Neutrosophic Sets and Systems, {Special Issue: Advances in SuperHyperStructures and Applied Neutrosophic Theories)}, Vol. 74, 2024

University of New Mexico

Impact of Irrigation Water Technification on Seven Directories of the San Juan-Patoa River Using Plithogenic n-SuperHyperGraphs Based on Environmental Indicators in the Canton of Pujilí, 2021

Yenson Vinicio Mogro Cepeda [1], Marco Antonio Riofrío Guevara [2], Emerson Javier Jácome Mogro [3] and Rachele Piovanelli Tizano [4]

[1] Technical University of Cotopaxi, Ecuador; vinicio.mogro@utc.edu.ec
[2] Technical University of Cotopaxi, Ecuador; marco.riofrio2916@utc.edu.ec
[3] Technical University of Cotopaxi, Ecuador; emerson.jacome@utc.edu.ec
[4] Cotopaxi Prefecture, Ecuador; rachele.piovanelli@cotopaxi.gob.ec

Abstract. The study analyzed interactions among economic, environmental, and sociocultural factors in agricultural irrigation systems to evaluate and promote integral sustainability, using the application of plithogenic n-SuperHyperGraphs. Significant interactions between vertex attributes were identified during the study's development. Results highlighted that optimizing economic profitability, implementing ecological pest management, and fostering social cohesion are essential for improving system sustainability. It is concluded that an interdisciplinary approach is critical for achieving comprehensive agricultural sustainability, proposing an evaluative model adaptable to local settings to strengthen sector resilience. Additionally, the application of plithogenic n-SuperHyperGraphs provides a useful tool across various study areas for management and decision-making in diverse agricultural environments.

Keywords: Agricultural sustainability, irrigation systems, plithogenic n-SuperHyperGraphs, food sovereignty

1 Introduction

The Pujilí Canton, located in the Cotopaxi Province, has a predominantly agricultural economy and a population of 458,581 inhabitants. In this region, land use is primarily determined by altitude, which influences the predominant crops in each area [1]. At lower altitudes (2200-2400 m.a.s.l. (meters above sea level)), sugar cane, fruit trees, and tomatoes are grown, while at higher altitudes (2400-3200 m.a.s.l.), maize, beans, wheat, barley, and tubers are the main crops [2]. Over the past two decades, livestock farming has expanded, primarily affecting the Andean forest areas. As a result, 42.88% of agricultural land has been allocated to pastures, 38.26% to short-cycle crops, and 18.86% to permanent crops, such as temperate fruits, sugar cane, and coffee [3].

Despite the agricultural importance of the region, there is a significant lack of previous studies on irrigation systems in the La Matriz parish, where the seven directories of the San Juan-Patoa River are located [4]. This gap limits the knowledge of producers regarding the potentials and deficiencies of their irrigation systems, hindering the continuous improvement of agricultural practices [5]. Hence, there is an urgent need to apply advanced tools for decision-making in the management of water resources and the sustainability of irrigation systems [6].

On the other hand, the low agricultural productivity in the region is attributed to the limited application of cultivation techniques and the lack of strategies to incorporate ecological technologies into the production processes. Additionally, the lack of awareness of environmental factors, such as the deterioration of local biodiversity, negatively affects productivity by contributing to land abandonment and degradation [7]. Users of the San Juan-Patoa River irrigation system need to understand the current state of agricultural management in the region to assess the sustainability of their practices and make informed investments [8].

To address this issue, the research proposes the application of plithogenic n-SuperHyperGraphs, an advanced mathematical tool that models complex interactions between social, economic, and environmental factors. This approach incorporates and considers the uncertainties and indeterminacies inherent to the agricultural system in the region. N-SuperHyperGraphs allow for the combination of vertices to form SuperVertices, organizing information into categories of known, indeterminate, and unknown, thus facilitating the representation of complex and contradictory relationships within the irrigation system [9]. This approach is essential due to the uncertain nature of the problem being addressed and the need to use statistics to make informed decisions.

