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EXPLAINING MUNICIPAL ENVIRONMENTAL REMEDIATION PERFORMANCE THROUGH INSTITUTIONAL CAPACITY PARTICIPATORY GOVERNANCE AND FUZZY DEMATEL ANALYSIS IN SOUTH INDIA

Arulmozhi R[1*], Cyril Mathew O[2]

[1] Research Scholar and Assistant Professor Department of Information Technology Al-Ameen Engineering College, Erode, Tamil Nadu, India Email: anbuarulmozhi@gmail.com
[2] Professor Department of Electronics and Communication Engineering (ECE) Al-Ameen Engineering College, Erode, Tamil Nadu, India Email: cyril.mathew421@gmail.com

Abstract: Effective environmental remediation requires not only strategic environmental assessment and pollution prediction but also capable local institutions that translate environmental priorities into coordinated administrative action. This study establishes a territorial framework that analyzes how six dimensions of governance (governance institutional capacity, coordination with intergovernmental agencies, citizen engagement, regulatory enforcement, financial resource availability, and digital environmental transparency) are interrelated and affect environmental remediation of municipalities in South India. Some research has focused on municipal sustainability, community environmental governance some have focused on, but the relation between the three is still not linked together within the same analytical approach. To overcome this issue, the study uses a Fuzzy DEMATEL, which provides support for handling uncertainties in judgments of experts and can detect causal relationships between dimensions of governance. Structured linguistic assessment instrument will be utilized to gather primary data from the municipal administrators, environmental practitioners, researchers, and governance practitioners. The analysis will separate out and display the cause and effect group dimension and its relationship with the other group will be understood. The proposed system will be able to give a systematic perspective of institutional and administrative arrangements linked to the process of remediation of the environment. The study is relevant to the field of environmental governance as it incorporates aspects of various dimensions of governance into a single analytical framework and a framework linking impacts to governance.

Keywords: Fuzzy DEMATEL; Environmental Governance; Municipal Environmental Remediation; Institutional Capacity; Intergovernmental Coordination; Digital Environmental Transparency.

1. Introduction

Environmental remediation is an integral component of sustainable development and pollution can affect community long-term liveability, public health, ecological integrity and economy. Urge that comes from the overgrowing pressure in public institutions to take preventive and corrective actions due to industrial emissions, mismanagement of waste, contamination of water and the worsening of the urban environment. Apart from these issues, other issues can be felt on the local level but are more specific to the local public (e.g. power outages), as well as the amount of local decisions that affect environment, land use, sanitation and waste management, environmental monitoring, and distribution of public services. Institutional-based measures that support plans and resources allocation, the implementation of rules and public accountability, should also be included in the realm of sustainable remediation, which should extend beyond what is technically viable. Local governments have a pivotal role in connecting environmental objectives and activities to the everyday efforts of government. In order to address the threats from the surroundings, their reactions are inter-agency coordination, intergovernmental cooperation and leveraging and local financial and technical resources and the involvement of the communities in environmental degradation issues. Institutional capacity is particularly significant if the environmental problem is trans-boundary, or if a particular investment will be required over a long period of time. Similarly, the inclusion of citizens and citizen access to the environment information can raise awareness in their locality of these issues and raise public monitoring of remedies projects. The policy and municipal climate adaptation research illustrates the importance

of building the capacities of the institutions to support the implementation of context-specific climate action from general sustainability goals (Salvador and Sancho, 2021; Glaas et al., 2022).

2. Related Work

The research of understanding the causal relationships between the barriers to implementing the Turkey zero-waste management system was also highlighted by Ayçin and Kaya (2021) to achieve goals in the transition towards circular economy. Likewise, Singh et al. (2022) used fuzzy DEMATEL to determine key success factors in the design of e-waste collection policies in India, which highlights the applicability of systematic decision making methods in the development of environmental policies. Jangre et al. (2022) applied F-DEMATEL and F-ISM to evaluate the sustainability of waste cooking oil-based biodiesel plants and Yadav et al. (2023) discussed the issues faced in the field of smart waste management in developing nations. Upon this research, Shanta et al. (2024) conducted mapping and research on the selection criteria for the technology used to manage MSW using Fuzzy Delphi and Fuzzy DEMATEL. Barriers to textile waste recycling in India were also explored using fuzzy DEMATEL by Ponnambalam et al. (2023), and the influence of stakeholders on sustainability in leather supply chain ecosystem was explored by Venkataraman and Rajkumar (2025). The results of these studies confirm the importance of causal modelling and structured multi-criteria analysis for addressing the complex problem of environmental governance, but do not focus on the seamless aspect of environmental governance across institutions, members of the public and the development of policy.

Institutional capacity is also a key aspect of environmental governance, as it relies on the administrative capacity, resources, coordination, and implementation of sustainability policies. Salvador and Sancho (2021) created an analytical framework that allows to analyze the institutional capabilities of local governments to support sustainable development policies. They highlight the need to evaluate the organisation's foundations needed to move policy goals into action. Kiliç and Yalçin (2021) introduced a method for comparative assessment of municipalities using uncertainty-aware decision-making which is based on neutrosophic DEMATEL and TOPSIS. The authors of Birchall et al. (2021) explored anticipatory planning in the context of climate adaptation governance and found that there is a need for balancing multiple interests in the face of environmental uncertainty. In their research paper (2022), Glaas et al. looked at capacities of municipal government to engage citizens in transformative initiatives of climate adaptation, with the aim of shedding light on the importance of organisational conditions influencing participative climate adaptation governance. Another example of the importance of administrative structures as vehicles to ‘living the SDGs’ is the study by Silva et al. (2023) which addresses the role of the local public administration in implementing the SDGs.

