativa, en la que se realizaron entrevistas y visitas sistemáticas al órgano de gestión. El trabajo realizado evidenció debilidades en la gestión a pesar de la preocupación ambiental de diferentes grupos sociales.

**Palabras Claves:** Gestión Integrada. Cuenca Hidrográfica. Comité de Cuenca.

## Abstract

This article addresses the progress and challenges of water resources management in the Rio dos Sinos basin. The integrated management of watersheds undoubtedly plays an important role, because it promotes the coordinated management of water, soil, and other natural resources under a social, economic and environmental approach. The basin of the Rio dos Sinos during the last two hundred years has seen in its three quarters of existence a predatory process of its natural resources, which has caused water pollution. The objective of the study was to reveal the contributions and insufficiencies of the COMITESINOS in the integrated management of the Rio dos Sinos basin, for which a qualitative research, in which interviews and systematic visits were made to the management body. The work done evidenced weaknesses in the management despite the environmental concern of different social groups.

**Key words:** Integrated Management. Hydrographic Basin. Basin Committee.

## INTRODUCCIÓN

Existen varias referencias a la gestión de los recursos hídricos, como los cambios en los cursos hidrológicos a través de la construcción de canales para la navegación o el riego, entre otras obras hidráulicas, en varias civilizaciones antiguas desarrolladas cerca de grandes ríos, como ejemplo China y Egipto (HECHT, 1988; WALLACE; BUCKNAM; HANKS, 1994; WANG, 2012; LU et al., 2017). En otras regiones áridas de Medio Oriente, India y China, en diferentes períodos históricos, hay registros de hombres que regulan corrientes, arroyos y manantiales para satisfacer sus necesidades (CHAUDHURI, 1991; HADAS, 2012; LUO et al., 2017).

Los griegos y los pueblos romanos fueron las primeras civilizaciones que, además de proporcionar agua para la agricultura, por razones de salud, crearon sistemas para el tratamiento de aguas residuales y acueductos domésticos para proporcionar agua de calidad para sus ciudades (DE FEO; MAYS; ANGELAKIS, 2011). La gestión de cuencas ha incorporado los diferentes conceptos a lo largo del tiempo y, debido a los múltiples eventos mundiales, las Naciones Unidas han fomentado la incorporación de los procesos de gestión de cuencas en los diferentes países miembros. En 1996 se creó la Global Water Partnership (GWP), teniendo como telón de fondo las conferencias de 1972 sobre el medio ambiente de Estocolmo, Buenos Aires 1977, así como la Declaración de Dublín de 1992 de las Naciones Unidas.

El origen del GWP tuvo entre sus objetivos la creación de una red internacional para garantizar la seguridad y la gestión sostenible de los recursos hídricos mediante la estimulación de la Gestión Integrada de los Recursos Hídricos (GIRH) (GLOBAL WATER PARTNERSHIP, 2009) e inicia un extenso trabajo a nivel internacional para que los gobiernos adopten este enfoque. Adoptada en la Conferencia de Río en 2009, la Agenda 21 extiende el concepto de GIRH al agregar la aplicación de enfoques integrados para el desarrollo, la gestión y el uso de los recursos hídricos. Los objetivos de las iniciativas de la Agenda 21 y GWP se han implementado en diferentes países, en los que se consideran las características de las cuencas y los mecanismos político-legales adoptados por diferentes gobiernos, con diversos grados de efectividad, pero con dificultades, según lo expresado por autores como Perevochtchhikova; Arellano-Monterrosa, (2008); Stewart; Bennett, (2016); Wohlfart et al., (2016).

El manejo integrado de recursos hídricos es relevante en el ámbito de la gestión, debido a que promueve la acción coordinada en el uso de los recursos naturales desde una perspectiva económica y socioambiental, que permitirá enfrentar los desafíos y oportunidades del contexto. Es por ello que este estudio se propuso como objetivo develar los aportes e insuficiencias del COMITESINOS en la gestión integrada de la cuenca del Río dos Sinos.

La gestión de los recursos hídricos requiere de un enfoque equilibrado, que implica tanto medidas de infraestructuras como institucionales. Los planes de seguridad hídrica precisan de la participación de diversos actores. La gestión de recursos hídricos, posee retos como lograr materializar acciones coordinadas a corto, mediano y largo plazo, que garanticen el uso sostenible de los recursos ambientales de la cuenca y disminuya los índices de contaminación.

## ESTRATEGIA METODOLÓGICA EMPLEADA

Se realizó una investigación cualitativa que develó los avances y desafíos de la gestión del COMITESINOS en el manejo de la cuenca del Río dos Sinos, para ello se utilizó el método de análisis de contenido cualitativo. Este método combina intrínsecamente la observación y producción de datos o el análisis e interpretación de datos siguiendo el método científico, por lo que es sistemático, objetivo, reproducible y válido (ANDREÚ, 2002). Además de los artículos científicos publicados en las bases de datos referenciadas, se consultaron documentos normativos del COMITESINOS, leyes y otras normas jurídicas.

El trabajo de campo permitió colectar informaciones relativas al objeto, indagar en lo cotidiano, interactuar con el objeto de pesquisa en su contexto y posibilitó poner atención a lo que está sucediendo. Es así que se entrevistó al presidente del COMITESINOS y a cuatro de sus integrantes, para conocer los criterios en relación a la gestión que realizan, así como las principales acciones que acometen. Además, se realizaron visitas sistemáticas a las reuniones de este órgano de gestión, con el propósito de analizar como participan los diversos actores en la gestión de la cuenca.

## LA GESTIÓN INTEGRADA DE RECURSOS HÍDRICOS EN BRASIL

La gestión de los recursos hídricos es un área estratégica para la sustentabilidad, porque contribuye a la planificación de las acciones que han de ser acometidas en el ecosistema. El manejo socioambiental, económico, cultural y físico, ha de ser efectuado desde una perspectiva múltiple y diversa, lo que posibilita una visión integrada de la cuenca y permite incorporar los principios del desarrollo sustentable. El manejo integrado de recursos hídricos es ideal para caracterizar, diagnosticar, evaluar y planificar el uso de los recursos, para ello es necesario el conocimiento de los factores socioculturales, además que se involucre la comunidad en el proceso.

La cuenca hidrográfica puede ser considerada como un espacio sistémico, pues el territorio definido envuelve actividades humanas, que pueden ser urbanas, industriales, agrícolas, entre otras. Puede decirse que en ella están presentes los procesos que hacen parte de un sistema. En ella ocurren formas de ocupación del territorio y de utilización de las aguas que allí convergen (PORTO & LAINA PORTO, 2008). La gestión sustentable de cuencas hidrográficas requiere de una perspectiva sistémica y de complejidad lo que mejora las capacidades colectivas en el manejo de los recursos hídricos.

La gestión integrada de recursos hídricos tiende cada vez más a un enfoque sistémico y ambiental, en el cual se considera a la cuenca como el entorno en el que se relaciona ese espacio físico, con los grupos sociales que viven y lo transforman. La gestión de la cuenca ha evolucionado pasando por diversas etapas de desarrollo. En la primera, formaba parte de la silvicultura y la hidrología, y no se contemplaba la participación de la población. En la segunda etapa se relacionó con la gestión de los recursos naturales. En la etapa actual dirige su atención a los beneficiarios, hoy se trata de una gestión participativa e integrada, con el compromiso de la población local.

La gestión de recursos hídricos maneja las intervenciones que se hacen sobre el ecosistema, los causes, el agua, para alcanzar logros predeterminados en escenarios negociados (DOUROJEANNI, 2007). Muchos países del mundo poseen Sistemas Nacionales de Gestión de Recursos Hídricos, y de ellos han surgido una serie de posiciones y principios con respecto a la gestión integral a nivel de cuencas hidrográficas, que han estado condicionados a las características geográficas y sociopolíticas propias de los diferentes territorios.

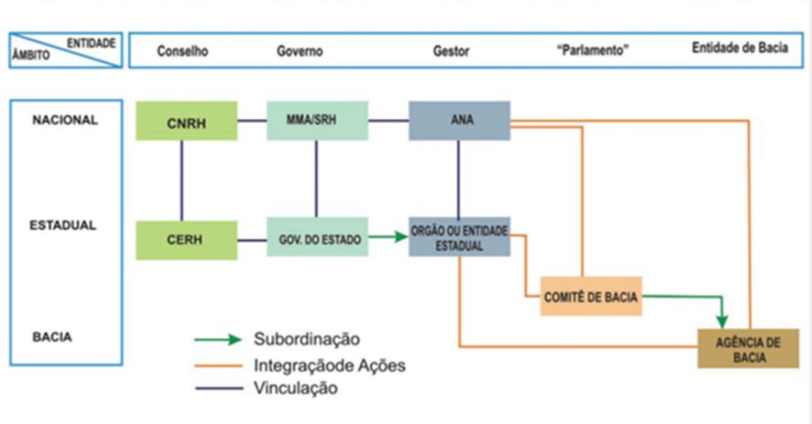
La gestión integrada, predictiva con alternativas y optimización de múltiples usos, ha de ser implantada a nivel de cuencas hidrográficas con la finalidad de descentralizar el manejo y dar oportunidades de participación de usuarios, el sector público y privado. Se precisa también educar a la comunidad y prepara a los gestores con nuevas perspectivas, para un necesario desarrollo de la gestión de los recursos hídricos en el siglo XXI (TUNDISI, 2008).

En Brasil, la gestión integrada de recursos hídricos (GIRH) comenzó en la década de 1980, implementando la política nacional del agua a fines de la década de 1990 con la promulgación de la Ley 9.433 / 97, que establece a la cuenca como una unidad territorial para la implementación de la gestión integrada de los recursos hídricos, el agua como un bien público y de valor económico y determina, de manera general, la gestión como descentralizada y el papel participativo de la sociedad en el proceso. Al año siguiente, se creó el Consejo Nacional de Recursos Hídricos como órgano asesor y deliberativo. Posteriormente, en el año 2000, se creó la Agencia Nacional del Agua (ANA) con el objetivo de implementar la política nacional sobre recursos hídricos (SILVA; HERREROS; BORGES, 2017).

Se observa que Brasil implementó un conjunto de normas legales que permitieron la organización e implementación de la GIRH a nivel federal y estadual, siguiendo los lineamientos de las organizaciones internacionales, lo que permitió que fuera uno de los primeros países en tener una estructura integral de GIRH, que se consolida con la organización de los Comités de Cuenca. Estos están compuestos por representantes de instituciones federales, estatales y municipales y tienen las siguientes responsabilidades: implementar planes de cuencas, resolver conflictos y establecer mecanismos de recolección, entre otras funciones (SILVA; HERREROS; BORGES, 2017).

Para mejorar la disponibilidad de agua en términos cuantitativos y cualitativos, con el sentido de implementar los instrumentos y directrices de acción, el Plan Nacional de Recursos Hídricos (PNRH) instituyó el Sistema Nacional de Gestión de Recursos Hídricos (Figura 1). Ese sistema, previsto en la Constitución Federal de 1988, fue reglamentado por la Ley de aguas, y es innovador en relación con el sistema ambiental en el sentido que utiliza mecanismos económicos para la gestión del agua. Por medio de la introducción en el país del concepto el que contamina paga y el usuario paga. El agua pasa a tener valor económico y su utilización está sujeta al cobro (BRAGA.; et al, 2008).

Figura 1. *Sistema Nacional de Recursos Hídricos.*




Fuente: Elaborado a partir de la AGÊNCIA NACIONAL DE ÁGUAS (2012).

En términos prácticos la gestión de cuencas hidrográficas depende de instrumentos que puedan ser aplicados para atender las expectativas de la comunidad y los limites impuesto por la naturaleza. En Brasil en la Ley no. 9.433/97 se establecen los siguientes instrumentos: planes de recursos hídricos; marco legal para los usos de los cuerpos de agua; compensación a los municipios; el sistema de información sobre recursos hídricos. La definición de estas herramientas aunque tienen una perspectiva utilitarista, pueden ser utilizadas con fines de preservación ambiental o para garantizar la sostenibilidad a largo o mediano plazo (PORTO & LAINA PORTO, 2008).

En Brasil, se creó toda una estructura legal y organizativa, en línea con las prácticas internacionales. La Ley No. 9433/97 institucionalizó la gestión de los recursos hídricos y estableció el comité de cuenca como un órgano de gestión, pero todavía hay dificultades en la GIRH ya que, a pesar de ser una de las naciones con las reservas de agua dulce más importantes del planeta, presenta una distribución irregular de la misma. Este país tiene regiones con poco acceso al agua debido a la ausencia de sistemas de distribución y otros con abundante disponibilidad pero limitados por la calidad debido a la falta de sistemas adecuados de tratamiento y problemas de contaminación de las aguas superficiales y subterráneas, como lo demuestran varios autores que exponen las necesidades de la GIRH en el país entre ellos Costa et al., (2017); Jacobi; Barbi (2007) y Tundisi, (2016).

En la planificación ambiental de la cuenca fluvial en Brasil, coexisten dos instrumentos de gestión, el plan de cuenca fluvial y la zonificación económico-ambiental. El plan de cuencas hidrográficas es un instrumento de la Política Nacional de Recursos Hídricos definida en la Ley No. 9433/1997, y la zonificación económico-ambiental fue establecida por el Decreto Federal 4,297 / 2002. Estos dos instrumentos se superponen en su función de gestión ambiental y realizan acciones en paralelo o superpuesto, causando dificultades para alcanzar los objetivos de la gestión de cuencas, lo que expone la ineficiencia del poder público y las incertidumbres legales (GUIMARÃES DE CARVALHO, 2014).