Moreover, the use of Plithogeny, developed by Smarandache, provides the appropriate theoretical framework to analyze irrigation systems by integrating multiple perspectives of uncertainty. By combining n-SuperHyperGraphs with log-linear statistical models applied to contingency tables [10], the research aims to identify patterns and relationships that affect the sustainability of irrigation systems in the region [11]. This approach enables a more precise evaluation of the viability of agricultural practices such as crop rotation, soil conservation, and the adoption of environmentally responsible ecological technologies.

Therefore, the main objective of this research is to analyze the interaction of economic, environmental, and sociocultural vertices in agricultural irrigation systems to evaluate and promote integral sustainability [12] [13], through the application of plithogenic n-SuperHyperGraphs. This comprehensive analysis is essential to provide farmers with the necessary tools to improve productivity, promote cooperation, and access new markets, thereby contributing to the sustainable development of the region.

2 Materials and Methods

This section contains two sub-sections, the first one is dedicated to explaining the basic notions of Plithogenic n-SuperHyperGraphs defined in[14]. Then, subsection 2.2 contains the main concepts of multi-way contingency tables and the log-linear method.

2.1 Plithogenic n-SuperHyperGraphs

Plithogenic n-SuperHyperGraphs were defined by Smarandache in the field of decision-making in[15] [16]

First, an n-SuperHyperGraph is defined as follows:

Given $V = \{V_1, V_2, \cdots, V_m\}$, where $1 \leq m \leq \infty$ is a set of vertices, containing *Single Vertices* that are classical, *Indeterminate Vertices* that are unclear, vague, partially known, and the *Null Vertices* that are empty or completely unknown.

$P(V)$ is the power set of V including $\emptyset$. $P^n(V)$ is the n-power set of V, which is defined recursively as follows:

$P^1(V) = P(V)$, $P^2(V) = P\big(P(V)\big)$, $P^3(V) = P\big(P^2(V)\big)$, … , $P^n(V) = P\big(P^{n-1}(V)\big)$, for $1 \leq n \leq \infty$. Where it is also defined as $P^0(V) = V$.

An n-SuperHyperGraph (*n-SHG*) is an ordered pair $n - SHG = (G_n, E_n)$, where $G_n \subseteq P^n(V)$ and $E_n \subseteq P^n(V)$, for $1 \leq n \leq \infty$. Such that, G_n is the set of vertices and E_n is the set of edges.

G_n contains all possible types of vertices in the real world:

- *Single Vertices* (the classics),
- *Indeterminate Vertices* (unclear, vague, partially known),
- *Null Vertices* (empty, totally unknown),
- *SuperVertex* (or *SubsetVertex*) contains two or more vertices of the above types put together as a group (organization).
- *n- SuperVertex* which is a collection of vertices, where at least one of them is a *(n-1) - SuperVertex,* and the others can be *r- SuperVertex* for $r \leq$ n.

E_n contains the following types of edges:

- *Single Edges* (the classics),
- *Indeterminate Edges* (unclear, vague, partially known),
- *Null Edges* (totally unknown, empty),
- *HyperEdge* (connecting three or more single vertices),
- *SuperEdge* (connecting two vertices, at least one of them is a SuperVertex),
- *n-SuperEdge* (connecting two vertices, at least one of them is an n- SuperVertex and may contain another that is an r-SuperVertex with $r \leq$ n).
- *SuperHyperEdge* (connects three or more vertices, where at least one of them is a SuperVertex),
- *n-SuperHyperEdge* (contains three or more vertices, at least one of which is an n-SuperVertex and may contain an r-SuperVertex with $r \leq$ n),
- *MultiEdge* (two or more edges connecting the same two vertices),
- *Loop* (an edge that connects an element to itself),

Graphs are classified as follows:

- Directed Graph (the classic one),
- Undirected Graph (the classic one),
- Neutrosophic Directed Graph (partially directed, partially undirected, partially indeterminate directed).

Within the framework of the theory of Plithogenic n-SuperHyperGraphs, there are the following concepts:

Enveloping vertex: A vertex representing an object comprising attributes and sub-attributes in the graphical representation of a multi-attribute decision-making environment.

SuperEnveloping vertex: An enveloping vertex comprises of SuperHyperEdges.

Dominant Enveloping Vertex: An enveloping vertex that is with dominant attribute values.

Dominant Super Enveloping Vertex: A super enveloping vertex with dominant attribute values.