Local governance responsive and accountable to citizens has also been a major concern in the design. Rosilawati et al. (2022) undertook a quantitative study on citizen participation in local governance of health and sanitation and discovered that citizen engagement is crucial for effective public service delivery. Following this line of thought, Jäntti et al. (2023) considered citizen participation to be an issue of embedding participatory mechanisms into local government, and Kurkela et al. (2024) looked at citizen participation as an organisational problem in the public sector. The studies show that effective consultation processes are not only available in official form but that the organisation is ready, the administrative process is committed and the decision-making is ready to include the public's voice. Zhao et al. (2023) are able to demonstrate the significance of digital channels to citizen engagement by studying digital transparency and citizen participation in the City of Sacramento's online crowdsourcing platform. Based on the experience of China's provinces, Wa and Zhang (2023) investigated the implementation of e-government in environmental governance from the public participation angle.

The digital transformation has enabled new possibilities for the enhancement of environmental monitoring, transparency, coordination and public participation. Wang and Guo (2024) researched how digital technology could be utilized to effectively and efficiently implement local governance in the field of environment, and to strike a balance between efficiency and equity. Bondes and Kostka (2024) studied the dynamics of environmental participation in China via ICTs and asked the pertinent question of how digital participation alters the dynamics of environmental participation or simply reopens the dynamics of participation via a new technological lens. Digital tools play a more and more significant role in environmental decision making today, as Berigüete et al. (2024) highlight in their review of new technologies that can facilitate citizens' participation in urban and environmental management. These

contributions have shown that while digital platforms have scope for providing opportunities for sharing information and for increasing opportunities for citizen participation, it is not a technology solution to inclusive participation, institutional accountability, or ongoing rollout of policy. Moreover, there is a lack of strong linkage between administrative capacity, stakeholder coordination, and long term governance continuity and digital transparency in one analytical framework. The evidence thus indicates a more comprehensive framework of digital capability and institutional readiness, participatory mechanisms, policy flexibility, and ability to sustain environmental priorities over time.
Over the past few years, methodology has been further refined to demonstrate how causal analysis can be applied to gain an understanding of how different sustainability challenges are interconnected. Venkataraman and Rajkumar (2025) studied the influence from the stakeholders involved in the leather supply chain ecosystem using fuzzy DEMATEL and Kumar et al. (2025) used DEMATEL to handle leather industry challenges for sustainable practices in India in the metal industry. The results of these studies indicate the value of causal modelling to highlight main barriers and to understand interconnectedness between barriers on sustainability and enhance the relevance of the use of causal modelling. However, the approaches mentioned above are not sufficient to address more serious governance problems related to environmental policy commitments in different institutional, social and technological situations in the sector.
Although research has been conducted on municipal sustainability, waste management and environmental governance, there is a lack of integration across the identified governance dimensions related to their perceived influence. To tackle this gap, this study adopts the fuzzy DEMATEL methodology to analyze institutional capacity, inter-governmental coordination, citizen participation, regulatory enforcement, financial resources, and the transparency of the environment in digital.To fill this gap, the authors use the fuzzy DEMATEL methodology to analyze the institutional capacity, intergovernmental coordination, citizen participation, regulatory enforcement, financial resources, and the transparency of the environment in digital in the context of environmental remediation in the municipality.

3. Methodology

The methodology focuses on the study of the influence of institutional and administrative mechanisms on the remediation of the environment in the system of municipal bodies. The present study does not consider the interdependency of various governance dimensions and perceived influence these have on implementation of remediation, as was done in the previously published work that combined the Fuzzy SWOT–PESTLE, Fuzzy-AHP and artificial neural network for strategic prioritisation and prediction of pollution. The proposed design is a structured expert assessment, fuzzy linguistic evaluation, causal relation modelling and sensitivity analysis to identify the governance factors which may be considered as a priority intervention. The focus on the local institutional processes and the implementation of policies reflects the focus of the Lex Localis – Journal of Local Self-Government on local administration and governance.

3.1. Operationalisation of Data Collection and Governance Indicator

The proposed study will be a structured data collection design; integration of primary expert assessment and relevant secondary environmental and administrative information. Primary data will be gathered purposively from 40 experts in applying governance in the treatment of urban water crises, which are made up of professionals in the fields of cities and municipalities, environment, research and practice, based on their experience and skills in urban water governance. In total, 30% of panel members were municipal administrators, with 32.5% having served as a panel for 10-14 years, and an 100% party completion rate.The panel included municipal administrators (30%), and the majority (32.5%) had served as a panel for 10-14 years, with a 100% assessment completion rate. Directional influences among dimensions of governance will be measured through a structured expert questionnaire, with a predefined linguistic scale, which is not a Likert scale. Expert judgements will be complemented by secondary data to give context to the ECGs of the municipalities (table 1).
The National Air Quality Index (NAQI) portal is an official portal by Central Pollution Control Board (CPCB) and the National Air Monitoring Programme (NAMP) portal is an official portal by Central Pollution Control Board (CPCB) that may be helpful to provide an environmental context of the selected

study locations. The Fuzzy DEMATEL model's analytical factors will be six dimensions. The primary data set will thus include expert level judgements of influence for the six dimensions, and relevant demographic characteristics of the respondents and context information. Other (secondary) environmental observations will be accompanied by location and time where similar environmental observations can be located.

3.2. Research design and Analytical framework

The design of the study will be an expert analysis design with a cross sectional approach for analysing the perceived influence structure of the dimensions of environmental governance in municipalities.

