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Abstract. This study reviews the main initiatives for the development and implementation of environmental sustainability and sustainable development indicators. The indicators, built specifically for the corresponding users, constitute a system of signals that allow each country to evaluate its progress toward sustainable development. The purpose of this research is to identify, through neutrosophic logic, the specific indicators of sustainable development with the highest incidence in Ecuador. For this, a documentary analysis is carried out to provide the primary information on which to carry out the analysis and the knowledge of experts in the area. Correlation coefficients applied to single-value neutrosophic numbers are used to obtain a ranking of sustainable development indicators. Finally, policies and projects can be adopted to strengthen the national infrastructure in favor of sustainability. At the same time, it is shown that the application of neutrosophic techniques is a pillar to be exploited, through which to generate better discussed and studied reasoning.

Keywords: Indicators of sustainability, development, neutrosophic logic, neutrosophic numbers.

1 Introduction

Multi-criteria decision-making methods are an important consideration in the discipline of decision sciences. In recent years, the need to simultaneously consider criteria and alternatives in decision problems is more vital, especially in the presence of uncertain data sets. Therefore, decision-makers use subjective evaluation methods to deal with this obstacle [1].

To enrich this technique and in order to minimize the impossibility of traditional multicriteria decision methods, to handle indeterminate and inconsistent data intrinsic to the real world, the neutrosophic sets proposed by Smarandache [2] are used. These generalize the concepts of Classical Set (CS), Fuzzy Set (FS), Intuitionistic Fuzzy Set (IFS), Interval Valued Intuitionistic Fuzzy Set (IVIFS), etc.

Logic and neutrosophic sets constitute generalizations of Zadeh's logic and fuzzy sets, and Atanassov's intuitionistic logic, among others [7]. The inclusion of Neutrosophic Sets in the method allows the uncertainty of the decision-making process to be taken into account, including indeterminacies. Experts will assess in linguistic rather than numerical terms, which is the most natural form of measurement in humans.

Neutrosophic Analysis (or Neutrosophic Arithmetic) is a general term that encompasses both interval and set analysis. The neutrosophic analysis deals with all kinds of series (not only with intervals), and also includes situations of indeterminacy (sets, functions, or other notions defined on those sets). If sets are used and there is no indeterminacy, then neutrosophic analysis agrees with set analysis. If instead of sets, only intervals are used and indeterminacy exists, then neutrosophic analysis agrees with interval analysis. If there is any indeterminacy, it doesn't matter if you use only intervals or sets, you have neutrosophic analysis.

To overcome the difficulty of generating uncertain and imprecise data during decision-making, [7] introduced the theory of fuzzy sets with several contributions in this field. However, the fuzzy set theory could not address all possible types of uncertainty, such as indeterminacy and inconsistency that normally exist in natural decision-making processes [8], [31].

Neutrosophic Set Theory is a powerful formal framework that generalizes the concepts of Classical Set, Fuzzy Set, Interval-Valued Fuzzy Set, Intuitionistic Fuzzy Set, Interval-Valued Intuitionistic Fuzzy Set, and others [7], [9]. Neutrosophy is a branch of philosophy started by [10]. This theory studies the origin, nature, and scope of neutralities, as well as their interactions with different ideational spectra [3]–[6],[11].

The birth of neutrosophy generates a new concept called <NeutA> that represents indeterminacy with respect to <A>. According to the author, this element can solve certain problems that cannot be solved by fuzzy logic [12].

Various real-life problems, such as weather forecasting, stock price prediction, and political elections, contain indeterminate conditions that fuzzy set theory does not handle well. This theory deals with imprecise and vague situations where exact analysis is difficult or impossible [3].

Following the contributions made by Smarandache, several notions for neutrosophic sets have been introduced that provide a more reasonable mathematical framework for dealing with indeterminate and inconsistent information.[13]. In such a framework, the concepts of an interval neutrosophic set (INS) and a single-valued neutrosophic set (SVNS) were proposed. These elements constitute subclasses of the neutrosophic sets and provided the theoretic set operators and various properties of SVNS and INS. Therefore, SVNS and INS can be applied in real scientific and engineering fields [14], [27, 33, 34, 35].