Dominant Enveloping Vertex is classified into *input*, *intervention,* and *output* based on the nature of the object's representation.

Plithogenic Connectors: The connectors associate the input enveloping vertex with the output enveloping vertex. These connectors associate the effects of input attributes with output attributes and these connectors are weighted by plithogenic weights.

2.2 Multi-Way Contingency Tables

A multi-way contingency table is a contingency table defined for two or more cross-ratio classification variables. Two-dimensional tables are generally called contingency tables, while the term multi- is applied when the number of variables is at least three [17].

A *Generic Multi-Way Table* is defined using $I = I_1 \times I_2 \cdots \times I_q$ as the set of indices for each variable to be studied $X_1, X_2, \cdots, X_q$, such that I_j is the set of indices corresponding to the possible classifications of the jth variable. Thus, $n_{i_1 i_2 \cdots i_q}$ is the frequency of occurrence of the classifications $i_1, i_2, \cdots, i_q$ for each of the corresponding variables.

The *Partial/Conditional Tables* involve fixing the category of one of the variables. Fixed variables are denoted in parentheses. For example, the XZ and YZ-partial tables are denoted by $n_{i(j)k}$ and $n_{(i)jk}$, respectively. Also, the *Partial/Conditional Probabilities* are calculated by $\pi_{ij(k)} = \pi_{\frac{ij}{k}} = Prob\left(X = i, Y = \frac{j}{Z} = k\right)$. *Partial/Conditional Proportions* are defined by $p_{ij(k)} = p_{\frac{ij}{k}} = \frac{\pi_{ijk}}{\pi_{++k}}$ for $k = 1, 2, \dots, K$. Where π_{++k} is the frequency for i and j setting k, for more information see.

Below, there is a brief explanation of what log-linear models consist of. To simplify the exposition, the case of the three-way contingency table is chosen. If X, Y, and Z are the variables, then the following possible models are obtained [16, 17]:

- Model (X, Y, Z): All variables are considered independent, the model is as follows:

$$\ln F_{ij} = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z \quad (1)$$

- Model (X, YZ): Only the YZ association is considered, while X is independent of the other two variables.
  $$\ln F_{ij} = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z + \lambda_{jk}^{YZ} \quad (2)$$
- Model (XY, YZ): X and Z are independent for each value of Y:
  $$\ln F_{ij} = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z + \lambda_{ij}^{XY} + \lambda_{jk}^{YZ} \quad (3)$$
- Model (XY, YZ, XZ): There is a pair-wise association between all variables, but there is no joint association between the three.
  $$\ln F_{ij} = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z + \lambda_{ij}^{XY} + \lambda_{ik}^{XZ} + \lambda_{jk}^{YZ} \quad (4)$$
- Model (XYZ): If the above model does not fit the data well, then the association between the three variables should be considered:
  $$\ln F_{ij} = \lambda + \lambda_i^X + \lambda_j^Y + \lambda_k^Z + \lambda_{ij}^{XY} + \lambda_{ik}^{XZ} + \lambda_{jk}^{YZ} + \lambda_{ijk}^{XYZ} \quad (5)$$

To contrast two different models, the statistic called *likelihood ratio is used*, which is calculated as:

$$G^2 = 2\sum f ln\left(\frac{f}{F}\right) \quad (6)$$

Where f is the observed frequency and F is the expected frequency according to the model. This statistic is distributed according to a chi-square under the hypothesis that the model is correct, with degrees of freedom depending on the parameters used to fit the model.

3 The Study

Sample: For the selection of the sample, a proportional stratified random sampling method was used, ensuring adequate representation of users under different irrigation implementation conditions. The sample consisted of 60 agricultural production units (UPA), selected from a total of 569 UPAs in the target population. In this calculation, the following parameters were assumed: the probability of success (P) was set at 0.5, and the probability of error (Q) was also set at 0.5, ensuring an optimal confidence level for the representativeness of the sample.

Weighting and consensus of the results: The weighting of the parameters was carried out through a consensus process, in which experts in the field were consulted. They assigned a value to each attribute based on the relative relevance of the parameters considered in the selected indicators (see Tables 1 and 2).

Table 1: Assessment elements. Source: Own elaboration.