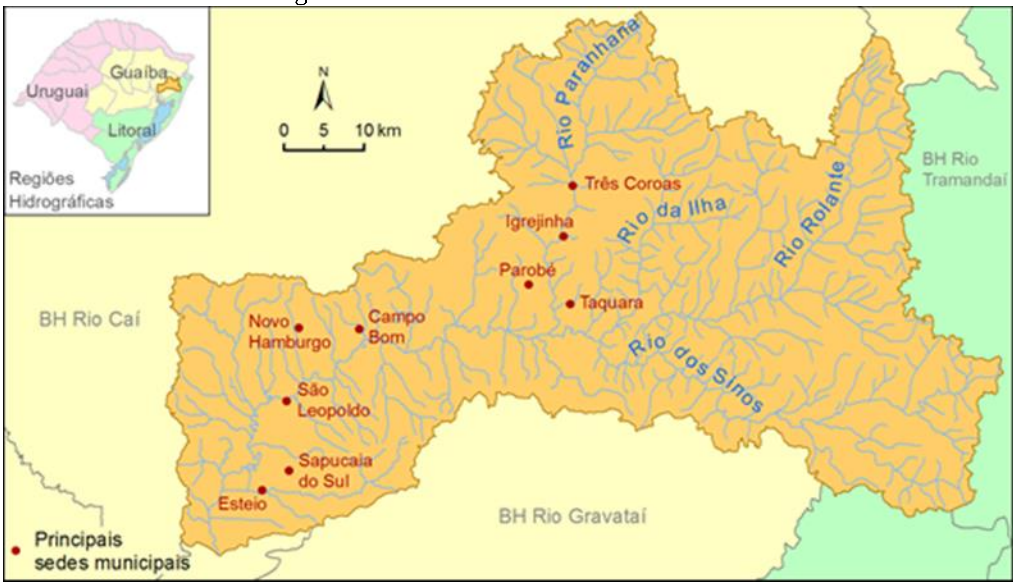
## GESTIÓN DE LA CUENCA DEL RÍO DOS SINOS

En el Estado de Rio Grande del Sur en el artículo 171 de la Constitución Estadual de 1989 se instituye el Sistema Estadual de Recursos Hídricos (SERH). El que incorpora modernos principios para la gestión de las aguas. Entre ellos se destacan: la adopción de cuenca hidrográfica como unidad de gestión, y la tarifa por el uso de las aguas y la reversión de los fondos en beneficio de la propia cuenca.

Los comités de gestión de cuencas son instituidos oficialmente por el Gobierno del Estado, tienen poder deliberativo para establecer las prioridades de uso y las intervenciones necesarias en la gestión de las aguas de la cuenca hidrográfica, para resolver conflictos en primera instancia. Los comités son órganos democráticos de discusión y debate que reúnen a los grupos que tienen interés directo en el manejo y conservación de las aguas, convirtiéndose en la práctica en una especie de parlamento de las aguas.

La cuenca hidrográfica del Río dos Sinos (Figura 2) se localiza al nordeste del estado de Río Grande del Sur, tiene un área total de 3679,2 $km^2$, englobando total o parcialmente 32 municipios, acoge municipios como Tres Coroas, Portao, Igrejinha, Estancia Velha, Parobé, Taquara, Campo Bom, Sapiranga, Esteio, Sapucaia do Sul, Canoas, São Leopoldo e Novo Hamburgo que juntos suman 90% de la población total, estimada en 1.325.830 habitantes. Los principales afluentes del Rio dos Sinos son el Rio Paranhana, o Rio Rolante y Rio da Ilha. Este último tiene su naciente en la ciudad de Caraá y desemboca en el delta del Jacuí.

Figura 2. Cuenca del Río dos Sinos




Fuente: Aportado por FRANÇA de LIMA, 2013

La cuenca hidrográfica del Rio dos Sinos, nombre que recibe por los primeros moradores europeos dada el carácter sinuoso de su curso, inicia apenas dos siglos con los asentamientos de colonos alemanes en 1824 con la fundación de la localidad de São Leopoldo. Los principales impactos que recibió el ecosistema de esta cuenca fue la extracción de recursos naturales como madera, carne de caza y pesca, así como la insipiente agricultura. Los primeros intentos de modificar el curso del rio, adaptando su cauce para la navegación se dan entorno a la segunda mitad del siglo XIX, las cuales fueron abandonadas por ser inviables económicamente, posteriormente dejaron de ser una prioridad con la introducción del ferrocarril, el cual incrementó el impacto por las obras realizadas para interconectar las pequeñas ciudades a lo largo del río con la capital Porto Alegre.

Los principales usos del agua en la cuenca están destinados al abastecimiento público, uso industrial e irrigación. Las áreas más conservadas están situadas aguas arriba de la cuenca. El problema encontrado es la descarga en los afluentes de los residuos industriales y principalmente domésticos sin tratamiento, en los cursos medio y bajo de la cuenca.

Durante la primera mitad del siglo XX las obras de construcción de carreteras como la actual BR-116 tuvieron un efecto de fragmentación del frágil ecosistema. También es en este periodo y en los años 50 y 60 que el control de las crecidas y su impacto social obtienen el interés de los diversos grupos políticos que se disputan los votos electorales, pero sin un efecto real en obras de control hídrico. En este periodo aparecen registradas en la prensa regional las primeras preocupaciones de grupos sociales sobre el ecosistema y el impacto de las proyectadas obras hidráulicas, civiles e industriales sobre el ecosistema de la cuenca del Rio dos Sinos, siendo el señor Roessler su mayor exponente (FLORES GUZMÁN, 2016).

El estado de Río Grande do Sul fue pionero en la gestión de los recursos hídricos, pues dos años antes del 8 de enero de 1997, en que fue dictada la Ley 9.433/97, que define la Política Nacional de los Recursos Hídricos, elabora la política del estado para la gestión de los recursos hídricos, la Ley nº 10.350/94 de la Política Estadual de los Recursos Hídricos (BRASIL, 1995). Está ley es un paso importante en la gestión integrada pues deja constituido el Consejo Estadual de Recursos Hídricos, el departamento de Recursos Hídricos subordinado a la Secretaría de Planificación Territorial y Obras, la creación de Comité de Cuencas Hídricas, como resultado de la experiencia previa del COMITESINOS. Por último y no menos importante la creación de Planes de Cuenca Hidrográfica, así como otras disposiciones como el otorgamiento y la cobranza por el uso del agua.

Según Laura (2004) en los años 70 en Brasil gana fuerza el concepto de gestión de cuencas hidrográficas como unidad integradora de la gestión ambiental, siendo este concepto importado desde corrientes europeas especialmente de Francia. En los años 80 esta idea conceptual gana fuerza al punto que a finales de esa década se crea con el apoyo y la anuencia de grupos ecologistas, medios de comunicación y políticos el "Comitê de Preservação, Gerenciamento e Pesquisa da Bacia do Rio dos Sinos", en fecha de 17 diciembre de 1987. Pero en fecha tan temprana como marzo del siguiente año es creado el "Comitê de Gerenciamento da Bacia Hidrográfica do Rio do Sinos" (COMITESINOS) por el decreto estadual Nº 32.774, DE 17 DE MARÇO DE 1988, lo cual era totalmente inédito en el ámbito de Brasil y dejaba sin efecto al comité creado el año anterior (DE LIMA TRINIDADE, 2016; GUTIÉRREZ, 2006; BLOCK, A.; et al, 2009).

En la cuenca del Río dos Sinos, su comité de gestión estaba constituido por el Decreto No. 32.774 / 1988, que tiene precedente en el Decreto No. 30.132 / 1981, que establece el sistema estatal de recursos hídricos y sus objetivos. Posteriormente, el estado de Rio Grande do Sul instituyó la Ley No. 10.350 / 1994, que definió los objetivos y atribuciones de los diferentes organismos en la gestión de las cuencas hidrográficas dentro de la jurisdicción del estado, en previsión de la Ley Federal No. 9433/1997. Esta ley en el capítulo II-Finalidades y Competencias, en su Artículo 5°, atribuye seis finalidades, tales como: promover estudios, proyectos e investigaciones, la integración políticas nacionales y estaduales; proponer normas para el uso, la conservación y la recuperación de la cuenca; integrar órganos, entidades usuarias de los recursos de la cuenca que realicen actividades administrativas.

En el artículo 6° se declaran como competencias: elaborar programas de acción, acompañar estudios, proyectos, obras, acciones; proponer medidas de prevención o mitigación o compensación; gestionar recursos financieros. Lo que evidencia que desde su nacimiento el COMITESINOS tiene un carácter propositivo, consultivo y deliberativo y no de gestión ambiental, lo cual es una discapacidad funcional a la hora de ejecutar planes, proyectos y acciones.

Al analizar los avances del COMITESINOS es importante reconocer que es uno de los primeros órganos para la gestión de cuencas hidrográficas en el país como expresó una miembro de este comité en entrevista, la que expresó que la gestión de cuencas en el Rio dos Sinos es precursora en Brasil pues fue la primera unidad territorial en establecer un comité a nivel nacional en 1988, por iniciativa de sus propios habitantes. Apuntó además que estamos hablando por lo tanto de una entidad relativamente consolidada e institucionalizada que ya tiene una fuerte influencia política en la región. Sin embargo, los resultados de su gestión han sido bastante limitados, si tomamos en consideración que la cuenca local se mantiene como una de las más contaminadas del país.

El COMITESINOS es un fórum legal en el cual la comunidad de la región delibera sobre los conflictos y demandas relacionados con la cantidad y calidad del agua. En plenaria los representantes escogidos por cada categoría y entidades usuarios del agua definen el plan de recursos hídricos. Se realiza un ejercicio complejo de participación para llegar al plan de la cuenca, el debate se realiza en cuatro etapas: encuadramiento, definición de las normas de uso en época de sequía y definición de acciones. Por lo que la participación de diversos actores es otro elemento positivo que debe ser destacado.

En entrevista efectuada con el presidente del COMITESINOS, se conoció que en sus inicios este funcionó por grupos de intereses, la presencia de un profesor de meteorología, incentivó la creación de puntos de monitoreo con redes meteorológicas, luego no se continuó sistematizando este trabajo y en los últimos años se ha dirigido básicamente a la gestión del agua, con énfasis en la calidad por la presión que ejerce la industrialización y la contaminación.

En la región de la cuenca del río dos Sinos se han efectuado acciones de educación ambiental lo que muestra el interés de los pobladores por proteger el ecosistema. Se han realizado actividades de enseñanza aprendizaje fuera del espacio escolar, involucrando estudiantes de diversas escuelas. Entre las actividades se han plantado árboles y se ha seguido su crecimiento, se crían peces para luego soltarlos en el río, además se recoge basura en las márgenes y nacientes. También se estudian las especies de la flora y la fauna. Se ha producido material didáctico por movimientos ambientalista, el COMITESINOS y órganos públicos como la Compañía municipal de Saneamiento de Novo Hamburgo y el Servicio Municipal de Agua e Esgoto de São Leopoldo (RÜCKERT, 2017).

Según refieren miembros del COMITESINOS, este ha promovido varias acciones de gestión mediante la implementación de proyectos para preservar áreas húmedas con la plantación de árboles en más de 500 hectáreas de la cuenca. Además, se han efectuado actividades de educación ambiental con escuelas y comunidades con la participación de universidades como UNISINOS, FEEVALE y otros actores importantes en la gestión de la cuenca, pero estas son aún insuficientes. En la gestión integrada de recursos hídricos la participación de los actores es relevante, se coincide con Bozzano (2017) al expresar que los procesos sociales en cualquier territorio son protagonizados por actores públicos, empresarios y ciudadanos, personas que encarnan y significan los espacios con acciones transformadoras.

Aunque la gestión del COMITESINOS ha mostrado avances durante los treinta años de existencia, han sido diversos los desafíos ambientales y organizacionales que ha tenido que enfrentar. Desde una acuciante y creciente contaminación de las aguas superficiales y subterráneas de la cuenca, causa de genotoxicidad en diversos organismos (CRISTINA SCALON STREB, 2009; MARQUES DA COSTA, 2011; GOLDONI, 2013), pérdida de biodiversidad por diversas causas, tales como: la muerte de especies y la ruptura de cadenas tróficas, la fragmentación y a pérdida de variabilidad genética, la explotación y extractivismo de recursos naturales (MEINCKE, 2013; OLIVEIRA; HENKES, 2013; THIESEN BAUM, 2013; SANTOS DE SOUZA et al., 2016; SCHNEIDER HENRIQUE, 2016).

Para lograr una gestión sustentable de la cuenca hidrográfica se precisa contar con indicadores que permitan evaluar sistemáticamente el manejo de la misma; estos pueden ser cualitativos y cuantitativos, ajustados a las particularidades de la localidad en la que se ubica la cuenca. Además, ha de considerarse elementos ambientales, económicos, culturales y sociales para mejorar la toma de decisiones. El COMITESINOS no posee un sistema de indicadores que permita evaluar su gestión.

Los indicadores de sustentabilidad tienen el propósito de transformar datos en informaciones, que pueden contribuir al diagnóstico que aporte la información necesaria para la gestión. Si la información se maneja adecuadamente por los actores que intervienen en la cuenca y se analiza colectivamente, es posible tomar decisiones por consenso, las que han de ser compartidas con la población. El sistema de indicadores también tiene la función de informar a la sociedad de forma objetiva.

Toda planificación destinada a definir políticas y decidir alternativas, requiere del conocimiento sobre los componentes que forman el espacio. Por lo que es esencial obtener datos que representen la realidad, los que han de estar bien formulados para poder ser interpretados. Esos datos constituyen base del conocimiento y cuando son interpretados se convierten en información relevante para la gestión (SANTOS, 2004 aput MAYNARD, CRUZ, GOMES, 2017).

El plan de cuenca en el Río dos Sinos se centra en estudios hidrológicos y variables como caudal mínimo para determinación de la cantidad de agua otorgada para sus diferentes usos. Disponibilidad de agua superficial y subterránea en determinados periodos de tiempo o estaciones del año. Demandas y consumos del agua para la producción agropecuaria, la industria y el consumo humano. El análisis de la carga contaminante de los efluentes pecuarios, industriales y domésticos vistos desde la perspectiva de la posterior necesidad de tratamiento del agua de consumo humano y no con una visión holística del problema socioambiental que causa. Así como la clasificación de los cuerpos de agua según parámetros de calidad. Este plan carece de un análisis integral de la situación ecológica, social y solo presenta la arista hidrológica quedando muy pobre el alcance de las acciones propuestas (PLANO DA BACIA DOS SINOS, 2017).

