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Integration of Fuzzy Set Theory and Neutrosophic Sets for Qualitative and Quantitative Analysis in Inclusive Service to Native Communities of Ucayali

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Abstract. This research focuses on the examination of public records and their potential to deliver inclusive service to the native populations of Ucayali, a key difficulty in the administration of public services in varied and culturally rich areas. The study tackles a gap in the current literature, where standard techniques do not effectively examine how transparency and sufficiency of services influence inclusive service quality. Using methodologies based on neutrosophic set theory, the research presents a novel way to examine the efficacy and accessibility of public registry services in a particular cultural setting. The findings reveal that the combination of Management Transparency (TG) and Service Adequacy (ADS) has a considerable beneficial influence on Inclusive Service Quality (CSI). This research underlines the necessity of tackling both aspects concurrently to enhance service quality. The contribution of the study is twofold: first, it advances theoretical knowledge by integrating advanced methods for evaluating public services in multicultural contexts; Second, it provides concrete practical recommendations, such as administrative simplification, cultural training of staff, and infrastructure improvement, that can be implemented to make public registry services more accessible and effective for the native communities of Ucayali.

Keywords: Native Communities, Set Theoretical Methods, SQA, Fsqca, Neutrosophic Sets, Public Records.

1 Introduction

In the context of public administration and access to important services, the inclusion of Aboriginal communities in the public records system is of crucial relevance. This research focuses on the assessment of the efficacy and degree of inclusion of public records services for the native populations of Ucayali, utilizing methodologies based on neutrosophic set theory. This problem is significant given that effective inclusion in public registers not only provides access to rights and services but is also a key component for social development and administrative justice [1]. As public policies become more integrative, there is a need to understand how they are being implemented in specific contexts and whether these policies are truly reaching the populations they are targeted at [2]. Historically, public records have grown from basic handwritten annotations to more technologically advanced systems [3]. In the past, a lack of infrastructure and resources hampered access and participation, particularly in distant areas and for indigenous groups. With the growth of technology and rising awareness of the need for inclusive services, several nations have undertaken attempts to upgrade these systems [4]. However, despite these efforts, persistent impediments continue to impede the capacity of Native people to receive these services successfully [5]. Ucayali, in

particular, represents an interesting case due to its cultural diversity and specific challenges in terms of accessibility and adequacy of public records services [6].

The central problem of this study can be formulated as follows: How can the effectiveness of public records be evaluated in terms of their inclusive service for the native communities of Ucayali, considering the complexity and diversity of their needs? Despite attempts to increase inclusion and access, existing evaluations frequently do not effectively reflect the lived experience of these populations and the unique hurdles they confront [7]. This work tackles this gap by employing approaches based on neutrosophic set theory to give a more thorough and nuanced evaluation. The aims of this research are, first of all, to assess the performance of the public records service in terms of inclusion and accessibility for the local populations of Ucayali using neutrosophic methodologies. Second, it aims to identify particular challenges that impact these populations and make practical solutions to promote inclusion and access. Finally, the purpose is to present an assessment methodology that may be utilized in other comparable situations to enhance the quality and equality of public services.

2. Preliminaries.

2.1. Public Records.

Public records are a crucial part of contemporary administration, representing rights, properties, and transactions that shape people's everyday lives. They serve as a formal framework for encapsulating and consolidating various aspects of society, such as property ownership and birth registration. Public records are essential for preventing confusion and promoting legal clarity, as they help in transferring rights and preventing legal confusion [8].

The history of public records dates back to ancient civilizations, with recording technologies evolving. However, these systems often face challenges such as lack of access, corruption, and inefficiency. To address these issues, it is essential to study how public records can be improved, including the use of emerging technologies like blockchain and digitization of documents. However, the adoption of these solutions must be carefully regulated to prevent exclusion or inequity [9].

Inclusion of all individuals, particularly those living in disadvantaged or rural regions, is a key feature of public records. Policies should focus on reducing obstacles that hinder individuals from obtaining registration services, ensuring no gaps perpetuate inequality. Data protection and secrecy are also crucial aspects of public records, and comprehensive procedures must be developed to secure information from illegal access and misuse. Collaboration between government bodies and the private sector is essential for the efficacy of public records. This comprehensive strategy should include the introduction of new technology, inclusion, and privacy.