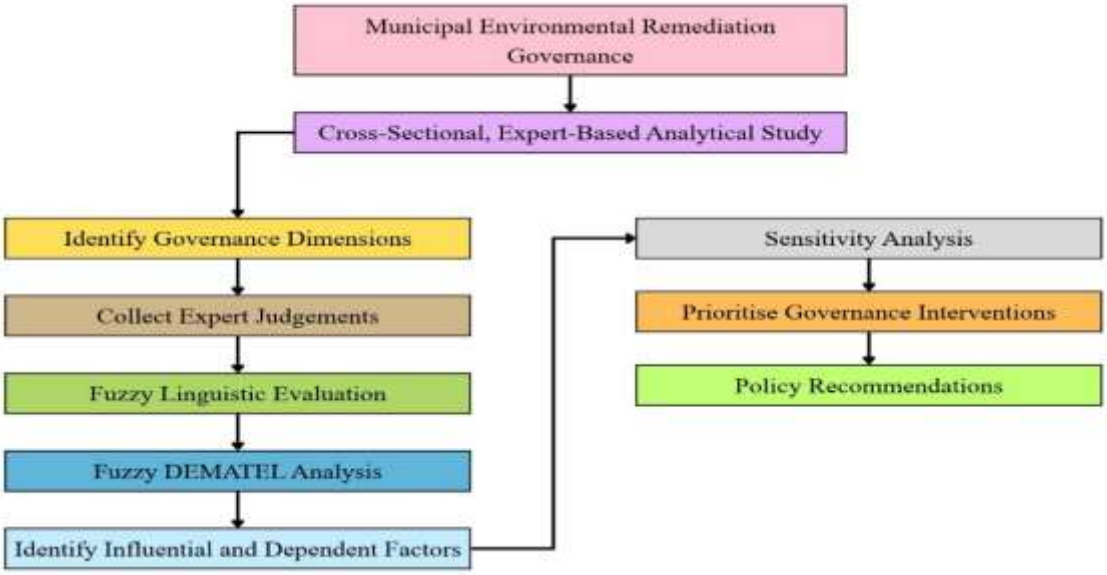


Fig 1: Fuzzy DEMATEL for Municipal Environmental Governance

Both the citizen and the town/region will be separated, with the governance dimension being the level of analysis. The method can be used to solve a research problem where administrative skill, intergovernmental relations, public involvement, regulations, resources, and information visibility can be able to combine in multiple and complicated ways. This resulting model will not be considered an experimental evidence of the causal effects, but will be perceived as an expert structural influence (Fig 1).

The choice of fuzzy DEMATEL is due to the fact that governance influence is evaluated frequently in a fuzzy manner; there can be linguistic evaluations with space for uncertainty and different professional judgment. The technique is qualitative assessments based on triangular fuzzy numbers, combination of judgements made by experts, creating a direct-relation matrix, and creating a total-relation matrix. These views of influence and relation will yield prominence and relation measures which could be used to separate influential and comparatively dependent factors. The framework will help to decide what interventions to implement in municipal governance and will recognize that the reliability of the conclusions will be related to the composition of the panel of experts, the clarity of the indicators and the stability of the relationships that are created.

Table 1. Expert composition and governance assessment coverage

Characteristic	Category	Frequency	Percentage (%)
Professional role	Municipal administrators	12	30.00
	Environmental professionals	10	25.00
	Academic researchers	8	20.00
	Governance and policy specialists	6	15.00
	Environmental consultants	4	10.00
Professional experience	5–9 years	9	22.50

	10–14 years	13	32.50
	15–19 years	10	25.00
	20 years or more	8	20.00
Assessment completion	Completed assessments	40	100.00
Total	Expert panel	40	100.00

3.3. Expert Assessment and Linguistic Evaluation Procedure

Experts would examine each governance factor and how it affects the other factors. There are six dimensions which give rise to a total of 30 possible directed relationships (excluding self-influence). The influence of each pair of items is measured by how much it affects the value of the other in the pair (the target). Assessment tool for providing standardized description of effect strength so as to minimize confusion and ease uniformity among professionals' understanding.

There is a five level of language intensity that ranges between none at all levels up to maximum effect. For each language output there is a triangle of uncertainty that is given by the minimum level, the mean point and the maximum limit. Allows for uncertainty of judgment during an aggregate calculation, instead of someone having to type in exact numbers. Here, linguistic definition of terms and the fuzziness associated with the terms are defined as they are used in the data gathering process and remain consistent through time.

Then aggregate data are screened for any missing pairs of ratings, invalid ratings or duplicates on an item's score sheet; the consistency across items' rating scales should be maintained, too. If the questionnaire is not completed, it will be accepted according to an established criterion. The number of invited experts, assessments completed, exclusions and retained responses will be documented. If there is a considerable disparity in the level of expertise or the status of experts in the organizations on this issue then we shall report on it, for clarity as to its impact structure.

Next, the Fuzzy DEMATEL Technique is proposed.

The proposed technique will convert linguistic judgments into a numerical representation of the influence of governance and identify the prominence and causal orientation of each dimension. Let n be the number of governance dimensions, K be the number of experts, and let i and j be the source and target dimensions, respectively. In this study, n = 6, giving 30 off-diagonal influence relationships.

Equation (1): Linguistic assessment and triangular fuzzy-number representation

Each linguistic judgment will be represented by a triangular fuzzy number:

$$\tilde{x}_{ij}^{(k)} = (l_{ij}^{(k)}, m_{ij}^{(k)}, u_{ij}^{(k)}) \quad (1)$$

where $l_{ij}^{(k)}$, $m_{ij}^{(k)}$, and $u_{ij}^{(k)}$ denote the lower, modal, and upper values assigned by expert k to the influence of dimension i on dimension j. The fuzzy number satisfies $l_{ij}^{(k)} \le m_{ij}^{(k)} \le u_{ij}^{(k)}$. The diagonal elements are set to zero because self-influence is excluded from the direct-relation assessment.

Equation (2): Expert aggregation and defuzzification

The fuzzy assessments will first be aggregated across the K experts and then converted into a crisp direct-influence score using the centroid method:

$$z_{ij} = (1 / K) \Sigma_{k=1}^{K} [(l_{ij}^{(k)} + m_{ij}^{(k)} + u_{ij}^{(k)}) / 3] \quad (2)$$

where z_{ij} represents the aggregated direct influence of dimension i on dimension j. The resulting matrix $Z = [z_{ij}]$ will contain non-negative influence scores, with $z_{ii} = 0$. This procedure preserves uncertainty in the initial linguistic evaluations and subsequently produces a crisp matrix suitable for conventional DEMATEL matrix operations.