Scale	Assessment	Level of sustainability
0	Very critical or extreme level of sustainability.	Extreme
1	Low or critical level of sustainability of production units.	Critical
2	Minimum sustainability threshold of production units.	Weak
3	Medium level of sustainability.	Medium
4	Maximum threshold at a high level of sustainability of production units.	High

Table 2: Sustainability levels. Source: Own elaboration.

Level of sustainability	Very critical	Low sustainability	Minimum sustainability	Medium sustainability	High sustainability
Decision criteria on a scale of 0 to 4	< a 1	1 to 2.4	2.41 to 2.9	2.91 to 3.4	3.41 to 3.9

Vertex, vertex attributes, vertex sub-attributes, and vertex sub sub-attributes: In this study, the vertices (V) are represented by the different dimensions influencing the irrigation systems in the Pujilí region, covering the economic, environmental, and socio-cultural areas. The dominant envelope of this problem is related to the attributes and sub-attributes of the following categories: economic, environmental, and socio-cultural, as well as their respective frequencies (see Table 3).

V_1 = Economic dimension
V_2 = Environmental dimension
V_3 = Socio-cultural dimension
Attribute sets = {Economic dimension, Environmental dimension, Socio-cultural dimension}.

Table 3: Absolute frequency obtained for each vertex, vertex attributes, and sub-attributes. Source: Own elaboration.

Vertex	Vertex attributes	Vertex sub-attributes	Vertex sub-sub-attributes	Frequency
Economic (V_1)	Food sovereignty (V_{11})	Extreme		3
		Critical		7
		Weak		25
		Medium		25
		High		0
	Economic profitability (V_{12})	Extreme		0
		Critical		3
		Weak		12
		Medium		30
		High		15
	Economic risk (V_{13})	Extreme		13
		Critical		14
		Weak		12
		Medium		15
		High		6
Environmental (V_2)	Conservation of soil life (V_{21})	Ground cover (V_{211})	Extreme	2
			Critical	2
			Weak	8
			Medium	35
			High	13
		Crop residue management (V_{212})	Extreme	0
			Critical	5
			Weak	11
			Medium	15
			High	29
		Crop diversification (V_{213})	Extreme	6
			Critical	11
			Weak	18
			Medium	15
			High	10
		Water supply (V_{214})	Extreme	2
			Critical	1
			Weak	18
			Medium	19

Vertex	Vertex attributes	Vertex sub-attributes	Vertex sub-sub-attributes	Frequency
			High	20
		Air pollution level (V_{215})	Extreme	0
			Critical	13
			Weak	17
			Medium	30
			High	0
	Risk of erosion (V_{22})	Predominant slope (V_{221})	Extreme	1
			Critical	13
			Weak	23
			Medium	15
			High	8
		Vegetation cover (V_{222})	Extreme	7
			Critical	13
			Weak	25
			Medium	12
			High	3
		Soil conservation works (V_{223})	Extreme	1
			Critical	2
			Weak	17
			Medium	25
			High	15
		Soil typology (V_{224})	Extreme	1
			Critical	11
			Weak	22
			Medium	10
			High	16
	Biodiversity management (V_{23})	Spatial biodiversity (Biodiversity and crop use) (V_{231})	Extreme	2
			Critical	12
			Weak	24
			Medium	16
			High	6
		Temporary biodiversity (Use of agroforestry) (V_{232})	Extreme	1
			Critical	11
			Weak	16
			Medium	16
			High	16
		Ecological management of pests and diseases (V_{233})	Extreme	1
			Critical	1
			Weak	2
			Medium	15
			High	41
		Local or improved seed diversity (V_{234})	Extreme	3
			Critical	3
			Weak	7
			Medium	10
			High	37
			Extreme	4

Vertex	Vertex attributes	Vertex sub-attributes	Vertex sub-sub-attributes	Frequency
		Property Succession Management (V_{235})	Critical	13
			Weak	24
			Medium	17
			High	2
Social-cultural (V_3)	Satisfaction of basic needs (V_{31})	Access to health and health coverage (V_{311})	Low coverage	7
			Medium coverage	28
			High coverage	25
		Housing (V_{312})	Critical conditions	5
			Poor conditions	30
			Optimal conditions	25
	Acceptability of the production system (V_{32})	Low acceptability		0
		Moderate acceptability		0
		High Acceptability		60
	Integration into organizational systems (V_{33})	Low		41
		Average		14
		High		5
	Ecological knowledge and awareness ()V_{34}	Low		41
		Average		10
		High		9
	Tourism potential ()V_{35}	Low		14
		Average		31
		High		15