2.2. Complexity and causality theory and neutrosophic sets.

Relationships between variables are typically more difficult than they appear and often express via patterns that are neither simple nor linear, as complexity theory argues [10]. This indicates that the same element might have distinct consequences depending on the context in which it happens. In this theory, three fundamental concepts stand out: conjunction, equifinality, and causal asymmetry:

- **Conjunction:** This concept focuses on the notion that numerous elements must work together to achieve an outcome, rather than working alone. In other words, the result is usually the result of the combination of different preconditions that interact with each other.
- **Equifinality:** According to this principle, a system can reach the same final state through different paths and initial conditions. That is, there is no single way to reach a certain result; Different trajectories can lead to the same endpoint.

- **Causal asymmetry:** This principle states that while certain conditions can contribute to the occurrence of a result, the absence of those conditions does not guarantee that the result will not occur

This shows that the relationship between factors is complex and non-linear. These principles emphasize that the connection between conditions and outcomes is complex and not always predictable. Furthermore, neutrosophy offers a valuable perspective for understanding these complicated relationships by incorporating the indeterminacy and uncertainty that are inherent to social phenomena [11]. Neutrosophic set theory, with its ability to handle ambiguity, provides a more nuanced and deeper view of causality in these complex contexts.

2.3. Neutrosophic Liker Scales

Surveys employing neutrosophy Likert scales [12, 13, 14] proficiently assess the variability of opinions and their impact on public policy and social discourse, delineating areas of consensus, dissent, and ambivalence.

We give the essential definitions and notions pertaining to neutrosophic sets and single-valued neutrosophic sets.

Definition 1 ([15]). Let U be a discursive universe. N ={(x , T (x), I (x), F (x)): $x \in U$ } is a neutrosophic set, denoted by a truth membership function, $TN : U \rightarrow]0^-, 1^+[$; an indeterminacy membership function, $IN : U \rightarrow]0^-, 1^+[$; and a falsity membership function, $FN : U \rightarrow]0^-, 1^+[$.

Single-valued neutrosophic sets provide a way to represent and analyze possible elements in the universe of discourse U

Definition 2 ([16, 17]). Let U be a discursive universe. A single-valued neutrosophic set is defined as N ={(x , T (x), I (x), F (x)): $x \in U$ }, which is identified by a truth membership function, $TN : U \rightarrow [0, 1]$; indeterminacy membership function, $IN : U \rightarrow [0, 1]$; and falsity membership function, $FN : U \rightarrow [0, 1]$, with $0 \leq TN(x) + IN(x) + FN(x) \leq 3$

Responses are categorized based on the aggregate of the True, Indeterminate, and False components utilizing neutrosophic scales with single value neutrosophic sets.:

- T+I+F<1: Incomplete
- T+I+F=1: Complete
- T+I+F>1: Contradictory

These values are derived due to the frequent incompleteness or contradictions in the opinions. This classification is a benefit of employing neutrosophic approaches, as it facilitates a more nuanced comprehension of varying degrees of truth, indeterminacy, and falsity in responses.

3. Proposed framework

Each stage of the diagram is accompanied by a brief explanation that facilitates the general understanding of the process. The steps involved in the proposed methodology are broken down below:

Definition of the result: The first stage involves identifying and precisely describing the specific phenomenon, event, or condition that you want to investigate. This phase is essential because it establishes the focus and framework for all subsequent analyses. Clearly defining the outcome not only focuses the study on what you want to examine but also provides a solid foundation on which to build the subsequent stages of the analysis.

Development of neutrosophic Likert scales: In this phase, neutrosophic Likert scales are designed to measure both the result and the associated variables. Unlike traditional Likert scales, which use a fixed range of values (e.g., 1 to 5) to evaluate responses, neutrosophic scales introduce an additional dimension by including elements of truth, indeterminacy, and falsehood. Each option on the scale is expressed by a triplet (T, I, F), where T represents the degree of truth, I the degree of indeterminacy, and F is the degree of falsehood. This approach provides a more nuanced and detailed interpretation of participants' responses and attitudes, allowing the complexity of their opinions to be captured more accurately.