Subsequently, the use of SVNS correlation coefficients based on the extension of the correlation coefficient of intuitionistic fuzzy sets was presented. This showed that the SVNS cosine similarity measure is a special case of the SVNS correlation coefficient, and was then applied to single-valued neutrosophic numbers applied to decision-making problems [15]–[17]. The application of neutrosophic methods constitutes a useful tool to determine the impact of development actions on sustainability. These methods make it possible to incorporate the conflicts that exist between economic, environmental, and social objectives, and between different decision-making levels.

The Sustainable Development Indicators (SDI) can be interpreted as a system of signals that make it easier to assess the progress of countries and regions toward sustainable development. The indicators are concrete tools that support the work of designing and evaluating public policy, strengthening informed decisions, as well as citizen participation, to drive nations toward sustainable development. It is important to keep in mind that both environmental and sustainable development indicators constitute an issue that is still in the process of development in the world, in which some countries have advanced more than others, in various aspects.

The experience is available, in varying degrees of print or digital publication, so accessing it is simple. The complicated thing is to be able to grasp it, because the diversity of initiatives is very wide, and it is increasing more and more. At the same time, initiatives have been emerging in various citizen spaces, study centers, and government, in the last five years.

The purpose of this paper is to identify the sustainability indicators with the greatest impact on Ecuador, through the use of neutrosophic logic. In this sense, correlation coefficients are a very important tool to judge the relationship between two objects. These coefficients have been widely applied to data analysis and classification, decision-making, pattern recognition, etc. [18], [19], [26]. The present study intends to carry out a selective evaluation of the SDI through the use of neutrosophic correlation coefficients.

In this paper, it is first discussed the preliminary aspects of neutrosophic logic and SVNS, as well as the formulas for the analysis of correlation coefficients defined in the domain of single-valued neutrosophic sets. Subsequently, the bases on which the analysis is carried out, the results, and the conclusions are presented.

2 Preliminaries

Definition 1. [20] Let X be a space of points (objects), with a generic element in X denoted by x. A neutrosophic set A in X is characterized by a membership function of truth $T_A(x)$, a membership function of indeterminacy $I_A(x)$, and a membership function of falsehood $F_A(x)$. The functions $T_A(x), I_A(x)$ and $F_A(x)$, are standard or nonstandard real subsets of $]0^-,1^+[$, that is, $T_A\,(x): X \to]0^-,1^+[\,, I_A\,(x): X \to]0^-,1^+[\; and\; F_A\,(x): X \to]0^-,1^+[$. There is no restriction on the sum of $T_A\,(x)$, $I_A\,(x)$ and $F_A\,(x)$, so $0^- \le supT_A(x) + supI_A(x) + supF_A(x) \le 3^+$.

Obviously, it is difficult to apply the neutrosophic set to practical problems. Therefore, [14] introduced the concept of a Single-Valued Neutrosophic Set (SVNS), which is an instance of a Neutrosophic Set, to be used in real scientific and engineering applications. Here is the definition of SVNS [14], [30].

Definition 2. [14] Let X be a space of points (objects) with generic elements in X denoted by x. An SVNS A in X is characterized by a truth membership function $T_A(x)$, an indeterminacy membership function $I_A(x)$, and a falsehood membership function $F_A(x)$ for each point x in X, $T_A(x), I_A(x), F_A(x) \in [0,1]$. Therefore, an SVNS A can be expressed as

$$A = \{x, T_A(x), I_A(x), F_A(x) \mid x \in X\}$$

So the sum of $T_A\,(x)$, $I_A\,(x)$ and $F_A\,(x)$, satisfies the condition $0 \le T_A(x) + I_A(x) + F_A(x) \le 3$.

Definition 3. [14] The complement of an SVNS A is denoted by Ac and is defined as

$$Ac = \{x, F_A(x), 1 - I_A(x), T_A(x) \mid x \in X\}$$

Definition 4. [14] A SVNS A is contained within another SVNS $B, A \subseteq B$ if and only if $T_A(x) \le T_B(x), I_A(x) \ge I_B(x)$, and $F_A(x) \ge F_B(x)$ for every x in X.