Table 3 presents the sustainability of the agricultural production system in three main vertices: economic, environmental, and socio-cultural. In the economic vertex, sustainability shows strengths in profitability, while economic risk is concentrated at critical levels, suggesting financial vulnerabilities that require attention. Meanwhile, in the environmental vertex, good practices in soil conservation and waste management are observed, but risks of erosion and variability in water supply persist, as these factors compromise long-term sustainability. However, in the socio-cultural vertex, the high acceptability of the production system is an advantage, although low ecological awareness and weak organizational integration represent areas for improvement. These results indicate the need for specific interventions to strengthen sustainability in critical areas and maintain existing strengths, thus achieving a comprehensive balance that favors system resilience.

To simplify the method, three-way contingency tables were used, allowing the examination of how different attributes relate within the social, economic, and environmental vertices. In each case, the G^2 coefficient was calculated to evaluate the intensity of interactions between the vertex attributes and their impact on the sustainability of the irrigation systems. A summary of the results obtained from this analysis is presented below (see Table 4).

Table 4: G^2 result of the processed models. Source: Own elaboration.

Model	G^2	Model	G^2	Model	G^2
v11* v21* v211	0.53387767	v12* v21* v211	0.07178898	v13* v21* v211	0.51354438
v11* v21* v212	0.88022916	v12* v21* v212	0.3611417	v13* v21* v212	0.8633287
v11* v21* v213	0.32416714	v12* v21* v213	0.25033138	v13* v21* v213	0.14454299
v11* v21* v214	0.58257722	v12* v21* v214	0.21431717	v13* v21* v214	0.68953039

v11*	v21*	v215	0.13292064	v12*	v21*	v215	0.12674366	v13*	v21*	v214	0.40037058
v11*	v22*	v221	0.27624909	v12*	v22*	v221	0.18219062	v13*	v22*	v215	0.29821965
v11*	v22*	v222	0.20498465	v12*	v22*	v222	0.37478081	v13*	v22*	v221	0.07388026
Model			**G^2**	**Model**			**G^2**	**Model**			**G^2**
v11*	v22*	v223	0.43860016	v12*	v22*	v223	0.04848691	v13*	v22*	v222	0.60701032
v11*	v22*	v224	0.51594351	v12*	v22*	v224	0.34520369	v13*	v22*	v223	0.47576924
v11*	v23*	v231	0.19771223	v12*	v23*	v231	0.17077222	v13*	v23*	v224	0.22130034
v11*	v23*	v232	0.46845231	v12*	v23*	v232	0.20274568	v13*	v23*	v231	0.41933184
v11*	v23*	v233	1.4774075	v12*	v23*	v233	0.77877943	v13*	v23*	v232	1.32022421
v11*	v23*	v234	1.17201392	v12*	v23*	v234	0.70106735	v13*	v23*	v233	0.94952424
v11*	v23*	v235	0.10495879	v12*	v23*	v235	0.23693938	v13*	v23*	v234	0.10806506
v11*	v31*	v311	1.22739172	v12*	v31*	v311	0.49178911	v13*	v31*	v235	1.08216903
v11*	v31*	v312	1.23772781	v12*	v31*	v312	0.47163422	v13*	v31*	v311	1.13491694
v11*	v32		2.77258872	v12*	v32		1.97972803	v13*	v32		2.44333893
v11*	v33		1.25925443	v12*	v33		0.91251033	v13*	v33		0.79308002
v11*	v34		1.40994678	v12*	v34		1.01691775	v13*	v34		0.87986628
v11*	v35		1.04388895	v12*	v35		0.40624927	v13*	v35		0.85068087

The analysis of Table 4, based on the G^2 coefficient, shows key interactions between economic, environmental, and socio-cultural factors in agricultural irrigation systems. These interactions highlight that strengthening biological pest management and biodiversity can optimize both food sovereignty and economic profitability. Improving biodiversity and succession planning reduces economic risk and promotes system resilience. Additionally, the high acceptability of the production system by the community emphasizes the need for sustainable practices that foster long-term social cohesion.