Data collection: The final stage consists of collecting relevant data on the cases in question, using a variety of indicators or measures that are related to the defined outcome. It is essential that the data be complete and accurately reflect the variables being studied. For this collection, neutrosophic Likert scales will be used in questionnaires and surveys. This method not only provides a richer data set, but also allows the complexity of respondents' opinions and attitudes to be captured in a more sophisticated way. The use of neutrosophic scales facilitates a deeper and more detailed understanding of the perceptions and responses of the participants, helping to unravel the complexity inherent to the phenomenon investigated.

Fuzzification: Finally, the obtained neutrosophic sets are transformed into equivalent fuzzy sets, following the procedure described in [18]. This step is essential for subsequent analysis, allowing you to handle the uncertainty and ambiguity inherent in the collected data. Be $AN = \{x, (TA(x), IA(x), FA(x)) : x \in X\}$a NS. Its equivalent fuzzy membership set is defined as $AF = \{(x, \mu A(x)) : x \in X\}$,where $\mu A(x) = s\left((TA(x), IA(x), FA(x)), (1,0,0)\right)$. So, using the similarity equation proposed in,

$$\mu A(x) = 1 - \frac{1}{2}[(1 - T_A(x)) + \max\{I_A(x), F_A(x)\}] \quad (1)$$

Since the range of the similarity measure function is the unit interval [0,1], μA(x) ∈ [0,1] for all x ∈ X. Therefore, the membership function of the derived fuzzy set belongs to [0,1] and therefore satisfies the property of a membership function of a fuzzy set (FS).

Analysis: Conduct fsQCA to determine the combinations of factors or conditions linked to the presence or extent of the outcome. The fsQCA software for Windows is utilized for data processing. [19].

The configuration's validity is assessed by measuring consistency and coverage values. Consistency quantifies the reliability of the pathways in generating the intended outcome. Coverage denotes the extent to which the outcome is elucidated by this configuration of paths. [20]:

$$Consistency\ (Y_i \leq X_i) = \frac{\sum \min(X_i, Y_i)}{\sum Y_i} \quad (2)$$

$$Coverage\ (Y_i \leq X_i) = \frac{\sum \min(X_i, Y_i)}{\sum X_i} \quad (3)$$

where:

$X_i$is the membership value of case i in the set of causal conditions.

$Y_i$is the membership value of case iii in the result set.

Both are employed in comparative analysis to assess the links formed between individual conditions, combinations of conditions, path configurations, and the outcome. Values exceeding 0.8 are typically regarded as signs of a robust association. [21].

4. Results.

For the study of public records and their inclusive service to the native communities of Ucayali, applying research methods based on the theory of neutrosophic sets, here is a simulated case with all the necessary calculations and data:

Definition of the Result

Defined result: Inclusive Service Quality (CSI).

Variables considered:

- **Access to Public Records (ARP):** Measurement of the ease with which native communities can access public records.
- **Adequacy of Services (ADS):** Evaluates the adequacy of the services offered in terms of inclusion and cultural adaptation.
- **Management Transparency (TG):** The degree to which the management of public records is transparent and accessible to native communities.

Community Survey

A survey was conducted with a group of 10 community leaders in Ucayali. The results are presented in Table 1.