Definition 5. [14] Two SVNSs A and B are equal, written as A = B, if and only if $A \subseteq B$ and $B \subseteq A$

Correlation coefficient of SVNSs

Definition 6 [21] For any two SVNSs A and B in the universe of discourse $X = \{x_1, x_2, \dots, x_n\}$, the correlation coefficient between two SVNSs A and B is defined as follows:

$$M(A,B) = \frac{1}{3n}\sum_{i=1}^{n}[\phi_i(1-\Delta T_i) + \varphi_i(1-\Delta I_i) + \psi_i(1-\Delta F_i)] \quad (1)$$

where

$$\phi_i = \frac{3-\Delta T_i - \Delta T_{max}}{3-\Delta T_{min} - \Delta T_{max}},$$

$$\varphi_i = \frac{3-\Delta I_i - \Delta I_{max}}{3-\Delta I_{min} - \Delta I_{max}},$$

$$\psi_i = \frac{3-\Delta F_i - \Delta F_{max}}{3-\Delta F_{min} - \Delta F_{max}},$$

$$\Delta T_i = |T_A(x_i) - T_B(x_i)|,$$

$$\Delta I_i = |I_A(x_i) - I_B(x_i)|,$$

$$\Delta T_i = |T_A(x_i) - T_B(x_i)|,$$

$$\Delta T_{min} = min_i|T_A(x_i) - T_B(x_i)|,$$

$$\Delta I_{min} = min_i|I_A(x_i) - I_B(x_i)|,$$

$$\Delta F_{min} = min_i|F_A(x_i) - F_B(x_i)|,$$

$$\Delta T_{max} = max_i|T_A(x_i) - T_B(x_i)|,$$

$$\Delta I_{max} = max_i|I_A(x_i) - I_B(x_i)|,$$

$$\Delta F_{max} = max_i|F_A(x_i) - F_B(x_i)|,$$

For all $xi \in X$ and i = 1, 2, . . ., n

However, the differences of importance are considered in the elements of the universe. Therefore, the weight of the element $x_i (i = 1,2,\dots,n)$ must be taken into account. A weighted correlation coefficient between the SVNS is presented below.

Definition 7. [21] Let w_i be the weight of each element x_i $(i = 1,2,\dots,n), w_i \in [0,1]$, and $\sum_{i=1}^{n} w_i = 1$, then we have the following weighted correlation coefficient between SVNS A and B:

$$M_w(A,B) = \frac{1}{3}\sum_{i=1}^{n} w_i[\phi_i(1-\Delta T_i) + \varphi_i(1-\Delta I_i) + \psi_i(1-\Delta F_i)] \quad (2)$$

Decision-making method using the correlation coefficient of SVNSs

In the multi-attribute decision problem with single-valued neutrosophic information, the characteristic of an alternative A_i $(i = 1,2,\dots,m)$ on an attribute C_j $(j = 1,2,\dots,n)$ is represented by the following SVNS: $A_i = \{C_j, T_{Ai}(C_j), I_{Ai}(C_j), F_{Ai}(C_j) | Cj \in C, j = 1,2,\dots,n\}$ where $T_{Ai}(C_j), I_{Ai}(C_j), F_{Ai}(C_j)) \in [0,1]$ and $0 \le T_{Ai}(C_j)$, $I_{Ai}(C_j), F_{Ai}(C_j) \le 3$, for $Cj \in C, j = 1,2,\dots,n,$ and $i = 1,2,\dots,m$.

For convenience, the values of the three functions $T_{Ai}(C_j)$, $I_{Ai}(C_j), F_{Ai}(C_j)$ are denoted by a single-valued neutrosophic value (SVNV) $d_{ij} = < t_{ij}, i_{ij}, f_{ij} >$ $(i = 1,2,\dots,m;\ j = 1,2,\dots,n)$, which is usually derived from the evaluation of an alternative A_i against a criterion C_j by the expert or decision maker. Thus, a single-valued neutrosophic decision matrix $D = (d_{ij})_{mxn}$. is obtained

In multi-attribute decision problems, the ideal point concept has been used to help identify the best alternative in the decision set. Although the ideal alternative does not exist in the real world, it does provide a useful theoretical construct against which to evaluate alternatives [22], [23], [24], [29], [32].