Regarding the sustainability vertices, the socio-cultural vertex achieves the highest sustainability index with a value of 2.70, highlighting social acceptance and access to essential services as pillars of sustainability in the agricultural system. It is followed by the environmental vertex with 2.63, reflecting progress in soil and biodiversity management, though with room for improvement. Finally, the economic vertex shows the lowest value (2.31), indicating the need to strengthen profitability and mitigate economic risks. Therefore, the vertices are within the sustainability acceptance zone.

Regarding the dominant attributes in each vertex, these include economic profitability in the economic vertex (2.95), ecological pest and disease management in the environmental vertex (3.57), and the acceptability of the production system in the socio-cultural vertex (4). These results indicate that, for integral sustainability, it is essential to balance the economic and environmental dimensions while strengthening social cohesion.

Measures to enhance sustainability in the San Juan-Patoa River sectors are:

- Economic: Promote the use of organic inputs and strengthen agroecological producer associations to optimize marketing and improve prices. Additionally, it is essential to strengthen institutions that support the agricultural sector and offer training in the economic-financial field.
- Environmental: Implement irrigation technology to prevent the loss of vegetation cover and train producers in environmental protection practices and agro-ecological production, while improving crop rotation to prevent soil erosion.
- Socio-cultural: Encourage community integration into organizational systems through the support of governmental institutions. Additionally, promote entrepreneurial projects to open new markets, create employment, and strengthen social and economic ties.

4. Conclusion

The study has demonstrated that in agricultural irrigation systems, the interaction of economic, environmental, and socio-cultural factors is key to achieving sustainability. Through the use of plithogenic n-SuperHyperGraphs that combine main vertices, dominant attributes in each dimension were identified. The acceptability of the production system and ecological pest management, as well as biodiversity, were highlighted for their significant contribution to sustainable balance. The results have shown that, although economic profitability is fundamental, its effect is limited when evaluated without considering other factors, thus emphasizing the priority of an interdisciplinary approach in agricultural management. The developed methodology, represents an advance in the comprehensive evaluation of sustainability, providing a replicable and adaptable model to different local environments, and facilitating agricultural resilience in diverse study areas.

References

[1] A. V. P. Peralta, S. A. G. Rivera, M. G. Tobar-Ruiz, M. E. Sánchez-Salazar, P. D. C. Oscullo, and L. F. M. Ñuste, "Typology and characterization of the agricultural productive units in the NE Amazonian region of Ecuador," (in eng), *J Adv Vet Anim Res,* vol. 11, no. 1, pp. 171-180, Mar 2024. [Online]. Available: https://pmc.ncbi.nlm.nih.gov/articles/PMC11055592/.

[2] F. Calizaya *et al.*, "Unveiling Ancestral Sustainability: A Comprehensive Study of Economic, Environmental, and Social Factors in Potato and Quinoa Cultivation in the Highland Aynokas of Puno, Peru," *Sustainability,* vol. 15, no. 17, p. 13163, 2023. [Online]. Available: https://www.mdpi.com/2071-1050/15/17/13163.

[3] M. Vizuete-Montero, P. Carrera-Oscullo, N. D. L. M. Barreno-Silva, M. Sánchez, H. Figueroa-Saavedra, and W. Moya, "Agroecological alternatives for small and medium tropical crop farmers in the Ecuadorian Amazon for adaptation to climate change," *Agricultural Systems,* vol. 218, no. June pp. 1-4, 2024/06/01/ 2024. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0308521X24001483.

[4] L. Toledo, G. Salmoral, and O. Viteri-Salazar, "Rethinking Agricultural Policy in Ecuador (1960–2020): Analysis Based on the Water–Energy–Food Security Nexus," *Sustainability,* vol. 15, no. 17, p. 12850, 2023. [Online]. Available: https://www.mdpi.com/2071-1050/15/17/12850.

[5] P. Carrión-Mero *et al.*, "Water Quality from Natural Sources for Sustainable Agricultural Development Strategies: Galapagos, Ecuador," *Water,* vol. 16, no. 11, p. 1516, 2024. [Online]. Available: https://www.mdpi.com/2073-4441/16/11/1516.