La variabilidad climática impacta negativamente en la actividad socioeconómica de la cuenca, la cual se manifiesta, por ejemplo, en inundaciones o periodos de sequía superiores a la media histórica. La gestión integrada de recursos hídricos (GIRH) es una herramienta que puede ser utilizada para enfrentar sus impactos, lo que se justifica porque: La GIRH reconoce el ciclo hidrológico y a sus usuarios de forma holística, se reconoce el papel de los actores y la necesidad de un plan para la ejecución de las acciones; es una herramienta para el desarrollo de órganos encargados de coordinar la gestión y aglutinar a los usuarios del recurso en una gestión equitativa y eficiente.

En la entrevista con el presidente del COMITESINOS se conoció que no tienen planificadas acciones para contrarrestar los riesgos climáticos, pero apuntó que los períodos de sequía afectan la cuenca y este aspecto se aborda en el comité a través de los representantes agrícolas y se tiene el acuerdo que cuando los niveles del agua del río están bajos se suspende la captación para la actividad productiva hasta que el nivel del agua alcanza los estándares establecidos, agregó además que las lecturas hidrológicas permite tomar medidas rápidas pues se realizan en la mañana y si los niveles son bajos en la tarde se suspende la captación.

La gestión del COMITESINOS ha evidenciado insuficiencias en modelo de gestión de cuenca implementado. Las insuficiencias fundamentales encontradas son: poca participación de actores de la sociedad civil, poca representatividad de la sociedad en la estructura del comité, dificultades en la gestión financiera y de proyectos, excesiva burocracia, limitada o inexistente capacidad administrativa o de gestión al no poseer un órgano o secretaría que lo ejerza, estando limitado a ser un ente del Estado de carácter consultivo, propositivo e deliberativo y no de gestión.

Las insuficiencias mencionadas han sido abordadas también por autores como, FLORES; MISOCZKY, (2008), KEMERICH; RITTER; DULAC, (2014); DE LIMA TRINIDADE, (2016); en estudios de otros comités de cuenca.

## CONSIDERACIONES FINALES

La gestión integral de los recursos hídricos constituye una significativa herramienta para el manejo socioambiental de estos importantes socioecosistemas. Las acciones de gestión conducidas por el COMITESINOS han logrado algunos avances como la plantación de árboles para la preservación de áreas húmedas. Un plan de cuenca con estudios hidrológicos y análisis de variables como caudal mínimo para determinación de la cantidad de agua otorgada para sus diferentes usos. También se analiza la disponibilidad de agua superficial y subterránea en determinados periodos de tiempo o estaciones del año, así como las demandas y consumos del agua para la producción agropecuaria, la industria y el consumo humano, entre otras.

Sin embargo, todavía no se logra planificar y materializar de forma consciente y articulada acciones dirigidas a eliminar la contaminación y al uso sustentable de los recursos naturales. Pues la gestión que se efectúa en la cuenca del Río dos Sinos, tiene limitaciones porque la ley apenas le otorga poder deliberativo, propositivo, consultivo y en modo alguno cuenta con capacidad administrativa o propiamente de gestión. No contar con un órgano ejecutivo limita el alcance de las políticas y el efecto de las acciones.

Entre los principales desafíos del COMITESINOS está la poca participación de actores de la sociedad civil. La participación es esencial en la gestión integrada de recursos hídricos, porque promueve el cambio social, estableciendo prioridades, generando un ambiente de tolerancia a la diversidad de enfoques y conceptos; esta se hace necesaria no solo en la toma de decisiones, además en la realización de acciones que contribuyan a la protección socioambiental. A través de la interacción de los actores de la sociedad civil se crean oportunidades para lograr soluciones colectivas.

EL COMITESINOS precisa lograr planes y acciones organizadas como un sistema, incorporar herramientas de mediación de conflictos integrada a la gestión, incrementar la participación de los actores que hacen parte de la vida socioeconómica de la cuenca. Además, existe un déficit de sistemas de indicadores para evaluar el desempeño de este órgano de administración. Asimismo, poca cooperación y colaboración entre las instituciones públicas y privadas para alcanzar las metas y objetivos.

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## CAPÍTULO 3

**PESTEL analysis based on neutrosophic cognitive maps and neutrosophic numbers for the Sinos river basin management**

**ARTIGO 3 SUBMETIDO**

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**CAPITULO 3**

# PESTEL analysis based on neutrosophic cognitive maps and neutrosophic numbers for the Sinos river basin management

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## Abstract

The Sinos River watershed is one of the most polluted water basins in Brazil with great efforts for its recovery through integral management. PESTEL is an analysis for the study of the external variables with influence in the efficiency of the organization or project. This paper presents a model to address problems encountered in the measurement and evaluation process of PESTEL analysis taking into account interdependencies among sub-factors and modeling uncertainty and indeterminacy in Sinos river basin. NCM was used for modeling the integrated structure of PESTEL sub-factors. A quantitative analysis was developed based on static analysis and neutrosophic numbers. To demonstrate the applicability of the proposal in the Sinos river external factor analysis a case study is developed-interdependencies among sub-factors and modeling uncertainty and indeterminacy. Sub-factor were ranked and reduced with Ecological, Technological and Social are the top three factors.

**Keywords:** Sinos River Basin; PESTEL; Neutrosophy; Neutrosophic Cognitive Maps; Static Analysis

## Introduction

PEST is an analysis for the study of the external variables with influence in the efficiency of the organization or project. These variables involved in the business environment are grouped in Political, Economical, Social, and Technological aspects [1].

The conceptual structure and nature of PEST require an integrated approach for considering importance and interrelation. The standard technical framework of the PEST approach mainly provides a general idea about macro conditions and the situation of an organization, so it is inadequate. Therefore, PEST analysis lacks a quantitative approach to the measurement of the interrelation between its factors [2]. When the environment and legal factors are included, it is named PESTEL (Political, Economic, Socio-cultural, Technological, Environment, and Legal) analysis [2]. Political variables refer to the regulatory aspects that directly affect the enterprise. Here enter the taxes rules or business incentives in certain sectors, regulations on employment, the promotion of foreign trade, government stability, the system of government, international treaties or the existence of internal conflicts or with other current or future countries — also the way in which the different local, regional and national administrations are organized [3]. Economic variables relate to macroeconomic data, Gross domestic product (GDP) evolution, interest rates, inflation, unemployment rate, income level, exchange rates, access to resources, level of development, economic cycles. Current and future economic scenarios and economic policies should also be investigated.

Social variables take into account are demographic evolution, social mobility and changes in lifestyle — also the educational level and other cultural patterns, religion, beliefs, gender roles, tastes, fashions and consumption habits of society. In short, the social trends that may affect the enterprise business [3]. Technological variables are somewhat more complicated to analyze due to the high speed of the changes in this area [3]. It is necessary to know the public investment in research and the promotion of technological development, the technology diffusion, the degree of obsolescence, the level of coverage, the digital divice, the funds destined to R & D + I, as well as the trends in the use of new technologies. Ecological variables are the main factors to be analyzed aware of the conservation of the environment, environmental legislation, climate change, and temperature variations, natural risks, recycling levels, energy regulation and possible regulatory changes in this area [4]. Legal variables refer to legislation that is directly associated with the organization functions, information on licenses, labor legislation, intellectual property, health laws, and regulated sectors [5].

PESTEL analysis has deficiencies for a quantitative approach to the measurement of interrelation among factors are generally ignored [6]. Fuzzy cognitive maps (FCM) is a tool for modeling and analyzing interrelations [7]. Connections in FCMs are just numeric ones: the relationship of two events should be linear [8].

The Neutrosophy can operate with indeterminate and inconsistent information, while fuzzy sets and intuitionistic fuzzy sets do not describe them appropriately [4]. Neutrosophic cognitive maps (NCM) is an extension of FCM where was included the concept indeterminacy [9, 10]. The concept of fuzzy cognitive maps fails to deal with the indeterminate relation [11].

In this paper, a PESTEL analysis based on neutrosophic cognitive maps is presented proposal methodological support and make possible of dealing with interdependence, feedback, and indeterminacy. Additionally, the new approach makes conceivable to category and to reduce factors.

This paper continues as follows: Section 2 reviews some essential concepts about the PESTEL analysis framework, NCM, and fuzzy numbers. In Section 3, a framework for the PESTEL show a static analysis based on NCM. Section 4, displays a case study of the proposed model applied to social-environmental management of a river basin. The paper finishes with conclusions and additional work recommendations.

**Case Study**

The Sinos River Basin is one of the most contaminated water basins in Brazil [31] which leads to great efforts for its recovery through integral management. 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 [32]. Through a participatory exercise with stakeholder members of the COMITESINOS, external variables were identified and a diffuse cognitive map was constructed representing the relationships among the variables. This process of identifying PESTEL variables was carried out with the members of the committee, for which work sessions were held in the coordination meetings. To elaborate the NCM, the Mental Modeler tool of the website http://www.mentalmodeler.org/ was used.

Initially, factors and sub-factors were identified for Sinos river basin management as follows:

I. Relevant Political-Legal Aspects

In the political dimension, the following variables were identified:

1. Influence of the federal government in the watersheds management (N1)
2. Importance of the state government in the management of the basin (N2)
3. Control of the municipal government in the watershed management (N3)
4. Impact of bureaucracy on management (N4)
5. Corruption impact (N5)

II. Relevant economic and socio-economic aspects

In the socioeconomic dimension, the following variables were identified:

1. Poverty (N6)
2. Per capita income(N7)
3. Quality of solid waste collecting services (N8)
4. Quality liquid waste service (N9)
5. Water supply service( N10)
6. The quality of public health (N11)
7. Quality of sewage and sewage services (N12)

III. Relevant social aspects

In the social dimension, the variables identified were:

1. Public education (N13)
2. Population access to food (N14)
3. Access to the housing (N15)

IV. Relevant sociocultural aspects

In the sociocultural dimension, the variables identified were:

1. Perception of the environmental relevance in the local culture (N16)
2. Knowledge of environmental risk (N17)

3. Understanding of environmental awareness( N18)

V. Relevant technological aspects

The variables identified in the technical dimension were:

1. Innovation(N19)
2. Cleaner production(N20)
3. Eco-efficiency (N21)

For the ecological dimension was possible to identify the following variables:

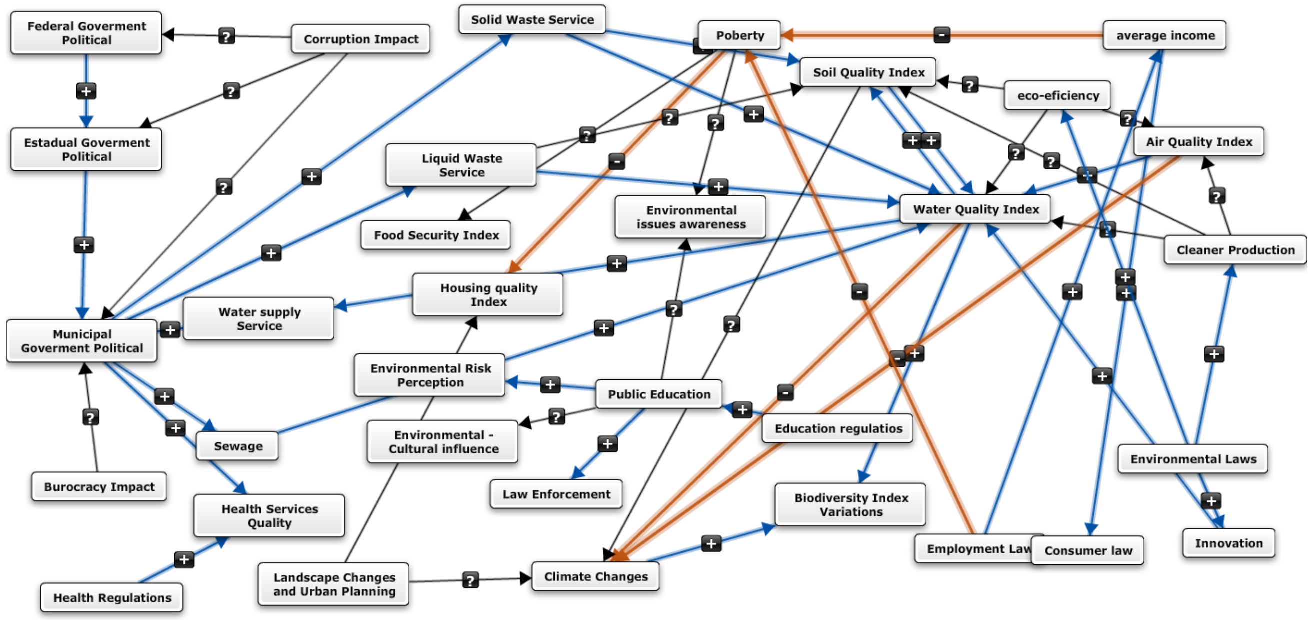
1. Water quality index (WQI)(N22)
2. Air Quality index (AQI) (N23)
3. Landscape change and urban planning(N24)
4. Variations in the biodiversity index of ecosystems value (N25)
5. Climate Change (N31)
6. Soil Quality index (N32)

Legal dimension include the following factors

1. Environmental Laws (N26)
2. Education regulation (27)
3. Health regulations (28
4. Environmental law (29)
5. Employment Laws (N30)
6. Consumer Law (33)

Interdependencies are identified and modeled using an NCM (Figure 1), with whose weighs represented in Table 1.

Fig. 1. Fuzzy Neutrosophic Cognitive Maps of PESTEL factors.




## Materials and Methods

### 1. Preliminaries

This article offers a first brief review by PESTEL analysis and the factors´ interdependency. The following is a review of the basic concepts of NCM.

### 2.1 PESTEL Analysis

The PESTEL method is a prerequisite analysis with a network function to identify the characteristics of the environment in which an organization or project operates, provides data and information so that the organization can make predictions about new situations and circumstances and act accordingly. [12, 13]. The variables analyzed in PESTEL are identified and evaluated independently. [2] not taking into account interdependency. In [14] this approach based on fuzzy decision maps is presented taking into account the ambiguity, the uncertainty in their interrelationships.