In the decision-making method, an ideal SVNV can be defined by $d_j^* =< t_j^*, i_j^*, f_j^* >=< 1, 0, 0 >$ $(j = 1, 2, \dots, n)$ in the ideal alternative A^*. Therefore, applying Equation (2), the weighted correlation coefficient between an alternative A_i $(i = 1, 2, \dots, m)$ and the ideal alternative A^* is given by:

$$M_w(A_i, A^*) = \frac{1}{3}\sum_{j=1}^{n} w_j\left[\phi_{ij}\left(1 - \Delta t_{ij}\right) + \varphi_{ij}\left(1 - \Delta i_{ij}\right) + \psi_{ij}\left(1 - \Delta f_{ij}\right)\right] \quad (3)$$

where

$$\phi_{ij} = \frac{3 - \Delta t_{ij} - \Delta t_{i\,max}}{3 - \Delta t_{i\,min} - \Delta t_{i\,max}},$$

$$\varphi_i = \frac{3 - \Delta i_{ij} - \Delta i_{i\,max}}{3 - \Delta i_{i\,min} - \Delta i_{i\,max}},$$

$$\psi_i = \frac{3 - \Delta f_{ij} - \Delta f_{i\,max}}{3 - \Delta f_{i\,min} - \Delta f_{i\,max}},$$

$$\Delta t_{ij} = \left|t_{ij} - t_j^*)\right|,$$

$$\Delta i_{ij} = \left|i_{ij} - i_j^*)\right|,$$

$$\Delta f_{ij} = \left|f_{ij} - f_j^*)\right|,$$

$$\Delta t_{i\,min} = min_j\left|t_{ij} - t_j^*\right|,$$

$$\Delta i_{i\,min} = min_j\left|i_{ij} - i_j^*\right|,$$

$$\Delta f_{i\,min} = min_j\left|f_{ij} - f_j^*\right|,$$

$$\Delta t_{i\,max} = max_j\left|t_{ij} - t_j^*\right|,$$

$$\Delta i_{i\,max} = max_j\left|i_{ij} - i_j^*\right|,$$

$$\Delta f_{i\,max} = max_j\left|f_{ij} - f_j^*\right|,$$

For $i = 1, 2, \dots, m$ and $j = 1, 2, \dots, n$. Using the correlation coefficient $M_w\ (A_i, A^*)$ $(i = 1, 2, \dots, m)$, the ranking order of all the alternatives and the best one(s) is obtained.

2.1 Materials and methods

For the development of the study, a bibliographic review was carried out on statistical, environmental, and economic data related to sustainable development indicators. The search was made by consulting databases provided by specialists and officials from related areas.

The sustainable development indicators obtained after the analysis were listed and submitted for review by the work team. For better understanding during this work, they were coded as shown in Table 1.

Code	Sustainable development indicators
SDI_1	Workforce Productivity
SDI_2	Highly biodiverse plant formations
SDI_3	Industrial waste pollution
SDI_4	Soil fragility

Code	Sustainable development indicators
SDI_5	Territorial planning
SDI_6	Expenditures on research and development per inhabitant

Table 1: Coding for sustainable development indicators. Source: own elaboration.

To carry out the analysis of the indicators and determine those with the greatest general impact, three evaluation criteria were selected. In the first criterion (C_1) the potential that these SDI have as tools in government decision-making, in relation to other priorities on the public agenda.

The second criterion (C_2) to be analyzed focuses on the cost that matters to develop a quality SDI system and operate it over time.

Finally, the social impact (C_3) of each SDI is assessed. For such purposes, the impact on groups, bodies, organizations, and other entities of society and the state is taken into account; considering that this issue concerns all social edges. So it is important to consider the economic effects caused from all aspects, both directly and indirectly.

For the evaluation of the indicators with respect to the selected criteria, the experts are asked to complete a small form in which an evaluation that is as precise as possible must be included in this regard. Likewise, they are asked to weigh the importance of each one of the criteria with respect to the rest. For this, the evaluations to be given must specify to what extent the expert considers that the alternative Ai is good (Tx), bad (Fx), or is not entirely sure (Ix) with respect to the criterion C_j. it is considered that the evaluated criteria have the same weight wj=0.33.

3 Results

To carry out the described analysis, the arithmetic mean of the evaluations made by the experts is considered. The results obtained from the evaluations allow for obtaining a resulting decision matrix D, which is shown below in Table 2.