Table 1. Survey Data

Leader	Access to Public Records (ARP)	Adequacy of Services (ADS)	Transparency in Management (TG)	Inclusive Service Quality (CSI)
1	(0.7, 0.2, 0.1)	(0.6, 0.3, 0.1)	(0.8, 0.1, 0.1)	(0.7, 0.2, 0.1)
2	(0.5, 0.4, 0.1)	(0.7, 0.2, 0.1)	(0.6, 0.3, 0.1)	(0.6, 0.3, 0.1)
3	(0.6, 0.3, 0.1)	(0.8, 0.1, 0.1)	(0.7, 0.2, 0.1)	(0.7, 0.2, 0.1)
4	(0.4, 0.5, 0.1)	(0.5, 0.4, 0.1)	(0.6, 0.3, 0.1)	(0.5, 0.4, 0.1)
5	(0.8, 0.1, 0.1)	(0.6, 0.3, 0.1)	(0.9, 0.1, 0.0)	(0.8, 0.1, 0.1)
6	(0.5, 0.4, 0.1)	(0.7, 0.2, 0.1)	(0.6, 0.3, 0.1)	(0.6, 0.3, 0.1)
7	(0.7, 0.2, 0.1)	(0.5, 0.4, 0.1)	(0.7, 0.2, 0.1)	(0.7, 0.2, 0.1)
8	(0.6, 0.3, 0.1)	(0.7, 0.2, 0.1)	(0.8, 0.1, 0.1)	(0.7, 0.2, 0.1)
9	(0.5, 0.4, 0.1)	(0.6, 0.3, 0.1)	(0.5, 0.4, 0.1)	(0.6, 0.3, 0.1)
10	(0.7, 0.2, 0.1)	(0.5, 0.4, 0.1)	(0.6, 0.3, 0.1)	(0.6, 0.3, 0.1)

Fuzzification is performed using Equation 1 to convert the neutrosophic sets to equivalent fuzzy sets.

Table 2. Fuzzy Values

Leader	Access to Public Records (ARP)	Adequacy of Services (ADS)	Transparency in Management (TG)	Inclusive Service Quality (CSI)
1	0.60	0.50	0.85	0.60
2	0.50	0.60	0.65	0.60
3	0.55	0.80	0.75	0.55
4	0.50	0.50	0.65	0.50
5	0.80	0.60	0.90	0.80
6	0.50	0.60	0.65	0.60
7	0.60	0.50	0.70	0.60
8	0.55	0.60	0.85	0.55
9	0.50	0.60	0.55	0.60
10	0.60	0.50	0.65	0.60

The consistency and coverage of the conditions are analyzed using fsQCA.

Table 3. Analysis of Necessary Conditions

Tested conditions	Consistency	Coverage
Access to Public Records (ARP)	0.5357	0.5857
Adequacy of Services (ADS)	0.5786	0.6000
Transparency in Management (TG)	0.6500	0.6571
Inclusive Service Quality (CSI)	0.6057	0.6286

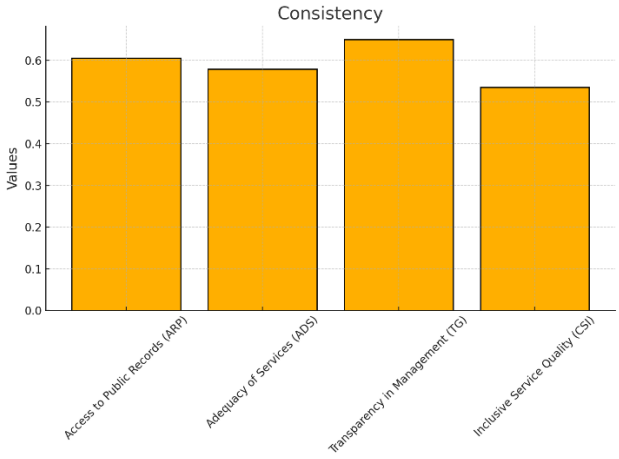

Figure 1. Analysis of Necessary Conditions (Consistency)

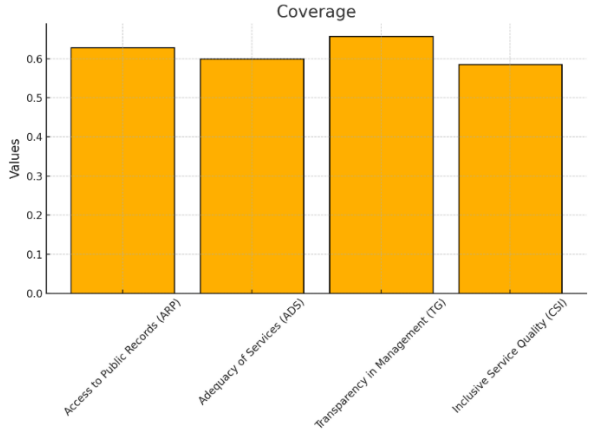

Figure 2. Analysis of Necessary Conditions (Coverage)

