Enhancing resilience in water management agriculture: A Social Network Analysis approach to identify Leverage Points for climate adaptation

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Abstract:
Climate change exposes vulnerabilities in water-agriculture governance by straining information flows, collaboration, and norms. This study couples Social Network Analysis (SNA) with resilience theory to examine how Murcia's actor configurations enable absorption of shocks, adaptation, and transformation. Using COSMIC—a platform co-developed with HDA that integrates multilingual surveys, real-time validation, and instant network visualization—stakeholders provided organizational profiles, mapped inter-actor ties, and identified leverage points. COSMIC generated an undirected graph and computed node metrics (degree, betweenness, closeness, eigenvector) plus network indicators (density, modularity). Preliminary findings reveal a polycentric structure: a core of interconnected institutions sustains redundant pathways (absorptive resilience), while clusters suggest opportunities for cross-sector collaboration (adaptive resilience). Qualitative interviews confirm public and academic actors perceive high cohesion—validating hubs' buffering roles—whereas civil society's lower cohesion ratings expose outreach needs. Divergent views on sustainability versus productivity highlight "intent"-level leverage points requiring value-focused dialogues. COSMIC's survey-to-analysis workflow enables rapid diagnosis of structural strengths and weaknesses, guiding parameter-level (data-sharing), feedback-level (incentives, mediation), and intent-level (value alignment) interventions. These preliminary insights will be tested and refined across remaining FARMWISE case studies.

Keywords: Climate Resilience, Social Network Analysis (SNA), Leverage Points, Water Management, Agricultural Governance

1.Introduction

The intertwined challenges of climate change and water scarcity are redefining the boundaries of sustainability in agriculture. Nowhere is this more evident than in semi-arid regions like Murcia, in southeastern Spain—a territory characterized by structural water stress, increasingly erratic precipitation, and intensifying socio-environmental pressures. With an average annual rainfall of only 300–350 mm and a historical dependency on intensive irrigation systems, the region has long been on the frontline of adaptive water governance (García-Ruiz et al., 2011; Iglesias & Garrote, 2015). Compounding the issue, Murcia has experienced at least 17 extreme weather events associated with DANAs (Depresiones Aisladas en Niveles Altos) since 2000, including the devastating floods of 2019, which brought more than 500 mm of rainfall in a matter of days (Pérez-Morales et al., 2021; Zabalza et al., 2018). These disruptions underscore the urgent need for governance systems that can anticipate, absorb, and adapt to climatic shocks.

Remarkably, Murcia has also emerged as a global reference in water reuse and efficiency. It currently recycles approximately 98% of its treated wastewater, compared to 9% in the rest of Spain and just 5% across Europe (Esamur, 2022). This performance reflects a sophisticated network of infrastructures and actors—ranging from public water authorities like the Confederación Hidrográfica del Segura and the Mancomunidad de los Canales del Taibilla, to regional administrations, farmer cooperatives, water user associations (WUAs), and municipal operators. Yet, despite this apparent success, the very complexity of this governance landscape may become a liability in times of crisis. Fragmented responsibilities, institutional inertia, and weak coordination mechanisms often erode the system's adaptive potential (De Stefano et al., 2015; López-Gunn et al., 2012).

Most research to date on Murcia's water governance has emphasized technological and infrastructural solutions. What remains underexplored is the role of actor configurations and network structures in shaping adaptive capacity. In other words, *how resilience is organized*, and not merely what technical tools are deployed. To address this gap, this paper adopts a relational perspective grounded in Social Network Analysis (SNA), resilience theory, and the concept of leverage points (Meadows, 1999; Bodin, 2017). We argue that understanding who interacts with whom, and how, is essential to revealing hidden vulnerabilities and unlocking transformative potential within governance networks.

Our case study draws on the ongoing Horizon Europe project FARMWISE, which aims to support climate adaptation in agriculture across eight European regions, both through the use of digital models and the inclusion of water innovations in each of the 8 case studies (Spain, Poland, Italy, The Netherlands, United Kingdom, Sweden, Finland and Ukraine). In this paper, we start by applying our methodology to Murcia - a region that exemplifies both institutional innovation and structural tension in water management - to later extend the approach to the other case studies in subsequent phases of the research. Our objective is threefold: (1) to map the actor networks involved in water-agriculture governance in the Murcia region; (2) to identify structural leverage points that may enhance system-wide resilience of the network; and (3) to offer strategic insights for more adaptive and inclusive governance arrangements in the region.