This study presents a model to address the problems encountered in the PEST measurement and evaluation process, taking into account the interdependencies between the subfactors. NCM modeled the integrated structure of the PESTEL subfactor, and the quantitative analysis is developed from a static analysis that allows to classify and reduce the factors in line with the proposals presented in [15].

### 2.2 Neutrosophic Cognitive Maps.

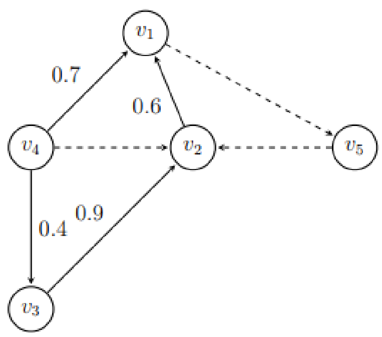
The Neutrosophic Logic (NL) like a generalization of the fuzzy logic was introduced in 1995 [16]. According to this theory a logical proposition P is characterized by three components:

$$NL(P) = (T,I,F) \qquad (1)$$

Where the neutrosophic component T is the degree of truth, F the degree of falsehood, and I is the degree of indeterminacy [17]. Neutrosophic set (NS) was introduced by F. Smarandache who introduced the degree of indeterminacy (i) as independent component [18].

A neutrosophic matrix content where the elements are $a = (a_{ij})$ have been replaced by elements in $\langle R \cup I \rangle$. A neutrosophical graphic has at least one edge is a neutrosophical edge [19]. If the indetermination is found in the cognitive map, it is called the neutrosophical cognitive map (NCM) [20]. NCM is based on neutrosophic logic to represent uncertainty and indeterminacy in cognitive maps [21]. An NCM is a directed graph in which at least one edge is an indeterminate border and is indicated by dashed lines [22] (Figure 2).

Fig. 2 Fuzzy Neutrosophic Cognitive Maps example.




In [9] a static analysis of an NCM is presented.

### 2.3 Neutrosophic numbers

The result of the static analysis is in the form of neutrosophic numbers (a+bI, where I = indeterminacy)  A de-neutrosophication process as proposed by Salmeron and Smarandache could be applied giving final ranking value [23].

A neutrosophic number is a number as follows [24] :

$$N = d + I$$
(2)

Where d is the determinacy part, and i is the indeterminate part. For example  s: a=5 +I si $i \in [5, 5.4]$ is equivalent to  $a \in [5, 5.4]$.

Let $N_1 = a_1 + b_1 I$ and  $N_2 = a_2 + b_2 I$ be two neutrosophic numbers then the following operational relation of neutrosophic numbers  are defined as follows [18]:

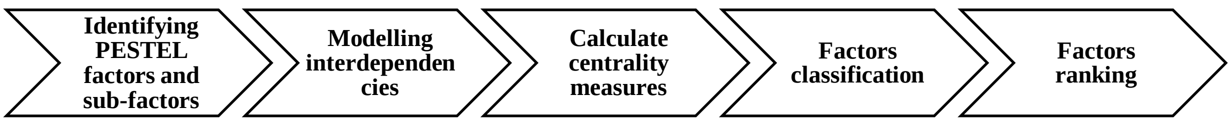
$$N_1 + N_2 = a_1 + a_1 + (b_1 + b_2)I \; ;$$

$$N_1 - N_2 = a_1 - a_1 + (b_1 - b_2)I$$

## 2. Proposed Framework

The aim was to develop and further detail a framework based on PESTEL and NCM [25]. The model was made in five steps (graphically, figure 3).

Fig. 3**.** The proposed framework for PESTEL analysis [25]




.

**3.1** Factors and sub-factors identification in the **PESTEL method**

In this step, the significant PESTEL factors and sub-factors was recognized. Identify factors and subfactors to form a hierarchical structure of the PESTEL model. Sub-factors are categorized according to the literature [2].

### 3.2 Modeling interdependencies

In this step causal interdependencies between PESTEL sub-factors are modeled, consists in the construction of NCM subfactors following the point views of an expert or expert teams.

When a selection of experts (k) participates, the adjacency matrix of the collective MCD is calculated as follows:

$$\mathrm{E} = \mu(\mathrm{E}_1, \mathrm{E}_2, \ldots, \mathrm{E}_\mathrm{k}) \qquad (3)$$

the operator is usually the arithmetic mean [26].

### 3.3 Calculate centrality measures

Centrality measures are calculated[27] with absolute values of the NCM adjacency matrix [28]:

1. Outdegree od(v_i) is the summation of the row of absolute values of a variable in the neutrosophic adjacency matrix, and It shows the cumulative strengths of connections ($c_{ij}$) exiting the variable.

$$od(v_i) = \sum_{i=1}^{N} c_{ij} \qquad (4)$$

2. Indegree $id(v_i)$ is the summation of the column of absolute values of a variable, and it shows the cumulative strength of variables come in the variable.

$$id(v_i) = \sum_{i=1}^{N} c_{ji} \qquad (5)$$

3. The centrality degree (total degree $td(v_i)$), of a variable is the sum of its indegree and outdegree

$$td(v_i) = od(v_i) + id(v_i) (6)$$

### 3.4 Factors classification and ranking

The factors were categorized according to the next rules:

a) The variables are a Transmitter (T) when having a positive or indeterminacy outdegree, $od(v_i)$ and zero indegree, $id(v_i)$.
b) The variables give a Receiver (R) when having a positive indegree or indeterminacy, $id(v_i)$., and zero outdegree, $od(v_i)$.
c) Variables receive the Ordinary (O) name when they have a non-zero degree, and these Ordinary variables can be considered more or less as receiving variables or transmitting variables, depending on the relation of their indegrees and outdegrees.

The de-neutrosophication process provides a range of numbers for centrality using as a ground the maximum & minimum values of I . A neutrosophic value is switched in an interval with these two values. ∈ [0,1].

The contribution of a variable in an NCM can be known by calculating its degree of centrality, which shows how the variable is connected to other variables and what is the accumulated force of these connections. The median of the extreme values as proposed by Merigo [29] is used to give a centrality value :

$$\lambda([a_1, a_2]) = \frac{a_1 + a_2}{2} \qquad (7)$$

Then

$$A > B \Leftrightarrow \frac{a_1 + a_2}{2} > \frac{b_1 + b_2}{2} \qquad (8)$$

Finally, a ranking of variables could be given.

### 3.5 Factor prioritization

The numerical value obtained in the previous step is used for sub-factor prioritization and/or reduction [30]. Threshold values may be set to 1.5 % of the total sum of total degree measures for subfactor reduction. Additionally, sub-factor could be grouped by parent factor and to extend the analysis to political, economic, social and technological general factor.

## Results and Discussion

## 4. Case of study result.

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0.28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.39 | 0.33 | 0.25 | 0.28 | 0.25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | i | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | i | i | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | i | -0.67 | 0 | 0 | i | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | -0.58 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.36 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.33 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.39 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | i | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.28 | i | i | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.42 | 0 | 0 | 0 | i | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | i | i | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | i | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | i | i | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | i | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.36 | 0 | 0 | 0 | 0 | 0 | -0.53 | 0.42 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.5 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | i | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | i | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.47 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.42 | 0.36 | 0.47 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | -0.58 | 0.42 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | i | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 1**. Neutrosophic Adjacency Matrix

Nodes are initially classified (Table 2)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| N1 | T | N10 | R | N19 | O | N28 | T |
| N2 | O | N11 | R | N20 | O | N29 | T |
| N3 | O | N12 | O | N21 | O | N30 | T |
| N4 | T | N13 | O | N22 | O | N31 | O |
| N5 | T | N14 | R | N23 | O | N32 | O |
| N6 | O | N15 | R | N24 | O | N33 | R |
| N7 | O | N16 | R | N25 | R | | |
| N8 | O | N17 | R | N26 | R | | |
| N9 | O | N18 | R | N27 | T | | |

**Table 2.** Nodes classification

Total degree (Eq. 5) was calculated. Results are shown in Table 3.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| N1 | 0,28 | N9 | 0.72+i | N17 | i | N25 | 0.64 | N33 | 0.36 |
| N2 | 0.56+i | N10 | 0.5 | N18 | 2i | N26 | 0.42 | | |
| N3 | 1.78+2i | N11 | 0.64 | N19 | 0.75 | N27 | 0.47 | | |
| N4 | I | N12 | 0.5 | N20 | 0.36+3i | N28 | 0.36 | | |
| N5 | 2i | N13 | 1.17+3i | N21 | 0.47 + 3i | N29 | 1.25 | | |
| N6 | 1.83+2i | N14 | i | N22 | 2.37+2i | N30 | 1+i | | |
| N7 | 1.36 | N15 | 0.67+i | N23 | 0.78+2i | N31 | 1.31+2i | | |
| N8 | 1.03 | N16 | 0.28 | N24 | 2i | N32 | 1.06+4i | | |

**Table 310.** Total degree

"The next step is the de-neutrosophication process as proposes by Salmeron and Smarandache. I ∈[0,1] is replaced by both maximum and minimum values" [33]. In Table 4 are presented as interval values.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| N1 | 0,28 | N9 | [0.72, 1.72] | N17 | [0,1] | N25 | 0.64 | N33 | 0.36 |
| N2 | [0.56, 1.56] | N10 | 0.5 | N18 | [0,2] | N26 | 0.42 | | |
| N3 | [1.78, 2.78] | N11 | 0.64 | N19 | 0.75 | N27 | 0.47 | | |
| N4 | [0,1] | N12 | 0.5 | N20 | [0.36, 3,36] | N28 | 0.36 | | |
| N5 | [0, 2] | N13 | [1.17, 4.17] | N21 | [0.47, 3.47] | N29 | 1.25 | | |
| N6 | [1.83,3.83] | N14 | [0,1] | N22 | [2.37, 4.37] | N30 | [1, 2] | | |
| N7 | 1.36 | N15 | [0.67, 1.67] | N23 | [0.78, 2.78] | N31 | [1.31, 3.31] | | |
| N8 | 1.03 | N16 | 0.28 | N24 | [0, 2] | N32 | [1.06, 5.06] | | |

**Table 4.** De-neutrosophication, total degree values

Finally, we work with the median of the extreme values (Table 5) [29].

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| N1 | 0.28 | N9 | 1.22 | N17 | 0.5 | N25 | 0.64 | N33 | 0.36 |
| N2 | 1.06 | N10 | 0.5 | N18 | 1 | N26 | 0.42 | | |
| N3 | 2.28 | N11 | 0.64 | N19 | 0.75 | N27 | 0.47 | | |
| N4 | 0.5 | N12 | 0.5 | N20 | 1.86 | N28 | 0.36 | | |
| N5 | 1 | N13 | 2.67 | N21 | 1.97 | N29 | 1.25 | | |
| N6 | 2.83 | N14 | 0.5 | N22 | 3.37 | N30 | 1.5 | | |
| N7 | 1.36 | N15 | 1.17 | N23 | 1.75 | N31 | 2.31 | | |
| N8 | 1.03 | N16 | 0.28 | N24 | 1 | N32 | 3.06 | | |

**Table 511.** Total degree using the median of the extreme values

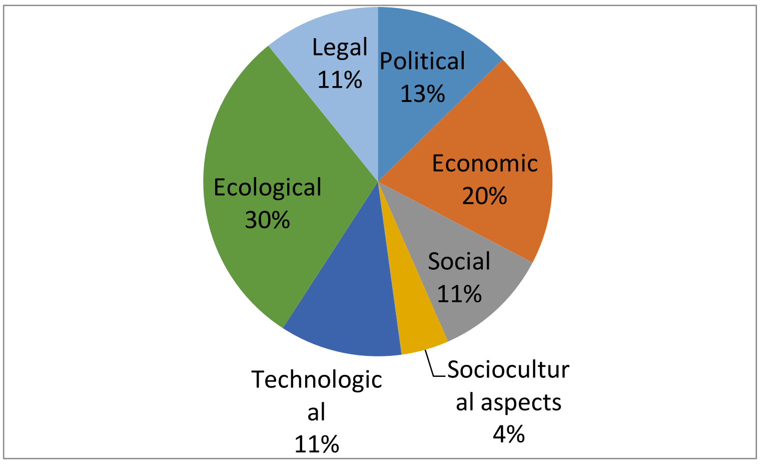
Top 6 nodes according to centrality are represented in table 6.

| | |
|---|---|
| N22 | 3,37 |
| N32 | 3,06 |
| N6 | 2,83 |
| N13 | 2,67 |
| N31 | 2,31 |
| N3 | 2,28 |

**Table 6.** Top 6 nodes

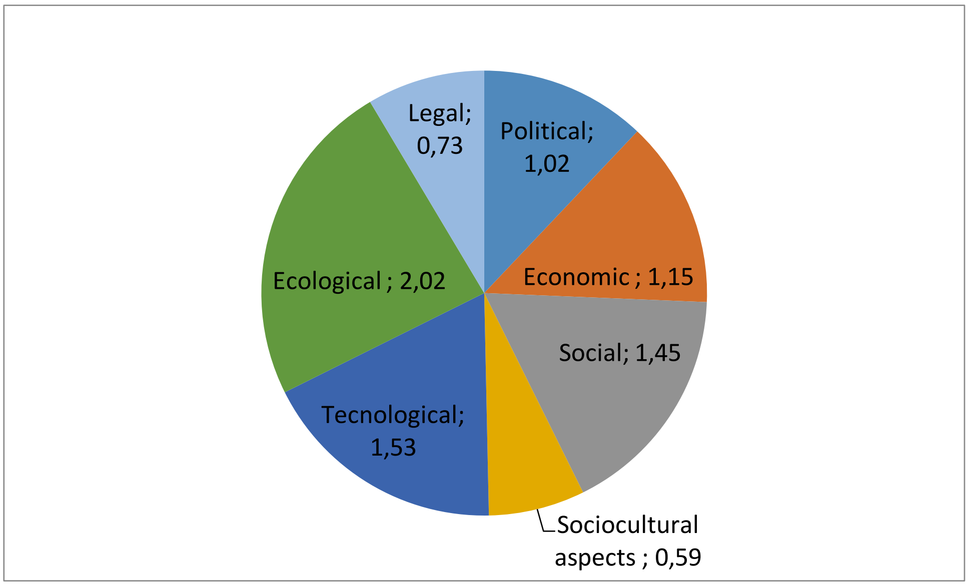
Water quality index, Soil Quality index and Poverty are the top three factors. Centrality measures of subfactor were grouped according to its parent factors (Figure 4).