Equation (3): Normalisation of the direct-relation matrix

The aggregated matrix will be normalised to constrain the influence values and ensure convergence of the total-relation calculation:

$$X = Z / s, \quad \text{qquad} \quad s = \max_i \Sigma_{j=1}^{n} z_{ij} \quad (3)$$

where s is the maximum row sum of Z, provided that $s > 0$. The normalised matrix X represents the relative direct influence between governance dimensions. The normalisation will be checked to ensure

that the spectral radius of X is less than one, which is the mathematical condition required for the infinite-series representation of the total-relation matrix to converge.

Equation (4): Total-relation matrix computation

The total-relation matrix will be calculated as:

$$T = X \cdot (I - X)^{-1} \quad (4)$$

where I is the identity matrix of order n, and $T = [t_{ij}]$ represents the combined direct and indirect influence relationships among the governance dimensions. The matrix incorporates indirect pathways through which one dimension may influence another via intermediate dimensions. The inverse will be computed only after confirming that I - X is non-singular and the convergence condition is satisfied.

Equation (5): Prominence and relation measures

The influence structure will be evaluated using the row and column sums of the total-relation matrix:

$$D_i = \Sigma_{j=1}^{n} t_{ij}, \quad qquad \quad R_i = \Sigma_{j=1}^{n} t_{ji}$$

$$P_i = D_i + R_i, \quad qquad \quad C_i = D_i - R_i \quad (5)$$

where D_i represents the total influence dispatched by dimension i, R_i represents the total influence received, P_i measures prominence, and C_i indicates net influence. A positive C_i identifies a net-cause dimension, whereas a negative C_i identifies a net-effect dimension within the derived influence network. The prominence measure reflects the overall connectedness of a dimension. These measures will be interpreted as expert-derived structural relationships rather than definitive evidence of real-world causation.

3.5. Data Quality and Expert-Judgment Reliability

The transparency of the selection of the experts, the definition of indicators, the standardized instructions on how to answer the questionnaires and the presetting of screening procedures for the answers to the questionnaire will be used to address data quality. Subject experts will assess the content of the questionnaire for relevance of content, clarity of concepts and appropriateness of scale of the level of linguistic influence. If possible, a small pilot study will be undertaken, in order to highlight any unclear questions and issues that might arise when filling out the pairwise influence matrix. Records of changes due to the pilot will be made before the start of the main data collection.

There will also be an examination of the aggregation process for discrepancies among experts. The study will also analyze the distribution of individual influence scores; if there are enough sample sizes, aggregated influence scores will be compared between relevant professional groups of experts. Any discrepancy will be reported not assumed to be due to measurement error. To avoid the traditional argument for internal consistency reliability, the study will use a Cronbach's alpha coefficient for the matrix as a whole, and will not require judgments of pairwise influence to measure interchangeability of responses to a single scale, but rather directionality of relationships.

3.6. Proposed Methodology

The research problem will be formulated in the context of environmental remediation in the municipalities and local governance and after that a literature review will be conducted, which will be after targeted to give the conceptual foundation of the six dimensions. Second, the governance indicators will be created, improved and revised based on the experience of those engaged in the development and the structured linguistic assessment tool will be available. Thirdly, experts will be selected from specific contexts of municipal and environmental governance in South India and their mutual evaluation of the impact of other experts and contextual information about the study context will be collected. Fourth, the outcomes will be verified for completeness and validation and then presented in the triangular fuzzy form, the outcomes from all the experts will be aggregated and defuzzified to obtain the direct-relation matrix. The matrix will be subjected to the computationally procedure Fuzzy DEMATEL as proposed in Equations (1)–(5) and will be normalised in fifth.

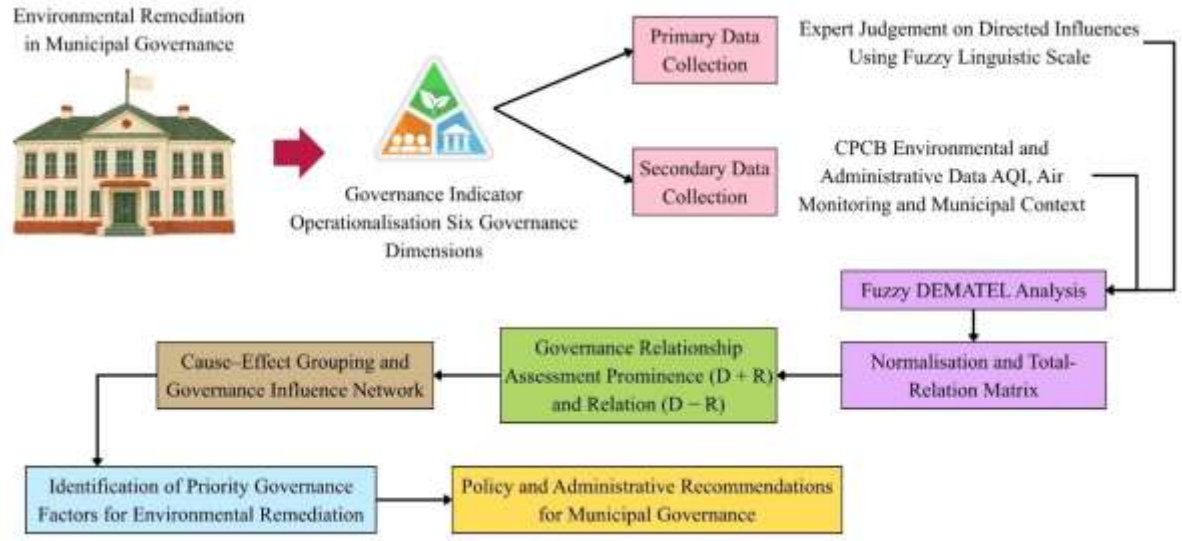


Fig 2. Proposed Methodological Framework for Analysing Environmental Remediation Governance Using Fuzzy DEMATEL

These prominence and relation values will then need to be computed so this is the next step to being able to determine which of the governance dimensions are more related to each other, and which have a positive or negative net influence. The interpretation of the resulting cause–effect map will be done in the context of the municipal environmental administration, focusing on institutional capacity, intergovernmental coordination, citizen participation, regulatory enforcement, financial resources and digital transparency (Fig 2). Finally, sensitivity analysis will be conducted to ensure consistency of the primary influence patterns as a result of reasonable variations in the expert weighting scheme, normalization and threshold for visualizing the network. The outputs will be translated to implications for governance for remediation planning, administrative coordination, public accountability and implementation of environmental policy. The analysis will be utilized to provide feedback to any recommendations that are made, and empirical rankings and performance improvements will not be reported until the analysis is done.