The study addresses three core questions:

- How are actors in Murcia's water-agriculture governance system interconnected, and what structural network patterns emerge?
- Where are the leverage points—nodes or relationships—that hold potential for amplifying resilience?
- How can these insights inform adaptive governance interventions in climate-vulnerable regions?

To operationalize this analysis, we developed a digital tool—**COSMIC (Collaborative Stakeholder Mapping of Interactions and Collaborations)**—built from the ground up through a collaboration between the Universitat Politècnica de València (UPV) and the University of Applied Sciences Darmstadt (H_DA). COSMIC facilitates the participatory mapping of governance networks through structured surveys, enabling the quantification and visualization of stakeholder relations. Governance networks refer to relatively stable configurations that emerge from the interactions of interdependent yet operationally autonomous actors, operating within a self-regulating framework shaped by external forces. These networks contribute to the collective attainment of public goals through ongoing coordination and collaboration (Isett et al., 2011; Kapucu, 2015; Sørensen & Torfing, 2005). Combined with qualitative data from interviews and focus groups, this mixed-methods approach allows us to trace not only the structure but also the meaning of interactions, what they enable, constrain, or fail to deliver.

By reframing resilience as an emergent property of relational dynamics, rather than a fixed institutional trait, this study contributes to ongoing debates on how to govern complex socio-ecological systems under increasing uncertainty (Folke et al., 2010; Chaffin et al., 2014; Biggs et al., 2012). Our findings have the potential to inform new strategies for leveraging collaboration, amplifying adaptation,driving reflection among stakeholders, and fostering long-term system transformation through governance.

2.Theoretical Framework

In this study, we are using 3 theoretical frameworks: SNA, Leverage points and resilience theory. The notion of leverage points is used as a conceptual bridge between network analysis and resilience theory. By identifying actors or relational patterns that play a disproportionately influential role in shaping collective behavior—such as brokers, connectors, or isolated subgroups—we aim to locate critical entry points for policy and intervention. These leverage points may not only signal opportunities for enhancing communication, trust, or legitimacy, but may also reveal deeper barriers to transformation, such as power asymmetries, siloed mandates, or entrenched mental models (Westley et al., 2011; Pereira et al., 2018).

2.1 Social Network Analysis in environmental governance

Social Network Analysis (SNA) has become an increasingly influential tool for understanding the relational underpinnings of governance in complex socio-ecological systems. Moving beyond static or institutionalist views, SNA conceptualizes governance as a dynamic web of interactions among diverse actors—government agencies, civil society organizations, private entities, and knowledge institutions—whose positions and relationships shape decision-making, knowledge circulation, and adaptive capacity (Wasserman & Faust, 1994; Prell et al., 2009; Janssen et al., 2006).

In the domain of environmental governance, SNA enables researchers to uncover not only *who* is involved, but *how* they are positioned relative to each other, *what kinds of ties* connect them (e.g., collaboration, authority, knowledge exchange), and *which structural properties, at the individual and network level* —such as centrality, density, or modularity—facilitate or constrain collective action (Bodin & Crona, 2009; Ingold & Balsiger, 2015). At the individual level, for instance, actors with high *degree centrality* often serve as visible influencers due to their numerous connections, while those with high *betweenness centrality* act as brokers or gatekeepers, strategically positioned to control the flow of information across otherwise disconnected subgroups (Burt, 2005; Bodin et al., 2006; Long et al., 2013). These positions can greatly influence the distribution of power, the legitimacy of decisions, and the ability to coordinate across scales or sectors (Knoke & Yang, 2008; Crona & Parker, 2012).

At the network level, measures such as *density* (the extent to which all possible ties are realized), *reciprocity* (mutuality of interactions), *modularity* (degree of clustering), and *centralisation* (unevenly a network's ties are concentrated on one or a few nodes rather than being evenly distributed) provide insight into how well-connected or fragmented a governance system is (Newman & Dale, 2005; Scott, 2017; Gava et al., 2025; Sandström, A. & Carlsson, L., 2008). Cohesive networks may promote trust, shared norms, and institutional learning (Henry & Vollan, 2014), while the presence of weak ties or bridging connections across clusters—what Granovetter (1973) famously called "the strength of weak ties"—can be crucial for accessing novel information and enhancing adaptive flexibility (Bodin, 2017; Sayles et al., 2019).