**Fig. 4** Aggregated total centrality values by factors




When the average is used as aggregation´s operator, the result is represented in Figure 5. Ecological, Technological and Social are the top three factors.

**Fig. 5** Average of total centrality values by factors




Factors with a little incidence of less than 1.5 % (0.606) are reduced for further analysis. In this case, we found nodes like N1,N4, N10, N14, N16, N17, N26, N27, N28 and N33.

After the application, in this case, study the model was found practical to use. The NCM gives high flexibility and takes into account interdependencies PESTEL analysis.

## Conclusions

This study presents a model to address problems encountered in the measurement and evaluation process of PESTEL analysis taking into account interdependencies among sub-factors and modeling uncertainty and indeterminacy in Sinos river basin. NCM modeled the integrated structure of PESTEL sub-factors, and quantitative analysis was developed based on static analysis and neutrosophic numbers.

To demonstrate the applicability of the proposal in the Sinos river external factor analysis a case study is developed. Sub-factor were ranked and reduced with Ecological, Technological, Social are the top three factors.

NCM modeled the integrated structure of PESTEL of factors and sub-factors. Our approach has many applications in complex decision problem that include interdependencies among criteria, and such as complex strategic decision support in river basin management.

Further works will concentrate on extending the model for dealing scenario analysis in conjunction with a multicriteria environment. Another area of future work is the development of a software tool.

## Conflicts of Interest

No conflict of interest are declared by the authors.

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## Data Availability Statement

The data used to support the findings of this study are included within the article.

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## CAPÍTULO 4:

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

## ARTIGO 4 PUBLICADO

Este artigo foi publicado na revista Neutrosophic Set and System, (Anexo 4).

## CAPÍTULO 4:

## 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 is one of ten more 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 in the determination of water quality, according to the Water Quality Index and using Neutrosophic Analytical Hierarchical Process with Technique for Order of Preference by Similarity to Ideal Solution for ranking scenarios. The methodology exposed in this research shows an improved method to be used by the Sinos River basin 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

## 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 Sinos River basin (SRB) [2] and how they are influenced by actions such as increase 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 consists using the Fuzzy 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 facts allow 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 study is discussed and presented in section 4. This article ends with inferences and some recommendation for future work.

## 2. Preliminary

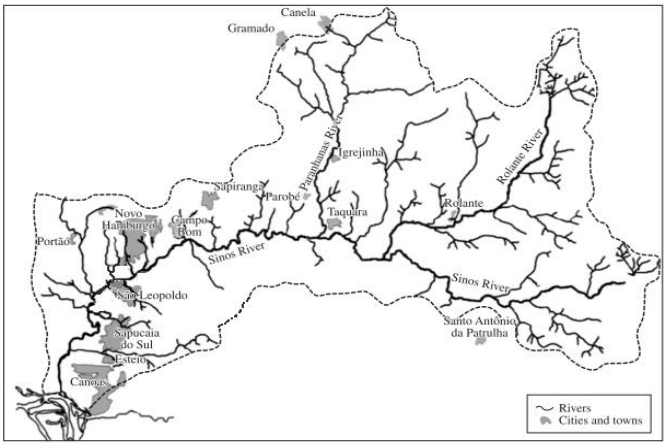
In this section the SRB and its environmental problems are presented then FCM fundamentals are discussed. Additionally necessary concepts about neutrosophic AHP and TOPSIS are presented.

### 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 SRB is frequently cited 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 has strong 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 is the 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. An example of this are *Pampa* and *Luis Rau* streams [12, 13]. 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 organics pollutants in the water, showing lower levels of OD, killing thousands of fish and other types of water 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 as Diethyl 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 first introduced 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:

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

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]:

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

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 interest in the use of FCM is crescent, 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.

### 2.3 Neutrosophic AHP

Smarandache [31] suggested the concept of a neutrosophic set, which uses the 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 | $\tilde{1}$=⟨(1, 1, 1); 0.50, 0.50, 0.50⟩ |
| 3 | Slightly influential | $\tilde{3}$==⟨(2, 3, 4); 0.30, 0.75, 0.70⟩ |
| 5 | Strongly influential | $\tilde{5}$=⟨(4, 5, 6); 0.80, 0.15, 0.20⟩ |
| 7 | Very strongly influential | $\tilde{7}$=⟨(6, 7, 8); 0.90, 0.10, 0.10⟩ |
| 9 | Influential | $\tilde{9}$=⟨(9, 9, 9); 1.00, 0.00, 0.00⟩ |

**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]:

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

and the accuracy degree of ã [4]:

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

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:

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

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

$$v_{ij} = r_{ij} \cdot w_j \tag{6}$$

where $w_j$ is the weight of the j$th$ 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 be the 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:

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

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

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

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:

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

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

### 3. Proposed 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 measure of a variable is the summation of its indegree and outdegree

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

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 their outdegrees 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].

4- 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].

## 4. Results

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 analyze essential 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 is crucial for all life in the water. |
| Coliforms T | The quantity of Thermotolerant Coliform bacteria is an indicator of domestic sewage pollution in the water body. |
| pH | pH is a measurement of water acidity or alkalinity, determined by hydrogen ions in the water |

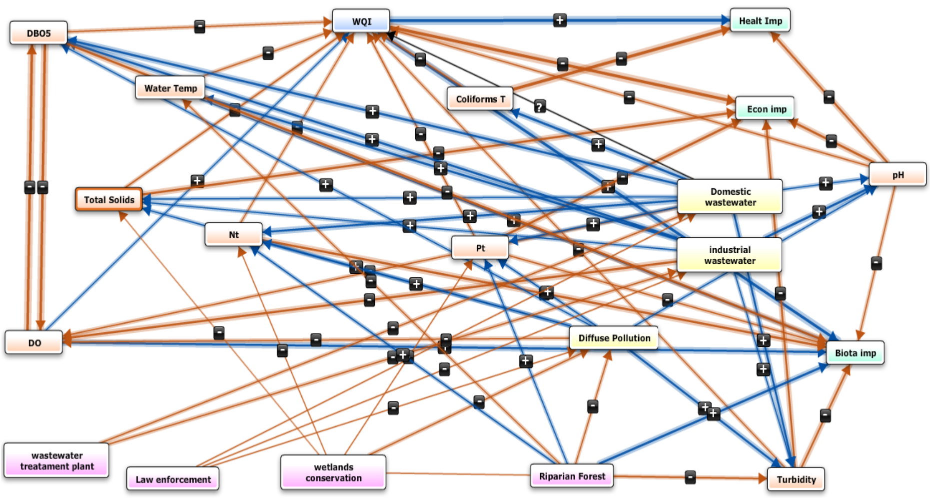
| | |
|---|---|
| Water Temp | This indicator is determined by solar radiation, or physical-chemical processes and the variability of the indicator could modify many water parameters such as surface tension or viscosity, which can affect the growth, reproduction or life of aquatic organisms? |
| Nitrogen 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 | It is a process of elimination of pollutants from industrial and domestic |

| | |
|---|---|
| Treatment Plant | 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.

| 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 conservation | 0 | 0.45 | 0.45 |
| 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.

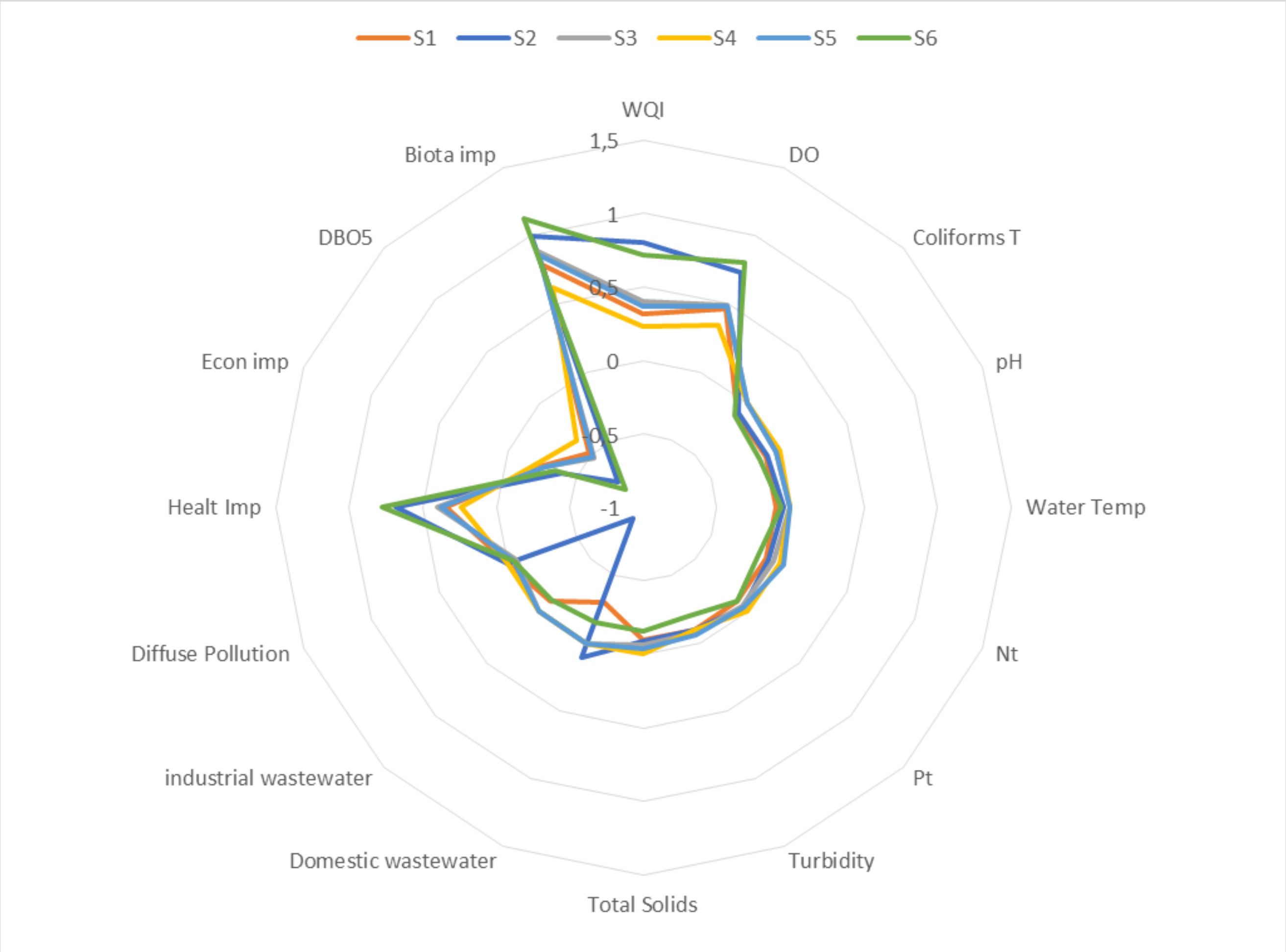
| Scenario | Description | Initial Stimulation |
|---|---|---|
| S1 | The actual capacity of wastewater treatment in the basin of Sinos River | WTP 5% |
| S2 | increase the quantity and capacity of the wastewater treatment system | WTP 35% |
| S3 | Increasing of natural or artificial Wetlands areas | 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 3.

Figure. 3 Scenarios' results




Scenarios ranked with NAHP-TOPSIS. Pairwise comparison matrix was obtained using triangular neutrosophic numbers. Nodes are weighted according to the AHP method as follows, see table 5.

| 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. They jointly comprise the 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 authors adopt that all the nodes are classified as benefit (higher scores are better). After TOPSIS procedure outcomes are displayed, and the scenarios are ranked (Table 6).

| 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 exercises and all of the stakeholders gain in knowledge about the 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.

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## CAPÍTULO 5:

## Methodology for the socio-environmental management of the social ecosystem Río dos Sinos.

## ARTIGO 5 SUBMETIDO

Este manuscrito foi submetido à avaliação pelo **Journal of Environmental Management** (Anexo 5).

## CAPÍTULO 5:

## Methodology for the socio-environmental management of the social ecosystem Río dos Sinos.

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### Abstract

The objective of this research was the social-environmental management of the social-ecosystem of the watershed and was taken as a case study the social-environmental system of the Sinos River basin. To reach the objective, was necessary to group into a theoretical support a set of theories, methods, approaches, and tools that resulted in the conceptualization of the model and the elaboration of the methodology, which constitute a theoretical-practical contribution and a methodological instrument to carry out social-environmental management into the hydrographic basin. When incorporated, the social-environmental management methodology of the social-ecosystem basin, put in practice by the basin committees, can contribute to the understanding and solution of socio-environmental problems and their complex interrelationships. This methodology is based on a holistic and integrative approach and joins up technologies and methodological tools of management, which consists of four interactive and sequential stages directed to reach the technical and organizational objectives of the socio-environmental management.

Keywords: Social-ecological; management; watershed; social-ecosystem; methodology; environmental management

## Introduction

The case study of this research was made on Sinos river watershed (SRW) (). The geographical location is in the east of Rio Grande do Sul state. The SRW have a 3696 km² area, which represents about 1,3% of all state area and 4,4% area of the Guaiba lake hydrographic region (PLANO SINOS, 2016). This river supplies water for 1,3 millions of people in 32 municipalities (BLUME et al., 2010)

Figure 1 Sinos River Watershed (Blume et al., 2010)


The Sinos River basin is made by many affluent streams and for their study it is separated into three regions, in correspondence with terrain relief. The above river section has 25 km of large, with a rapid water flux, several rapids, waterfalls and an altitude variable between 600 m and 60 m. The middle section is five times larger than the superior one and has no significant terrain relief variations. The bottom part is two times larger than the superior one and has a flatbed with a low stream flux (FIGUEIREDO et al., 2010).

The superior section of the Sinos river has a low population density, which is high in the middle part and very high in bottom one, having more population density in this section than the estate mean, increasing anthropic pressure over the watershed ecosystem.