[6] Y. Zhu, Y. Zhang, L. Ma, L. Yu, and L. Wu, "Simulating the dynamics of cultivated land use in the farming regions of China: A social-economic-ecological system perspective," *Journal of Cleaner Production,* vol. 478, no. November, p. 143907, 2024/11/01/ 2024. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0959652624033560.

[7] Q. Ji, X. Feng, J. Zhang, and B. Fu, "Uncovering leveraging and hindering factors in socio-ecological interactions: Agricultural production in the Yellow River Basin as an example," *Journal of Environmental Management,* vol. 368, no. September, p. 122197, 2024/09/01/ 2024. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0301479724021832.

[8] G. Herrera-Franco *et al.*, "Water Sowing and Harvesting (WS&H) for Sustainable Management in Ecuador: A Review," *Heritage,* vol. 7, no. 7, pp. 3696-3718, 2024. [Online]. Available: https://www.mdpi.com/2571-9408/7/7/175.

[9] R. Devi and G. Muthumari, "Properties on Topologized Domination in Neutrosophic Graphs," *Neutrosophic Sets and Systems,* vol. 47, no. 1, p. 32, 2021. [Online]. Available: https://digitalrepository.unm.edu/cgi/viewcontent.cgi?article=1996&context=nss_journal.

[10] F. Smarandache, "Plithogeny, Plithogenic Set, Logic, Probability and Statistics: A Short Review," *Journal of Computational and Cognitive Engineering,* vol. 1, no. 2, pp. 47-50, 2022. [Online]. Available: http://ojs.bonviewpress.com/index.php/JCCE/article/view/191.

[11] L. Naranjo *et al.*, "A scenario-specific nexus modelling toolkit to identify trade-offs in the promotion of sustainable irrigated agriculture in Ecuador, a Belt and Road country," *Journal of Cleaner*

Production, vol. 413, no. August, p. 137350, 2023/08/10/ 2023. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0959652623015081.

[12] M. Luna and L. Barcellos-Paula, "Structured Equations to Assess the Socioeconomic and Business Factors Influencing the Financial Sustainability of Traditional Amazonian Chakra in the Ecuadorian Amazon," *Sustainability,* vol. 16, no. 6, p. 2480, 2024. [Online]. Available: https://www.mdpi.com/2071-1050/16/6/2480.

[13] P. Khatri, P. Kumar, K. S. Shakya, M. C. Kirlas, and K. K. Tiwari, "Understanding the intertwined nature of rising multiple risks in modern agriculture and food system," *Environment, Development and Sustainability,* vol. 26, no. 9, pp. 24107-24150, 2024/09/01 2024. [Online]. Available: https://doi.org/10.1007/s10668-023-03638-7.

[14] L. J. Reales-Chacón *et al.*, "Study of the Efficacy of Neural Mobilizations to Improve Sensory and Functional Responses of Lower Extremities in Older Adults with Diabetic Peripheral Neuropathy Using Plithogenic n-SuperHyperGraphs," *Neutrosophic Sets and Systems,* vol. 74, no. Special, pp. 1-12, 2024. [Online]. Available: https://fs.unm.edu/nss8/index.php/111/article/view/5191.

[15] M. Rahmati and M. Hamidi, "On Strong Super Hyper EQ Algebras: A Proof-of-Principle Study," *Plithogenic Logic and Computation,* vol. 2, no. August, pp. 29-36, 08/04 2024. [Online]. Available: https://sciencesforce.com/index.php/plc/article/view/351.

[16] F. Smarandache, "Foundation of SuperHyperStructure & Neutrosophic SuperHyperStructure," *Neutrosophic Sets and Systems,* vol. 63, no. 1, p. 21, 2024. [Online]. Available: https://digitalrepository.unm.edu/cgi/viewcontent.cgi?article=2577&context=nss_journal.

[17] M. Hamidi, F. Smarandache, and E. Davneshvar, "Spectrum of superhypergraphs via flows," *Journal of Mathematics,* vol. 2022, no. 1, pp. 1-10, 2022. [Online]. Available: https://onlinelibrary.wiley.com/doi/full/10.1155/2022/9158912.

Received: July 04, 2024. Accepted: September 14, 2024