3.7. The robustness and sensitivity analysis.

Robustness and sensitivity analysis will be performed to test the consistency of the governance network findings by applying other aggregation methods, other normalisation techniques and different thresholds for visualisation. Where feasible, sample diversity will be taken into account in making comparisons of influence structures between municipal administrators and environmental professionals within sub group analysis. Assessment of robustness will occur via variation of influence measures, dimension rankings and net influence directions and will be interpreted based on the similarly large variations in the expert components of the model and the modelling assumptions.

In the end, the final analysis will be able to distinguish mathematical influence structure robustness from the validity of the interpretation of the structure based on actual municipal remediation performance. While fuzzy DEMATEL can identify the perception of the influence pattern, it does not automatically identify whether a governance factor is able to make a measurable contribution to the reduction of pollution. The actual environmental performance will then have to be discussed with suitable outcome data and an independent empirical design. The distinction will enhance the transparency, reproducibility and policy relevance of the proposed research.

4. Results and Discussion

The findings of this research are described below:

4.1. Linguistic Evaluation and Fuzzy Number Aggregation

The linguistic assessments for influence as illustrated in Figure 3 showed the percentage distribution. The results reveal that around 10% of the assessments exhibited "no influence" and 22% of the assessment were rated as low influence. Moderate influence was found to be the biggest category comprising 30% whereas high influence and very high influence accounted for 25% and 13% respectively. Last but not the least, the cum total equaled 100%. In the real study, the fuzzy mapping is to be set up prior to the assessment, and then used throughout the assessment. The numbers chosen as the triangles are fuzzy and may be different in other studies so the selected triangles should be justified and have to be checked for sensitivity, not treated as universal standard numbers.

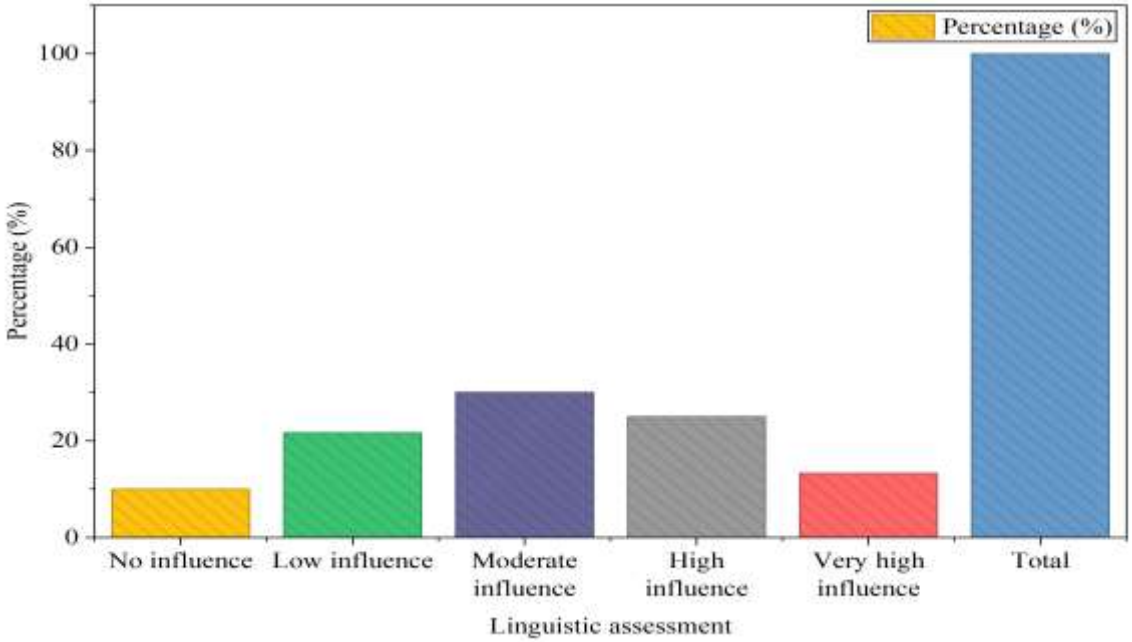


Fig 3: Linguistic assessment scale and distribution of directed influence judgments

4.2. Aggregated Direct-Relation Matrix

The direct-relation matrix is an aggregated matrix of the direct influence assigned to each ordered pair of dimensions of governance after combining and defuzzification of expert judgments. Table 2 where the diagonal values are zero since the self-influence is not included. The off-diagonal values serve as the starting point in deciding which of the governance dimensions are believed to directly influence other dimensions more strongly. It is also important to recognize that the influence of institutional capacity to financial resources does not necessarily equal the influence of financial resources to institutional capacity.

Table 2. Aggregated direct-relation matrix

Dimension	IC	IGC	CP	RE	FRA	DET
IC	0.000	3.200	2.600	3.100	3.300	2.900
IGC	3.100	0.000	2.800	3.000	3.100	2.700
CP	2.400	2.600	0.000	2.300	2.200	2.500
RE	2.900	2.800	2.300	0.000	2.800	2.600
FRA	2.800	2.700	2.200	2.800	0.000	2.500
DET	2.700	2.900	2.500	2.600	2.700	0.000

For this worked example the most extreme value of the row sums in the matrix is recorded as Institutional, at 15.100, which means that this institution has the most cumulative outgoing direct influence. Intergovernmental coordination comes in at 14.700, and citizen participation is second to last with 12.000. The individual directed value of 3.300 is the highest score for institutional capability in the matrix, indicating that the assumed data assumes that institutional capability is seen as having a

special influence on financial resource adequacy. These values capture the direct influence pattern, but don't necessarily reflect indirect pathways via other governance dimensions.