Set Coincidence Analysis

Table 4. Set Coincidence Analysis

Conditions	Coincidence
ARP, ADS, TG	0.5500
ARP, ADS	0.5250
ARP, T.G.	0.5700
A.D.S., T.G.	0.5850

Superset Analysis

Table 5. Results of Superset/Superset Analysis

Terms	Consistency	Coverage	Set
ARP, ADS, TG	0.5357	0.5857	0.5607
ARP, ADS	0.5250	0.5500	0.5375
ARP, T.G.	0.5700	0.5750	0.5725
A.D.S., T.G.	0.5850	0.5900	0.5875
ARP	0.5357	0.5700	0.5529
ADS	0.5786	0.6000	0.5893
T.G.	0.6500	0.6571	0.6536

The investigation demonstrates that Management Transparency (TG) and Service Adequacy (ADS) have the highest influence on Inclusive Service Quality (CSI). The greatest matches are discovered in the combination of TG and ADS , showing that these parameters have a significant and positive association with the intended result. Based on the findings collected, the following steps are suggested:

- **Optimization of the Public Registry Process**

Administrative Simplification: It is proposed to simplify the administrative processes of public documents to promote access for native populations. This may involve digitizing records and building online platforms that enable communities to access services without

These findings suggest that Transparency in Management and Adequacy of Services are critical factors to improve Inclusive Service Quality. The high coincidence between TG and ADS implies that when both elements are treated well, a considerable gain in service quality is obtained. This may be because more openness and appropriateness in service management promotes more fair and effective access. Our findings are in accord with prior research that stresses the relevance of transparency and adequacy in service delivery. Previous studies has demonstrated that openness in public administration may promote user confidence and improve service efficiency. However, they vary from several research that has shown that openness alone is not enough without proper supporting infrastructure. Our research expands this approach by demonstrating that the combination of openness and sufficiency of services leads in a stronger influence on the quality of the included service. A key weakness of this research is the likely difference in the impression of service quality across various native populations. The absence of longitudinal data also limits determining long-term consequences. The findings imply that future studies should further examine how the combination of openness and appropriateness may be enhanced.

5. Conclusions

This research demonstrates that Management Transparency (TG) and Service Adequacy (ADS) have a considerable influence on Inclusive Service Quality (CSI). The research reveals that the combination of these elements causes a considerable increase in the quality of the service supplied to native populations. This conclusion shows the need of addressing these two characteristics simultaneously to optimize the efficacy of public services. The practical relevance of these results is considerable. Recommendations derived from our analysis, such as administrative simplification, staff training, and cultural adaptation of services, offer clear guidelines to improve the accessibility and efficiency of public records. Implementing these suggestions can facilitate more equitable access to services and better respond to the specific needs of Native communities, ultimately contributing to a more inclusive and effective service system. The study makes a significant contribution to the field by demonstrating how the combination of transparency and appropriateness in service management can substantially improve inclusive service quality. Although previous studies have highlighted the importance of each of these factors individually, our work expands this knowledge by showing how their joint interaction offers more robust results. This innovation in evaluation methodology and the identification of the most impactful factors provide a solid foundation for future research and practice in improving public services. However, the research has several limitations that must be noted. Variability in perceptions of service quality between different communities and lack of longitudinal data prevent a full assessment of long-term impact. These limitations should be taken into account when applying the results and designing additional research. For future research, it is recommended to explore complementary methods that can offer a broader perspective on how to optimize the combination of transparency and appropriateness in different contexts. Expanding the study to other regions and populations could also help validate and generalize these results, providing a more comprehensive view of improving inclusive public services. Continued evaluation and implementation of reforms based on these findings are crucial to ensuring that public record services are more accessible and effective in the future.

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