"The Sinos river basin is often referred to as a highly degraded watershed. A series of impacts on the water soil and air quality has been recurrently reported over the years in this environment. This situation of environmental degradation has its origin in the process of large economic development, decoupled from environmental conservation concerns. Adequate zoning and urban planning did not precede the consequent intense urbanization observed for municipalities within the river basin." (SPILKI; TUNDISI, 2010).

The growth of towns and villages without following the guidelines of territorial planning, the occupation of flood areas, deforestation of riparian forest and insufficient treatment of domestic sewage in the water body of SRW, contribute to the degradation of surface and underground waters and threaten the biota of the basin ecosystem. However, the growth of cities on the river's edge has also brought about industrial facilities increase, which poured, and do until today their dumping into the water bodies of the region. Therefore, the primary sources of SRW pollution are two: the industrial wastewater and domestic sewage (Flores Guzmán, 2016). Also, the growth of urban centers and the economy of municipalities in the SRW region influences air pollution with increased vehicular traffic and industrial smoke, causing chronic lung diseases and genetic changes at the cellular level (Barbosa Dorneles, 2012; Daniel Alves, 2014; Meincke, 2013). Deforestation, due to the urbanization growth, has brought a wide variety of ecosystem impacts, ranging from changes in climate to the fragmentation and reduction of species richness and the diminution of biological diversity (Lucheta, 2017). Inadequate disposal of industrial dumping, particularly in the leather and footwear sector, has a detrimental impact on water quality and the diverse species of aquatic organisms, as evidenced by the surveys of Blume et al. (2010); Cristina Scalon Streb, (2009); Goldoni, (2013). The insufficient treatment capacity of domestic sewage in cities, the connection of pipes to rainwater systems and the progressive accumulation of organic matter causes harmful impacts on biota (Flores Guzmán, 2016; Nascimento; Naime, 2009). It is also responsible for waterborne diseases such as hepatitis, enteritis, and others confirmed by Bordin da Luz (2014) e Staggemeier (2009). Diffuse pollution from agricultural, industrial, and vehicular sources cause adverse impacts on the environmental quality of SRW. Substances such as chromium, iron, nickel, mercury, and cyanides are found in different concentrations, with values above the limits, depending on the seasonality (Oliveira and Henkes, 2013; Reis de Oliveira, 2015).

Despite the many social and environmental problems reported, the Sinos River Basin has been historically pioneer in implementing strategies for managing water resources. Identified multiple ecological issues and their impacts on society and the basin ecosystem, members of civil society organizations promoted the creation of the Rio dos Sinos Management Committee (COMITESINOS), this constituted being left on March 17, 1988, using the state decree 32.774 /1988. (BRASIL, 1988). The committee is composed of three representative bodies, which are grouped into three different groups, such as Water Users Group, Population Representing Group, and Public Power Group.

Despite being in operation for the past 30 years, the results of the committee in the management of socio-environmental problems in the basin are few perceived by the committee members themselves. The identify the issues in the social-environmental management of the Rio dos Sinos basin; research is carried out with the structure shown in Figure 2.

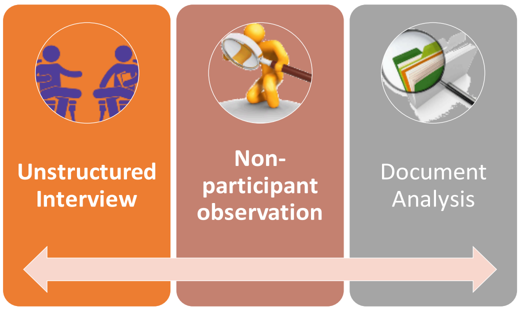



Figure 2 Structure of the research

*The qualitative research tools shown results threw in Table 12*

| Identified problems | Description of the problem |
|---|---|
| Organizational and management problems | - Little participation by members<br>- Have a little integration with the civil society and stakeholders.<br>- Little legal knowledge of members.<br>- Limited capacity for decision<br>- Technical decision prevail to arrangements negotiated between the stakeholders |
| Financial economic problems | - Excessive bureaucracy in financial management<br>- Inadequate budget execution |
| Planning and control problems | - Weakness the watershed management plan implementation<br>- Insufficient control of the planned activities. |
| Structural & functional problems | - The agreements concluded are not binding for municipal governments and other actors, so lack of practical value<br>- Insufficient use of management tools<br>- Structures Not very flexible and adaptable to changes |

Table 12 Problems identified in the management of the COMITESINOS

Based on the deficiencies and problems identified in the management of the basin committee, the objective is to model the socio-environmental management and design a methodology as a tool that facilitates the integration of the managing of social and environmental problems that are interrelated.

### *Material and methods*

The elaboration of a management model requires a study to identify and analyze the structural, functional and environmental components, determining which are essential for its operation and how to contribute with its improvement through the variables defined and characterized and establishing the realities existing and that make up the system. The model must be able to represent the object of study, but also help define how it will be changed in the future. Arriving to visualize what allows to synthesize the management methodology, which originates from the previous theoretical analysis, providing to this tool the boundaries, requirements, principles, limitations, and premises, related to the object studied in particular, which contributes to paying attention to the needs of the management of the purpose in a unique way (HOMER, 1996; LIDIA et al., 2006; SILVA, 2012).

For carry out the modeling, the following procedure was followed:

The first step was to analyze the academic reference on management in general and socio-environmental management in particular. The second step was a description of the Social - Environmental Management Model, identifying the input and output variables, the spatial and functional borders, the components and the general processes of the system. The third step was to elaborate the process map, identifying the central, strategic, support, and second-order processes. The fourth step is the integration of theories, models, and approaches necessary for the conception of the socio-environmental management model of the hydrographic basin. The fifth and last step was to describe the methodology and its components.

### *Results and Discussions*

#### *Introduction to Water management*

There are several archaeological references to the management of water resources, such as changes in hydrological courses through the construction of channels for navigation or irrigation, among other hydraulic works, in several ancient civilizations developed near rivers, such as China and Egypt (HECHT, 1988; WALLACE; BUCKNAM; HANKS, 1994; WANG, 2012; LU et al., 2017). In other arid regions of the Middle East, India and China, in different historical periods, there are records of men regulating streams and springs to supply their needs

(CHAUDHURI, 1998; HADAS, 2012; LUO et al., 2017). The Greeks and Romans were among the earliest civilizations which, in addition to providing water for agriculture, for health reasons, have set up domestic sewage treatment systems and aqueducts to provide quality water for their cities (DE FEO; MAYS; ANGELAKIS, 2011).

Basin management has incorporated different concepts over time and, due to multiple global events, the United Nations had been encouraging the incorporation of basin management processes in the various member countries. In 1996 was created the *Global Water Partnership (GWP),* which has its background on the environmental Stockholm conferences of 1972, Buenos Aires in 1977, as well as the United Nations Declaration sign in Dublin in 1992. The GWP's origin includes the creation of an international network to guarantee secure and sustainable management of water resources through the stimulation of Integrated Water Resources Management (GIRH) (Global Water Partnership, 2009).

### *Management concepts approach*

The researchers Pérez Campdesuñer (2006) and, Rigol Madrazo and Pérez Campdesuñer (2010) analyzed 62 concepts derived from the words: management, administration, and direction. They performed the identification of the variables involved, eliminated the prepositions, conjunctions, and synonyms and from a statistical analysis of conglomerates concluded that: "... management is a dynamic, interactive, efficient and effective process. This consist in the planning, organizing, leading and taking control actions of the organization, developed through a steering mechanism where groups of people have the resources and authority to create, achieve and improve the constitutive purposes of the organization, based on laws knowledge and social principles, human nature and technology, as well as information in general."(Rigol Madrazo; Pérez Campdesuñer, 2010, our translation). Batista (2013) criticizes this concept and says that it lacks functional mechanisms and does not take into account the context of organization development, suggesting the incorporation of his arguments into this concept.

The authors assumed the management concept defined by Pérez Camdesuñer (2006), improved by Rigol Madrazo and Pérez Campdesuñer (2010) and then Batista (2013). This concept refers that the management is a sociotechnical process, with a dynamic character, and consists in planning, organizing, leading and controlling the organization actions, with efficient and effective use of human, financial, technological, informative and time resources, This allows the concretization of objectives, based on context, through the construction of mechanisms and the auxiliary functions of the process.

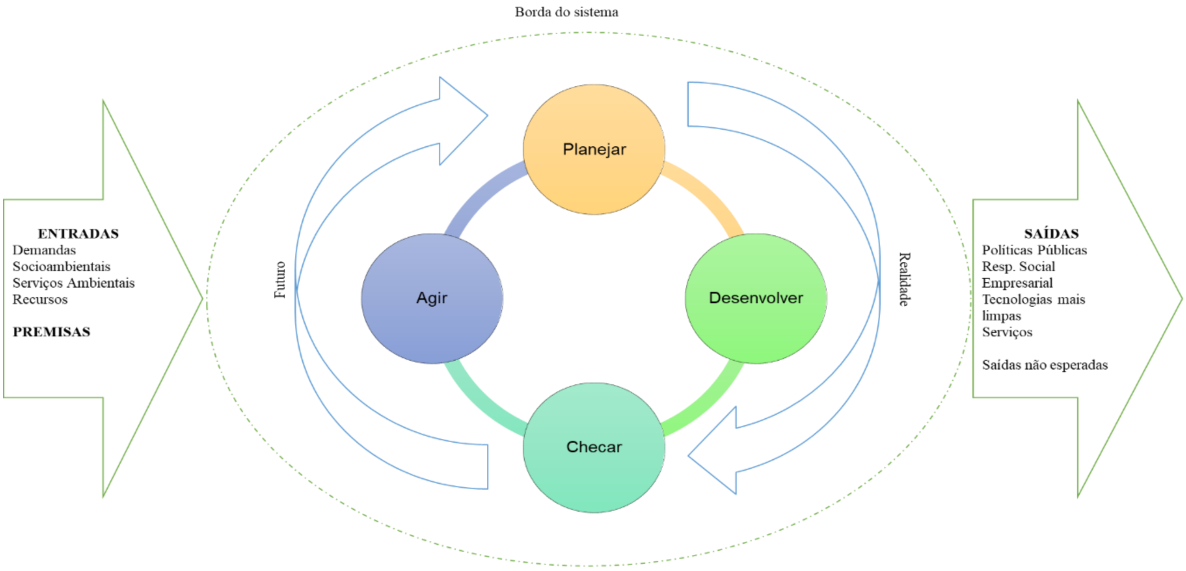
*Social management. Socio-environmental concept.*

Social management is a participatory and democratic process, free of coercion, where everyone has equal expression freedom and information access; is a coordinated action between the public power and society in favor of social, political, economic and cultural well-being in a territory (TENÓRIO, 1998, 2005; RAMOS; MATOS, 2009; OLIVEIRA; CANÇADO; PEREIRA, 2010; MONJE-REYES, 2011). The authors determine different variables to define social management, such as participatory, collaborative and communicative process, joint learning, developed through coordinated actions, through inter-institutional relationship spaces, with an inclusive approach to environmental variables (SIQUEIRA, 2009). However, socio-environmental management is a dynamic and adaptable model, inserted throughout the management process, aiming to reach the goals and objectives most sustainably (NASCIMENTO; LEMOS; MELLO, 2008; TACHIZAWA; ANDRADE, 2011; BERTÉ, 2012). The analysis of the concept explained above shows that socio-environmental management incorporates concepts, theories, and approaches integrated into the form of a system.

*Description of the basin socio-environmental management system model*

Based on the general and specific information obtained, as well as the principles and postulates of the general theory of management, the basin socio-environmental management model was synthesized, describing and characterizing the main components, namely: demands - objectives - results, edge system environment, system components, system processes, system inputs, system outputs, assumptions, principles and requirements (Figure 3). This model represents the necessary elements of the management process and its functional relationships, allowing the understanding of its logic and thus improving the indicators of processes and results of the basin social-environmental management system.

Figure 3 Social - Environmental Management Model




*Limitations and preconditions of the socio-environmental management system of the socio-ecosystem basin.*

Outstanding to the complexity of the system, it is not possible to model or conjecture all the interactions that take place in the object behavior in reality, nor to consider all the external influences of the environment on the socio-environmental management system of the watershed socio-ecosystem, nor on its stakeholders.

For this research, we do not consider the indirect relationships that may occur and disrupt the operation of the system due to its socio-technical character, nor do we find multiple stakeholders actions that deliberately impede the functioning of the system.

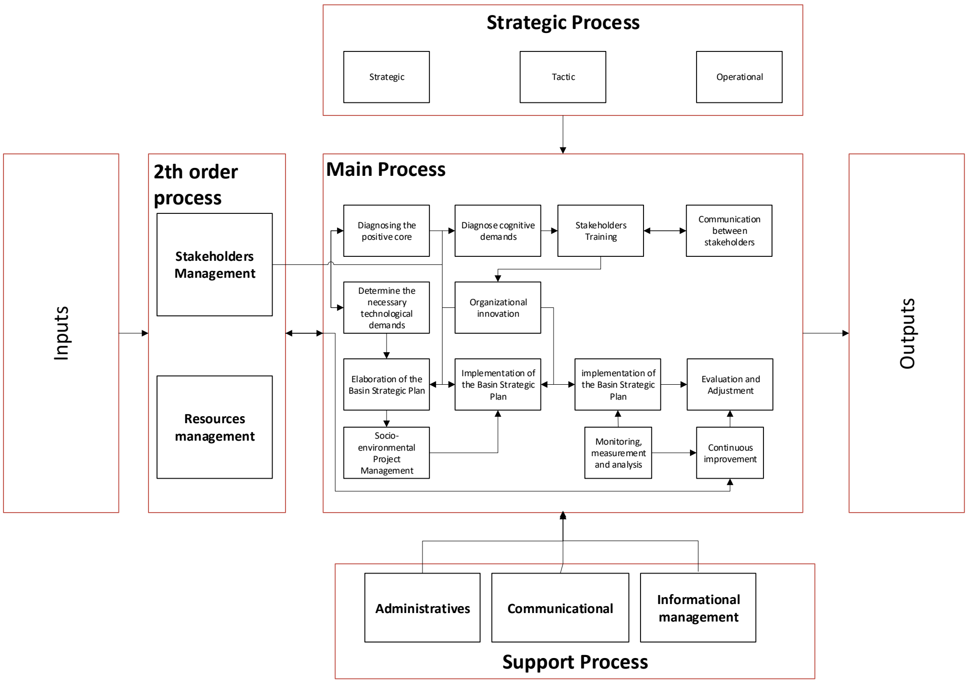
*To defining limits of the socio-environmental management system of the socio-ecosystem basin.*

The socio-environmental management system of the hydrographic basin socio-ecosystem has two limits, one clearly defined and the other diffuse; the first border consists of a physical - geographical boundary defined by the orography and hydrography of the river basin. The second border is diffuse because it is not limited to the places where actions, plans, and goals are concretized, but to all the institutions of society directly or indirectly, based on stakeholders' actions or attitudes. Although these actions, plans, and goals are developed, adopted, approved and agreed in a democratic way and driven by the positive core of the management system.