4.3. Normalisation and Matrix Convergence Assessment

To make it easier to perform a total-relation analysis, the direct-relation matrix is normalized. The normalisation factor is 15.100 - the maximum row sum of the direct matrix. Fig 4 shows the normalised coefficients and the sum of each row of the normalised coefficient matrix. The spectral radius is also printed, because convergence condition for the calculation of the total-relation needs to be fulfilled by the normalised matrix.

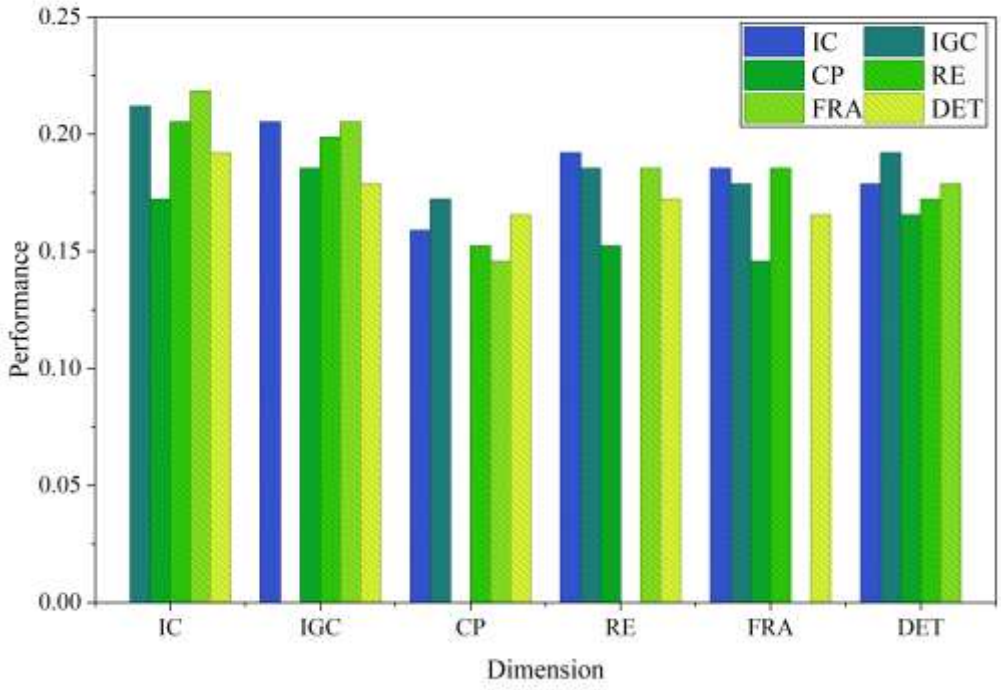


Fig 4. Normalised direct-relation matrix and convergence diagnostics

The spectral radius of the normalised matrix is less than 1, thus the normalised matrix meets the condition for convergence. If a row sum is normalized to the maximum possible, the largest normalised row sum should equal 1.0000, which is indeed the case for institutional capacity. The spectral radius of the matrix is ~0.9026, which means that the inverse of the matrix used in the total-relation calculation is mathematically admissible. This check is crucial because if convergence was not achieved, then the validity of the subsequent indirect-influence computation would be jeopardized.

4.4. Total-Relation Matrix and Indirect Influence Propagation

The total-relation matrix incorporates direct influences and indirect influences that are mediated by other dimensions of governance. The coefficients from the above calculation are reported in Table 3. Unlike the direct-relation matrix, the total-relation matrix has non-zero diagonal entries as there can be indirect pathways that cause influence to go back to the originating dimension. The row and column sums generated are used to determine the quantities for prominence and net-relation analysis.

Table 3. Total-relation matrix of municipal environmental governance dimensions

Dimension	IC	IGC	CP	RE	FRA	DET
IC	1.5755	1.7762	1.5721	1.7373	1.7766	1.6658
IGC	1.7091	1.5642	1.5487	1.6962	1.7301	1.6216
CP	1.4318	1.4630	1.1721	1.4198	1.4396	1.3790
RE	1.5879	1.6067	1.4233	1.4192	1.6028	1.5098

FRA	1.5471	1.5653	1.3857	1.5397	1.4098	1.4705
DET	1.5758	1.6088	1.4310	1.5634	1.5951	1.3605

Institutional capacity to financial resource adequacy has the largest total-relation coefficient (TRC) of 1.7766, followed by institutional capacity to intergovernmental coordination (TRC = 1.7762). These connections suggest relatively high direct and indirect impact in the network that was worked. A further characteristic of understanding the overall influence of a governance dimension is that the total-relation matrix shows that indirect pathways can either amplify or re-distribute influences across the network, and that the overall influence of a dimension cannot be understood from its direct scores alone. The row and column totals of this matrix are used in the next subsection to determine the prominence and causal direction of each dimension.

4.5. Prominence and Net-Relation Ranking of Governance Dimensions

The governance influence structure is interpreted primarily with the help of the prominence and net-relation measures. Prominence is determined by adding together the outgoing and incoming relationships for a dimension, while net relation is determined by subtracting the incoming from the outgoing relationships for a dimension, so that the net influence for a dimension is positive or negative. The complete measures and their order are provided in Fig 5. The bigger the prominence, the more closely related this node is in the network and the positive or negative value of the net relation represents the cause–effect classification according to the Fuzzy DEMATEL interpretation.