0.4	**0.2**	**0.2**	**0.2**	**0.2**	**0.3**	**0.1**	**0.2**	**0.5**
0.3	0.2	0.5	0.7	0.1	0.2	0.6	0.3	0.3
0.4	0.3	0.2	0.5	0.4	0.3	0.5	0.1	0.2
0.7	0.1	0.1	0.1	0.2	0.5	0.4	0.2	0.2
0.2	0.3	0.5	0.6	0.1	0.2	0.3	0.2	0.3
0.6	0.1	0.2	0.5	0.2	0.3	0.6	0.3	0.2

Table 2: Decision matrix D. Source: own elaboration

In accordance with what has been described for the development of the method and the obtaining of the results, the values of the operators φ, μ and ψ are determined to obtain the correlation coefficients, to carry out the method. Tables 3 and 4 show the results of such operations. [25], [28]

	SDI	**SDI**	**SDI**	**SDI**	**SDI**	**SDI**
ΔTmin	0.6	0.3	0.5	0.3	0.4	0.4
ΔImin	0.2	0.2	0.2	0.1	0.2	0.2
ΔFmin	0.2	0.1	0.1	0.1	0.1	0.1
ΔTmax	0.9	0.7	0.6	0.9	0.8	0.5
ΔImax	0.5	0.5	0.3	0.5	0.5	0.3
ΔFmax	0.2	0.3	0.4	0.2	0.3	0.3

Table 3: Minimum and maximum values of variation in the membership functions of truth, falsehood, and indeterminacy. Source: own elaboration.

Indicators	φ_1	φ_2	φ_3	μ_1	μ_2	μ_3	ψ_1	ψ_2	ψ_3
SDI_1	1	0.87	0.8	1	0.96	0.87	1	1	1
SDI_2	0.8	1	0.95	0.87	1	0.96	0.96	1	1
SDI_3	0.95	1	1	1	0.96	1	0.92	0.88	1
SDI_4	1	0.67	0.83	1	0.83	0.96	1	0.96	1

Indicators	φ_1	φ_2	φ_3	μ_1	μ_2	μ_3	ψ_1	ψ_2	ψ_3
SDI_5	0.78	1	0.83	0.87	1	0.96	0.92	1	1
SDI_6	1	0.95	1	1	0.96	1	1	0.96	0.9

Table 4: Values of φ, μ, and ψ for each selection alternative. Source: own elaboration.

In this way, by using equation (3) the values of the correlation coefficients M_w (A_i, A^*) are obtained. Table 5 shows the values obtained and the ranking corresponding to the results.

Sustainability indicators	M coefficient
Workforce Productivity	0.55
Territorial planning	0.58
Soil fragility	0.62
Highly biodiverse plant formations	0.64
Industrial waste pollution	0.64
Expenditures on research and development per inhabitant	0.70

Table 5: Weighted correlation coefficients. Source: own elaboration.

According to the analysis carried out, it can be seen that, according to the criteria of the experts and the criteria analyzed, the sustainable development indicator with the highest incidence in Ecuador is the expenditure on research and development per inhabitant. In order close to this, but below, there is a high incidence of pollution by industrial waste.

For the analysis carried out and the objectives of this study, the promotion of research and the development of sustainability projects constitute a strong element for the sustainable organization of Ecuadorian society. On the other hand, it should be noted that constant industrial development is opposed to environmental sustainability. Therefore, immediate actions are required to balance these aspects, with the support of the community.

Conclusions

Using neutrosophic tools, it is possible to overcome uncertainties in the decision-making process. This ensures that the resolution of real-life problems has the imprecise elements of the complex decision-making process. In this study, the main experiences are highlighted, and the implications that development has for work in Ecuador are discussed. The analysis was carried out based on its development (environmental, sustainable development, systemic-binding).

Through the development of this study, the selection of the main Sustainable development indicators by using neutrosophic correlation coefficients. As a result of the application of the method, the existence of expenditures in research and development per inhabitant, and the Industrial waste pollution above the other indicators analyzed were verified.

Sustainable Development indicators are tools that constitute a system of signals that allow the evaluation of the progress of countries toward sustainable development. Through the application of neutrosophy and the neutrosophic correlation coefficients, it was possible to analyze this real-life problem of relevant importance and impact at an economic-social level for Ecuador.

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