*Modeling the management process map.*

The model (Figure 4) is composed of management processes i) inputs (social and environmental demands, technological resources, resources, necessary pre-conditions); ii) outputs (outcomes, socio-environmental services, plans, public policies, adoption of cleaner technologies, CSER approaches, environmental education and unexpected outputs)

Figure 4 Management Process Map




Also, management processes were identified (Figure 4), so it was necessary to study the process approach, which is a tool that allows the optimization of the management process for all types of organizations. This approach defines that any activity or set of activities interconnected with each other, using resources and control mechanisms to transform input elements into results, can be considered processes (ISO9001, 2015).

A process consists of inputs and outputs, which can be tangible or not, unintentional and intentional. The process approach and constraint theory can be applied to the set, not only to determine the critical factors that hamper management success but also to know the causal factors and the relationships between them (RAHMAN, 2002).

*Theories, approaches and integrated methods for the conception of the socio-environmental management system of the basin.*

For understand socio-environmental management, it was tried to explain it as a sociotechnical system, so it was necessary to study the general theory of systems, which is constituted by a set of ideas and assumptions presented initially as "The whole is more than the sum of their parts." The objectives of the general systems theory describe characteristics, behaviors, and functions as well as to develop standards that apply to them, by defining laws, covering the system as a whole and all its parts together (BERTALANFFY, 1968, 1976; ARNOLD; OSORIO, 1998; UHLMANN, 2002), allowing us to classify socio-environmental management as a system and to identify its subsystems.

Also, it was necessary to study the general theory of management, since socio-environmental management has a dynamic nature. With processes such as planning, organization, direction, and control of the actions of the organization, achieving efficient and effective administration, through the creation of structural and functional mechanisms, of resources based on the context, such as human, financial, technological, informative and time resources (STONER; FREEMAN; GUILBERT, 1996; HITT; BLACK; PORTER, 2006; PÉREZ CAMPDESUÑER, 2006; KOONTZ; WEIRHRICH, 2007; RIGOL MADRAZO; PÉREZ CAMPDESUÑER, 2010; BATISTA, 2013). It was also necessary to identify the limitations and barriers of socio-environmental management, which led to the incorporation of elements of the theory of constraints. Which can be summarized as: "The whole system presents at least one constraint and the existence of constraints represents opportunities for improvement." (RAHMAN, 1998), is a set of procedures that make use of cause-effect logic, with a systemic approach, that allows identifying the causes that prevent the organization from reaching its goals. While the theory is mostly applied to the business sector, it can be used to the management of any organization. It is divided into five steps: identifying constraints; decide how to exploit them; subordinate actions to system constraints; break or raise the restrictions and recognize new limitations, going back to the first step if the limits were broken (GOLDRATT, 1990; RAHMAN, 2002; RIBEIRO, 2007; FILHO; PERGHER; SILVA, 2009).

Since socio-environmental management has a peculiar characteristic of being an open and distributed management system, it was necessary to incorporate the precepts of the appreciative inquiry, which is in practice a flexible and adaptive research method based on forces, being constructivist and participative, however , is a highly dynamic process that encourages the use of innovative techniques (COOPERRIDER, 1985; WHITNEY; COOPERRIDER, 2003; WHITNEY; TROSTEN-BLOOM, 2010; NYAUPANE; POUDEL, 2012) Appreciative inquiry incorporates tools like the 4D model. This model is in opposition to the Deming cycle, once that the latter makes extensive use of the general problem-solving method, which looks for the problems and their causes. Whereas, in the 4D model one obtains better performances when they focus on the individual forces as well as in the successes achieved as a team by the stakeholders, instead of focusing only on the problems. These problems are usually multifactorial and multicausal and generate a climate of tension between the members of the organization when searching for the culprits for the failures (SOUZA; MCNAMEE; SANTOS, 2004; TRAJKOVSKI et al., 2013; SALAMA; MACLEAN, 2017). Stakeholders are those who have interests, expectations or needs in processes and results that they define and require. Karassin e Bar-Haim (2016) classify them as consumers, suppliers, employees, associates, financial institutions, local communities, and interest groups, and it will be those who need performance measurement to be able to determine if the process requires some correction or improvement based on its outcome.

Nevertheless, in the socio-environmental management of the socio-ecological watershed basin, it is not sufficient to incorporate the appreciative inquiry tools, since it involves multiple governmental and non-governmental actors with asymmetric forces, it is also necessary to integrate complementary tools such as the multi-stakeholder governance model (MSGM). This model incorporates processes of cooperation, communication, and participation in the coordination and joint management of stakeholders, governmental and non-governmental institutions in the search for solutions and implementation of those that best fit, allowing a balance between the forces and interests of participants and thus reducing the conflicts of interest. Given a mutual interdependence, this becomes an essential characteristic to create the processes of collaboration and cooperation, allowing to reach mutually beneficial solutions (DEWULF, 1985; HEMMATI, 2002; KOEN SIPS, 2013; VERMEESCH et al., 2013). To accomplish this, the MSGM becomes an adequate tool to balance the hegemonic power relations of large corporations and governments, which, without it, would act in favor of their interests and detriment of those of other stakeholders, what would limit them to achieve the common objectives and the welfare state of society. These common objectives aim to achieve the sustainable development of society, which requires the reduction of the damages of the negative impacts to the social-ecosystem by socioeconomic activities, making these damages either reversible or mitigate.

For reach these objectives, the stakeholders were classified as suppliers of products or services must incorporate this practice into their institution's concept of corporate social – environmental responsibility **(CSER),** which is born in the union of the concepts of the corporate social responsibility (CSR) and the corporate environmental responsibility (CER). The CSER is an instrument unified in corporate management, formed by alliances between companies and communities, sharing or developing products, technologies or services. With the implementation of non-profit strategies or activities and non-economic objectives, aimed at achieving well-being, including obligations and responsibilities to the environment, trying to mitigate, remedy or protect it from the negative impacts of activities on the formation of products or services (VOLPON; MACEDO-SOARES, 2007; RABELO; SILVA, 2011; HOLTBRÜGGE; DÖGL, 2012; COLES; FENCLOVA; DINAN, 2013; CHEN; YU; HU, 2016).

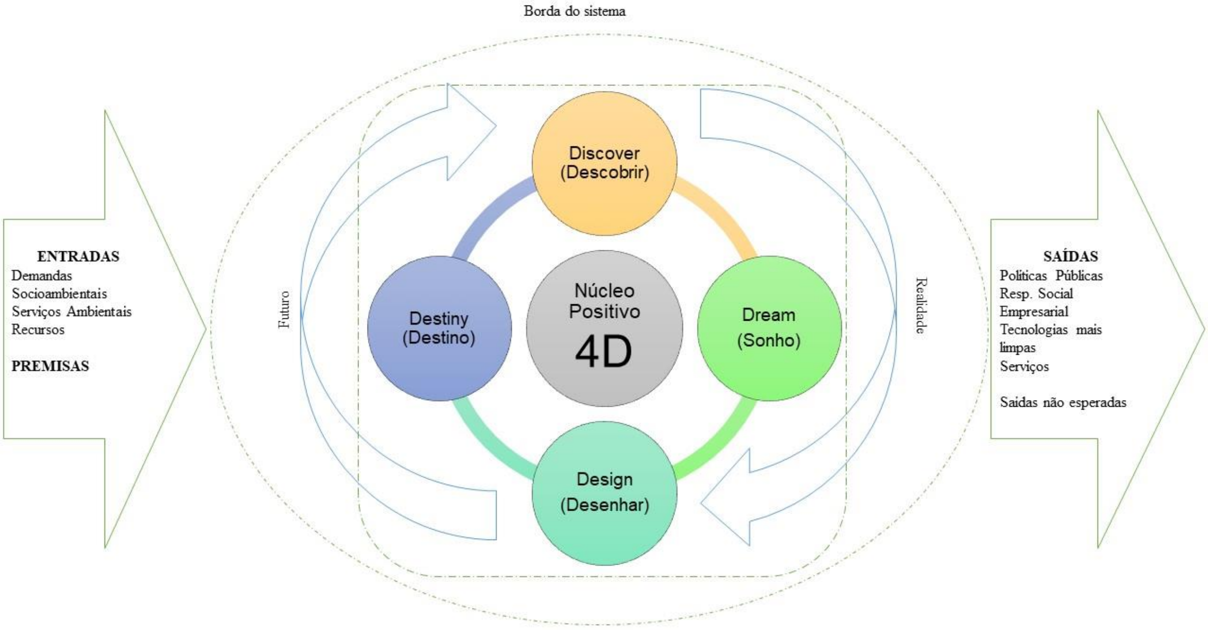
However, the incorporation of the CSER concept may not be attractive to specific stakeholders, who cannot see the benefits of incorporating such practices to their economic activity. It is, therefore, necessary to include, into the CSER, the philosophical precepts of eco-efficiency, which encourages companies to strike a balance between efficient production and environmental responsibility, allowing production or service institutions to become more competitive, innovative and more responsible for the environment (WBCSD, 1996; ROHRICH; CUNHA, 2004; BERTÉ, 2012; GODECKE; MAURICIO, 2015; LEANDRO et al., 2015; MEHMETI; TODOROVIC; SCARDIGNO, 2016). Therefore, Eco-efficiency stands out for reducing the consumption of raw materials and energy, also minimizing the emission of pollutants in the atmosphere, water, and soil. The production of long-life articles and the increased recycling of these products make companies more sustainable and less vulnerable to environmental risks (ARAMBURÚ, 2009; STANCHEV; RIBAROVA, 2016; TODOROVIC; MEHMETI; SCARDIGNO, 2016; CAIADO et al., 2017).

By incorporating Eco-efficiency into business management, it will enable products and services with a minimal environmental footprint and highly competitive, satisfying personal needs, adding quality of life to basin inhabitants and reducing the cumulative effects of environmental impacts, contributing to sustainable development.

**Description of the methodology**

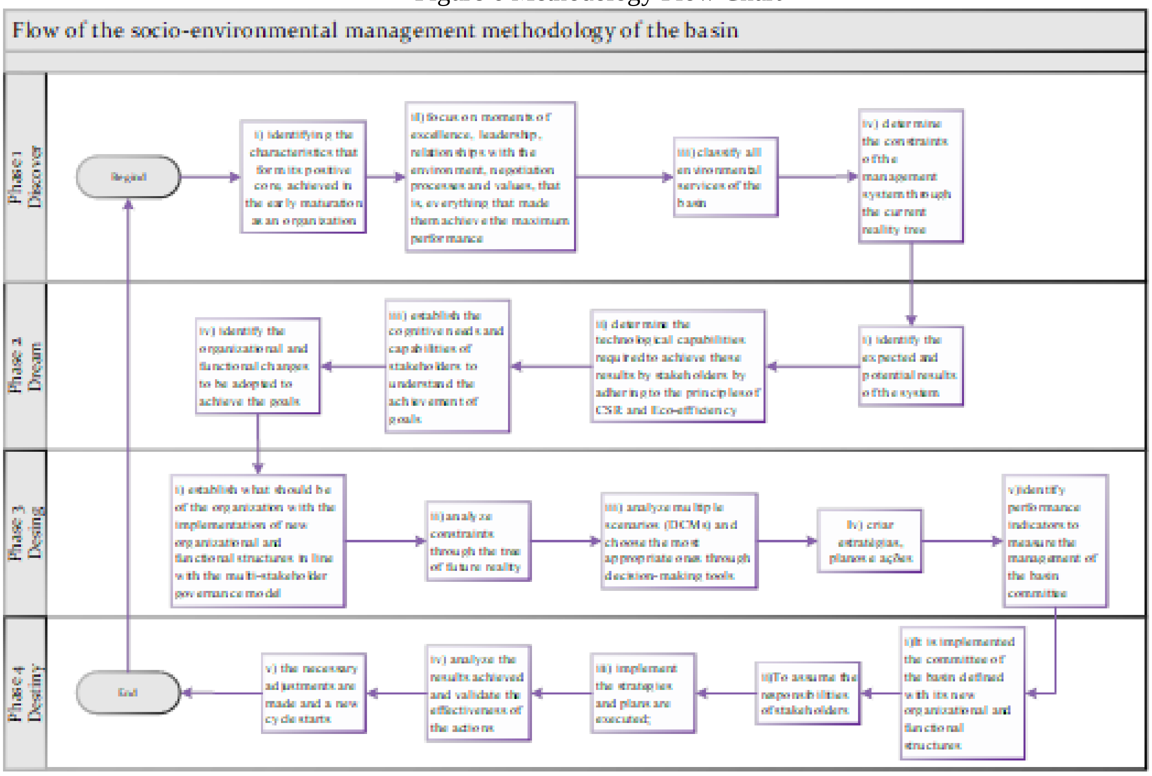
The methodology is based on the 4D model of the appreciative inquiry approach (figure 5), adapted to the characteristics of socio-environmental management. The 4D model (*Discover, Dream, Design, and Destiny*) focuses on the discovery of those forces that distinguish the organization and its members, which facilitates concentrate on goals and reduces conflicts. (COOPERRIDER, 1985). The identification of its positive nucleus that is that set of multidimensional variables that conditions the structure and functioning of the organization, associated with the image shared by all its members is fundamental to the process of change towards positive management.