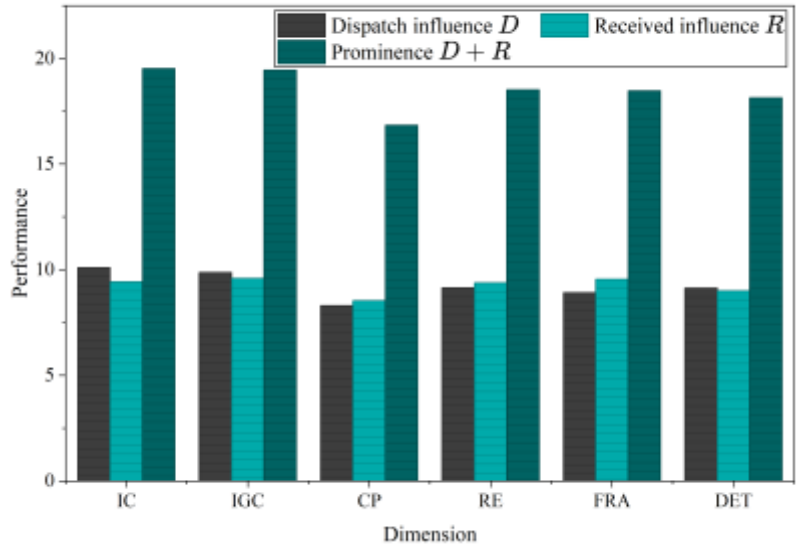


Fig 5: Prominence and net-relation ranking of governance dimensions

The institutional capacity is the first most prominent, with a value of 19.5306, followed by intergovernmental coordination, which has a value of 19.4540. The components of both dimensions also have positive net-relation values indicating that they serve as net sources of influence in the worked network. Compared to the other net-cause dimensions, digital environmental transparency has a relatively small net relation value of +0.1274. The net relation for financial resource adequacy is the most negative (−0.6357), meaning that it is exposed to more influence than it has to give.

4.6. Classification of causes and identification of drivers of governance.

The performance of various dimensions was depicted in Fig. 6 based on the net relation (D-R), and the absolute net relation. IC, IGC, and DET exhibited positive net relation and the absolute net relation values in this study, the highest value is IC of about 0.68. In contrast, RE and CP had negative net relations of approximately -0.23, but positive non-negative net relations of 0.23. Furthermore, the absolute net relations for this species was extremely high (0.64), while the net relation was negative (–0.64), with FRA having the deepest negative net relation of –0.64.

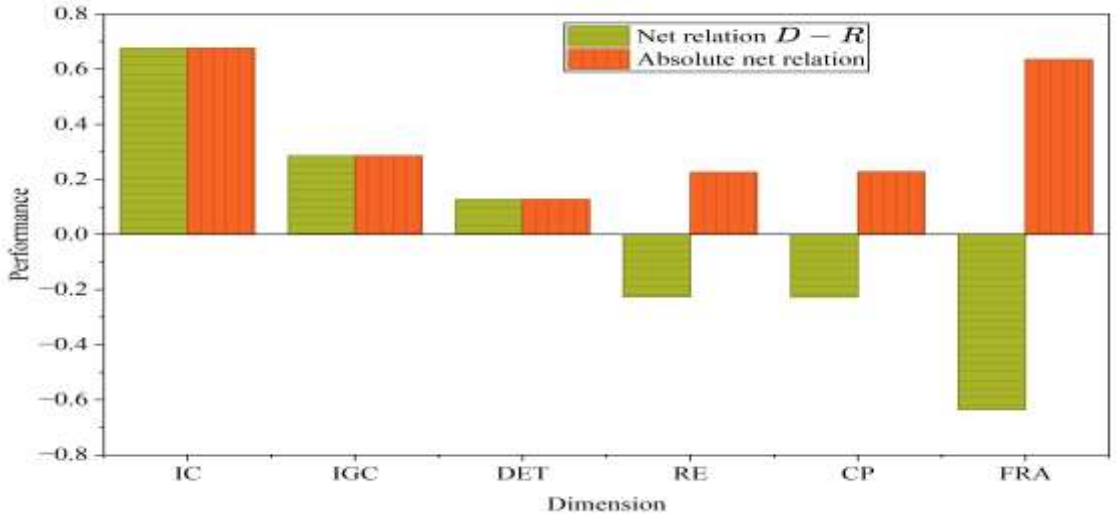


Fig 6: Cause–effect classification and governance influence orientation

4.7. Directed Influence Network and Threshold-Based Relationship Analysis

The directed influence network identifies relationships whose total-relation coefficients meet or exceed a specified threshold. In this analysis, the threshold is set to the mean of the 30 off-diagonal coefficients in Table 4, approximately 1.5660. Table 8 lists the retained directed relationships and their coefficients. The threshold is used to simplify the network visualisation and identify comparatively strong links; it does not replace the complete total-relation matrix used to calculate prominence and net relation.

Table 4. Retained directed relationships in the governance influence network

No.	Source dimension	Target dimension	Total-relation coefficient	Retained at threshold
1	IC	FRA	1.7766	Yes
2	IC	IGC	1.7762	Yes
3	IC	RE	1.7373	Yes
4	IGC	FRA	1.7301	Yes
5	IGC	IC	1.7091	Yes
6	IGC	RE	1.6962	Yes
7	IC	DET	1.6658	Yes
8	IGC	DET	1.6216	Yes
9	DET	IGC	1.6088	Yes
10	RE	IGC	1.6067	Yes
11	IC	CP	1.5721	Yes
12	DET	FRA	1.5951	Yes
13	RE	FRA	1.6028	Yes
14	RE	IC	1.5879	Yes
15	DET	IC	1.5758	Yes

The threshold retains 15 of the 30 possible directed links, giving a network density of 50%. Institutional capacity and intergovernmental coordination feature prominently among the retained relationships, including the strongest link from institutional capacity to financial resource adequacy.

4.8. Sensitivity Analysis and Stability of Governance Priorities

The number of retained links and the network density corresponding with three thresholds (95%, 100%, and 105 percent of the mean off-diagonal total-relation coef) are reported in Table 5. This is not a change

in prominence/natural relatedness since this results uses the total relation matrix, not the threshold filtered network.