Figure 5 Social - Environmental Management by 4D Model




Once the positive nucleus had been identified, the following steps of the methodology, summarized in, will be given: (figure 6)

Figure 6 Methodology Flow Chart



a) *Discover.* At this stage, the basin committee should:

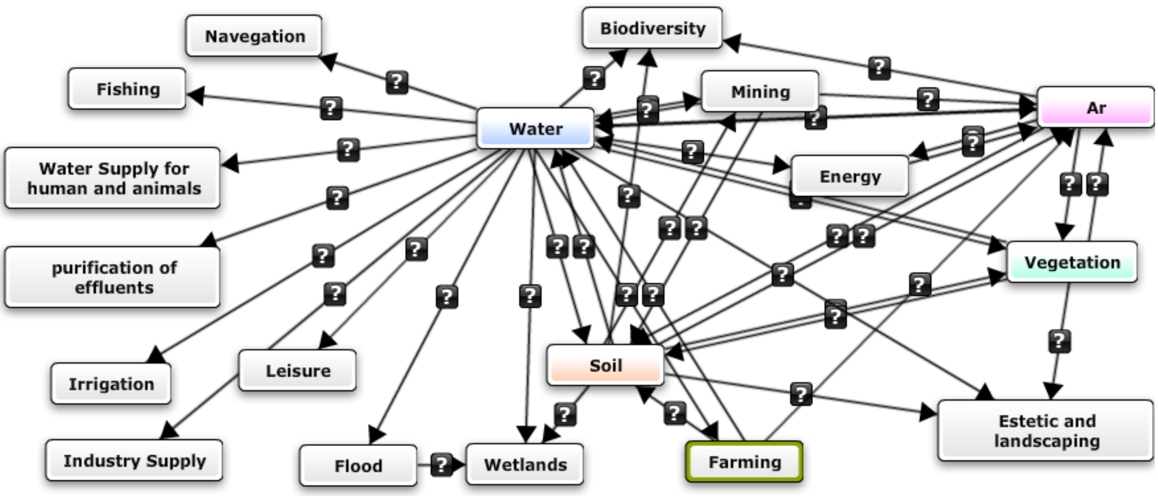
i. To identify those characteristics that form its positive core, achieved in the years of maturity as an organization;

ii. To focus on moments of excellence, leadership, relationships with the environment, negotiation processes and values, that is, everything that made them achieve maximum performance;

iii. To classify all environmental services of the basin (7);

iv. To determine the constraints of the management system through the current reality tree.

Figure 7 Fuzzy Cognitive Maps for ecosystemic services




b) *Dream.* At this stage the objectives are:

i. To identify the expected and potential results of the system;

ii. To determine the technological capabilities needed to achieve those results by stakeholders, by adhering to the principles of CSER and Eco-efficiency;

iii. To establish the cognitive needs and capacities of stakeholders to understand the achievement of goals;

iv. To identify the organizational and functional changes that need to be adopted to achieve the goals.

c) *Design.* At this stage the committee contrasts the dream with reality, it is time:

   i. To establish what should be of the organization with the implementation of new organizational and functional structures in line with the multi-stakeholder governance model;
   ii. To analyze the constraints through the tree of future reality;
   iii. To analyze multiple scenarios and choose the most appropriate ones through tools that help decision making, DCM;
   iv. To create strategies, plans, and actions;
   v. To identify performance indicators that allow the management of the basin committee to be measured.

d) *Destiny.* In this final phase all the resources are integrated to reach the dream results of the organization:

   i. It is implemented the committee of the basin defined with its new organizational and functional structures;
   ii. To assume the responsibilities of stakeholders;
   iii. The strategies and plans are implemented;
   iv. To analyze the results achieved and validate the effectiveness of the actions;
   v. Do the necessary readjustments are made and a new cycle starts.

**Conclusions**

The evolution of socio-environmental management and conceptual models are essential reference points in the holistic understanding, but they do not provide all the methodological support, because they were not designed to be applied in the context of socio-environmental management of the socio-ecosystem basin. The proposed theoretical model incorporates the fundamental aspects of administration, such as demands, objectives, results, inputs, outputs, constraints and a positive and dynamic core of management.

The complexities of socio-environmental management of the watershed socio-ecosystem and the shortcomings of the theoretical methods used so far were insufficient to explain the whole dimension of the problem. Therefore, it was necessary to create a methodology to integrate into a conceptual framework, general systems theory, the general theory of direction, constraint theory, process approach, appreciative inquiry method, multi-stakeholder governance model, corporate social responsibility and eco-efficiency, as well as integrating other tools.

The management methodology presented has four sequential and iterative phases, which allow integrating several technologies and methodological or managerial tools, directed to reach the technical-organizational objectives of the socio-environmental management process of the basin.

The theoretical model and methodology have not yet been put into practice, so after its future implementation, its effectiveness should be evaluated and its results published in later articles.

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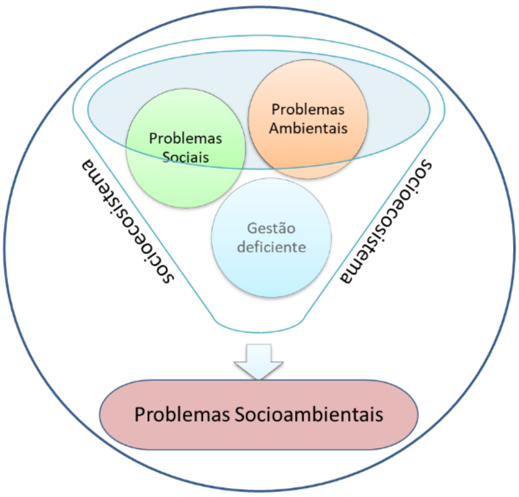
## CONSIDERAÇÕES FINAIS

Esta tese teve como objetivo principal compreender as interações entre as dimensões ambiental, social e econômica e como determinam o desempenho dos processos de gestão socioambiental no socioecosistema bacia Rio dos Sinos.  O estudo foi realizado a partir da revisão de literatura científica e de uma análise dos processos de gestão do Comitê de Bacia Hidrográfica do Rio dos Sinos.

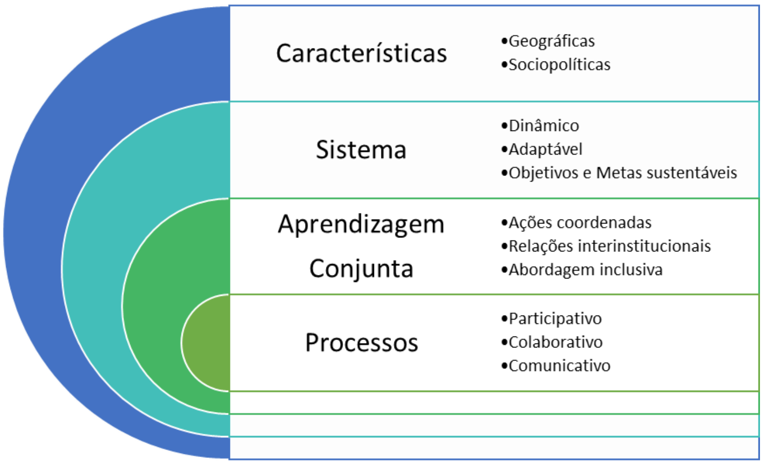
Foi possível identificar 171 artigos, os quais foram meticulosamente processados, analisados e classificados pelo método de análise de conteúdo qualitativo. Após a exclusão daqueles que não cumpriam com os critérios de inclusão propostos sobraram um total de 49 artigos, dos quais 28 eram apresentações de casos de estudos, 20 eram aproximações teóricas e um deles mostrava uma comparação da gestão de três rios, um na américa, outro da África e um terceiro da Ásia. As revisões de literatura permitiram identificar cinco tipos de metodologias de gestão de bacias hidrográficas, entre as quais inclui-se a Gestão Integrada dos Recursos Hídricos que é o paradigma de gestão empregado no Brasil e, portanto, pelo Comitê de Bacia do Rio dos Sinos. Neste capítulo analisa-se as dimensões dos sistemas socioambientais, as características e os problemas de gestão que apresentam (Gráfico 1)

Gráfico 1 Gestão Socioambiental




Os resultados das revisões de pesquisas nacionais e locais sobre o tema em questão revelaram as caraterísticas que apresenta um sistema de gestão integrada de recursos hídricos (Gráfico 2), assim como um número restrito de estudos mostraram acertadamente e coincidentemente as limitações legais, organizativas e de gestão que se apresentam aos Comitês de Bacia na hora de executar as suas atribuições.

Gráfico 2 Características da GIRH




Realizou-se ainda uma pesquisa que revelou os avanços e as deficiências na gestão socioambiental na bacia do Rio dos Sinos, que teve uma etapa de trabalho de campo para coletar informações e levantar dados e que utilizou a entrevista não estruturada e a observação não participante. Estas técnicas permitiram perceber as forças e fraquezas do interno do COMITESINOS e dos seus processos de gestão. (Tabela 1)

| Vantagens | Desvantagens |
|---|---|
| • Definir a Bacia Hidrográfica como unidade de gestão<br>• Ter um sistema legal<br>• Possuir um comitê de bacia (o COMITESINOS)<br>• Implantação de projetos e trabalho com unidades de ensino (Escolas e Universidades) | • Não possui indicadores de gestão<br>• Plano de bacia centrado em estudos e variáveis hidrológicas (não é holístico nem integrador)<br>• Não se inclui no plano de bacia análises, perigos, vulnerabilidades e riscos.<br>• Pouca participação da população na gestão<br>• Insuficiente representatividade dos diferentes grupos da população no Comitê de Bacia<br>• Dificuldades na gestão financeira e de projetos<br>• Excessiva burocracia<br>• Limitado o COMITESINOS por lei a ser uma entidade estatal de natureza consultiva, deliberativa e não de gestão. |

Tabela 1 Vantagens e Desvantagens na gestão do COMITESINOS

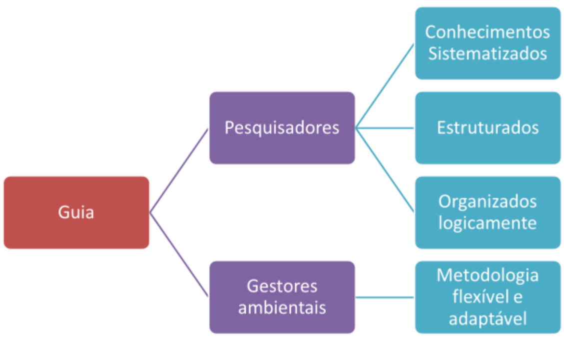
Para compreender melhor as inter-relações e interdependências das variáveis das dimensões estudadas foi necessário realizar exercícios com os membros do comitê, com o auxílio de mapas cognitivos difusos e mapas cognitivos neutrosóficos, com a finalidade de facilitar a identificação das inter-relações entre os diversos fatores e ajudar na solução prática dos problemas, na tomada de decisões e nas análises de cenários em estudos prospectivos, o que permitiu dotá-los com modelos matemáticos e dar melhor sustento às decisões do comitê de bacia.

As diversas atividades de pesquisa do objeto de estudo possibilitaram a conceptualização e desenho de um modelo teórico de gestão socioambiental sustentado na integração de teorias, abordagens e métodos integrados. Proporcionou, ainda, desenhar o mapa de processos de gestão em que se identificam as entradas e saídas do sistema, os processos estratégicos, de suporte e principais. Além disso, permitiu definir que o sistema de gestão deve ser um sistema aberto e distribuído que para ser efetivo é necessário incorporar na prática os preceitos da indagação apreciativa, pois as limitações legais com que nasceram os comitês de bacia – que declaram que são órgãos deliberativos, propositivos e consultivos, com um marcado caráter mediador entre os diferentes atores – limitam o seu desempenho em um modelo de gestão de tipo empresarial, em que os papéis dos atores estão claramente definidos, e que é totalmente diferente em um sistema aberto e distribuído em que os papéis dos atores se sobrepõem ou intercambiam.

O estudo também oferece uma metodologia baseada no modelo 4D que permite centrar-se nas forças do trabalho em rede dos *stakeholders*, incorporar o modelo de governança *multi-stakeholder* e aderir a concepções e princípios como: Ecoeficiência, responsabilidade socioambiental empresarial, em um modelo de melhora contínua, cíclica, iterativa e sequencial.

Esta metodologia, de acordo com suas caraterísticas, poderá ser no futuro referência para pesquisadores e gestores. (Gráfico 3)

*Gráfico 3 Guia  para pesquisadores e gestores ambientais*




Recomenda-se para futuras pesquisas a implementação prática, em parte ou na sua totalidade, deste trabalho a fim de validar a proposta e mudar o atual modelo de gestão do comitê de bacia. Dessa forma, poderão ser confrontados os resultados de 30 anos de existência do modelo vigente na atualidade, que parece muito bom no papel, mas não na prática conforme resultados obtidos pelo novo modelo.

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To: Olga Alicia Gallardo Milanés <oaliciagallardo2013@gmail.com>

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Agradecemos a submissão do seu manuscrito "Gestión integrada en la cuenca del Río dos Sinos. Avances y desafíos" para Revista Tecnologia e Sociedade. Através da interface de administração do sistema, utilizado para a submissão, será possível acompanhar o progresso do documento dentro do processo editorial, bastanto logar no sistema localizado em:

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Capítulo 4. Sinos River basin social-environmental prospective assessment of water quality management using fuzzy cognitive maps and neutrosophic AHP-TOPSIS

Sincerely,

**The University of New Mexico - Gallup**

Mathematics Department
705 Gurley Ave.
Gallup, NM 87301, USA

Dear authors, It's my pleasure to inform you that, after the peer review, your paper, Sinos river basin social-environmental prospective assessment of water quality management using fuzzy cognitive maps and neutrosophic AHP-TOPSIS, from the authors Rodolfo González Ortega, Maikel Leyva Vázquez, João Alcione Sganderla Figueiredo and Alfonso Guijarro-Rodríguez, has been ACCEPTED in Neutrosophic Sets and Systems (NSS), Vol 22, 2018, ISSN (print): 2331-6055, ISSN (online): 2331-608X.
Thank you for working with NSS.

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