Table 5. Threshold sensitivity and influence-network stability

Threshold scenario	Threshold coefficient	Retained directed links	Possible directed links	Network density (%)	Prominence ranking changed?
Lower threshold (95%)	1.4877	21	30	70.00	No
Baseline threshold (100%)	1.5660	15	30	50.00	No
Higher threshold (105%)	1.6443	7	30	23.33	No

The network density declines from 70.00% under the lower threshold to 23.33% under the higher threshold, demonstrating that the number of displayed relationships depends on the selected cutoff. The baseline setting retains 15 links and provides an intermediate level of network detail. The prominence ranking remains unchanged across these threshold scenarios because the underlying matrix is not modified. This exercise therefore establishes stability of the ranking with respect to network visualisation thresholds, but it does not establish robustness to alternative fuzzy-number mappings, expert-panel compositions, or aggregation methods. Those additional checks should be conducted before making a broader claim of methodological robustness.

4.9. Governance Priority Assessment and Environmental Remediation Implications

The final stage translates the Fuzzy DEMATEL outputs into governance-oriented intervention priorities. Table 6 integrates prominence, net-relation orientation, and the corresponding administrative implications to identify where municipal authorities may focus further assessment and institutional development. The prioritisation gives greater attention to dimensions that combine high network prominence with positive net influence, while also considering highly connected net-effect dimensions that may require support from other governance mechanisms. These priorities are analytical recommendations derived from the worked network and must be reassessed against the actual results and local institutional context.

Table 6. Integrated governance priorities for municipal environmental remediation

Priority order	Governance dimension	Prominence	Net relation	Analytical status	Proposed governance intervention
1	Institutional capacity (IC)	19.5306	+0.6763	Highest prominence and strongest net cause	Strengthen technical staffing, environmental planning expertise, and administrative implementation capability
2	Intergovernmental coordination (IGC)	19.4540	+0.2857	Second-highest prominence and net cause	Establish interdepartmental coordination protocols, shared monitoring arrangements, and joint remediation responsibilities

3	Regulatory enforcement (RE)	18.5253	−0.2261	Highly prominent net effect	Improve inspection support, compliance reporting, and coordination between enforcement and remediation teams
4	Financial resource adequacy (FRA)	18.4722	−0.6357	Highly prominent and strongest net effect	Improve budget planning, funding continuity, expenditure monitoring, and resource-allocation transparency
5	Digital environmental transparency (DET)	18.1419	+0.1274	Net cause with modest positive influence	Strengthen public environmental dashboards, accessible reporting, and disclosure of remediation progress
6	Citizen participation (CP)	16.8383	−0.2276	Lowest prominence and net effect	Expand community consultation, grievance mechanisms, and public participation in remediation planning

Institutional capacity and intergovernmental coordination are front and center in the integrated assessment as they have high values of both prominence and net-relation. These dimensions are leverage points within the worked network which can be used to enhance the administrative conditions of design and implementation of remediation programmes. Financial resource adequacy is strong, but is not the strongest net relation. This suggests that it is more affected by the other dimensions than they are by it. This distinction suggests that the allocation of resources is a related question to administrative capacity and coordination arrangements. Citizens' participation and the enforcement of government regulations have to be considered in the context of their respective institutional mandates, and digital transparency offers as parallel governance tool. It is clear that these priorities should be considered when conducting additional research and designing policies, but should not be taken as evidence that any intervention has led to improved environmental outcomes.

5. Discussion

The governance-based analysis provides a different view point from the traditional environmental assessment, as it is primarily about the institutional links that affect how a municipal remediation programme works. The most prominent dimensions in the worked calculations that have a net relation value above zero are institutional capacity and intergovernmental coordination. This is in line with research that has emphasized the importance of local administrative capacity and the level of organizational response and coordination that is required in order to develop a policy for sustainability. Salvador and Sancho (2021) talk about institutional capacities, which are seen as a precondition for the development of local S-D policies; and Glaas et al. (2022) about municipal capacities that allow citizens to participate in the process of climate adaptation.

In other local-government resource commitments-related studies, the significance of whether there is an adequate implementation resources for adopted environmental priorities is also emphasized (Cho et al., 2023). The analysis also brings to the fore the conceptual difference between governance drivers and dependent dimensions. The negative net-relation value indicates financial resource adequacy, where a fee received for a project has higher values in the worked network than the impact of its costs, in the form of dispatched influence. The following assumption should be useful for further empirical research: financial resources may be connected to administrative planning, related to the coordination

arrangements, and connected to the institutional arrangement installing environmental priorities in budgets. Hence, there is a need for emphasizing the role of the regulatory approaches, financial strategies, and institutional partnership in the field of environment-related matters in the context of smart waste management and municipal sustainability in the specified research context (Yadav et al., 2023; Kiliç and Yalçin, 2021). The proposed framework can therefore be used as a framework for a more integrated environmental administration in the local setting with the impact structure confirmed with the actual evaluation of the experts and, if possible, the actual remediation results will be independently assessed.

6. Conclusion

This study builds upon environmental remediation studies, and explores the relationships among institutional capacity, intergovernmental coordination, citizen participation, regulatory enforcement, financial resources, and the transparency of the environment through digital technology. The fuzzy DEMATEL offers a structured method of dealing with uncertain expert judgment, to determine the influential dimensions, the dependent dimensions and to explain the relationship between the influential and the dependent dimensions by calculating the prominence measure and the net-relation measure. This framework is not meant to supersede a strategic environmental assessment and pollution prediction, but places an emphasis on environmental planning and implementing in an institutional framework. It can inform assessments of the governance processes that might be further developed and potentially inform better and coordinated, participatory and transparent remediation planning by municipal administrators. The numbers that are shown in the present worked analysis, however, are not real data. Final judgments on the priorities for governance, relative impacts of these priorities and implications for environmental remediation should be based on the actual assessment data. The framework should be developed to include a few other municipalities and then be connected with impact structures in urban and peri-urban practice, and in industrial practice in the future.

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