Empirical studies have demonstrated the relevance of SNA for water and agricultural governance. In Zimbabwe, Manzungu and Machiridza (2005) used SNA to expose how informal hierarchies and poor coordination among irrigation users led to inefficient water allocation and conflict, rooted in a lack of structural cohesion. In coastal Kenya, Crona and Bodin (2010) showed that actors occupying central and bridging positions were essential for linking ecological knowledge with governance processes, particularly in fragmented watershed contexts. Meanwhile, Berardo and Scholz (2010) analyzed U.S. estuarine policy networks, revealing how the *density* and *multiplexity* of ties—actors interacting across multiple domains—fostered cooperation and trust in conditions of uncertainty. Their "risk hypothesis" posits that actors facing high interdependence are more likely to establish stable, cooperative ties, thus enhancing the system's capacity to self-organize.

Methodologically, SNA provides a versatile platform to examine both the **structural** properties of governance systems (who is connected, how, and how often) and the **functional** implications of those structures—how power, influence, or knowledge circulate; where bottlenecks or gaps exist; and which nodes or relationships are most critical for systemic change (Reed et al., 2009; Borgatti et al., 2009). Moreover, by incorporating *tie content* (e.g., cooperation, conflict, funding, regulation), researchers can analyze not only the form but also the quality of interactions—an essential dimension in climate governance, where institutional misalignment and power asymmetries often hinder transformative action (Stein et al., 2011; Bodin, 2017).

2.2 Leverage points in complex systems

In the context of complex socio-ecological systems, the question of *where* to intervene is often more consequential than *how* to intervene. This idea lies at the heart of the concept of *leverage points*, introduced by Donella Meadows (1999), who argued that certain elements within a system exert disproportionately high influence over system behavior. Leverage points are strategic locations where a small change can catalyze substantial and lasting transformations across the whole system.

Meadows (1999) proposed a hierarchy of leverage points, ranging from shallow interventions—such as adjusting numerical parameters—to deep interventions that shift the goals, structures, or paradigms of the system itself. While shallow leverage points may offer immediate results, they are often insufficient to address persistent or structural problems. Deep leverage points, by contrast, target underlying causes and worldviews, and therefore hold greater transformative potential, even if they are more politically or institutionally challenging to access (Abson et al., 2017; Fischer & Riechers, 2019).

This distinction has gained increasing relevance in sustainability science, where the complexity of environmental challenges calls for change processes that go beyond technical fixes or incremental adjustments. Abson et al. (2017) identify four realms of leverage—design, intent, parameters, and feedbacks—and argue that interventions targeting design (e.g., governance architectures) and intent (e.g., normative goals) are more likely to result in transformative change than those focused on parameters or feedback regulation. Similarly, Fischer and Riechers (2019) contend that leverage points must be approached relationally, as interacting across different system levels—material, institutional, and cognitive—in ways that either reinforce or obstruct change.

In governance contexts, leverage points are not limited to technical solutions but include shifts in institutional arrangements, collective behaviors, and underlying narratives. For instance, transformative governance may emerge from changes in how problems are framed, how legitimacy is distributed, or how power asymmetries are addressed (Westley et al., 2011; Blythe et al., 2018). Transformative potential also depends on timing and context; socio-political shocks, crises, or policy windows can act as catalysts for deeper shifts if actors are prepared to engage with them strategically (Herrfahrdt-Pähle et al., 2020; Patterson et al., 2017).

Importantly, the identification of leverage points is not a purely analytical task—it is deeply normative. What constitutes a desirable intervention point depends on whose values, interests, and visions of change are prioritized (Meadows, 1999; Leach et al., 2010). This insight has led scholars to advocate for participatory and reflexive approaches to leverage points research, emphasizing inclusion, imagination, and collective learning as vital components of any transition process (Pereira et al., 2018; O'Brien, 2012).

Ultimately, leverage points thinking invites a fundamental reorientation in how we approach change. Instead of treating symptoms, it seeks to act on root causes. Instead of managing systems, it asks how systems can evolve. And instead of focusing solely on action, it also engages with intention—shifting not only what we do, but what we aim for, and why (Table 1).

Table 1. Leverage Points for Sustainability Transformation (Adapted from Abson et al., 2017)

Leverage Point Depth	Type of Intervention	Description	Examples	Transformative Potential
Shallow	**Parameters**	Adjustments to measurable variables within the system without altering its underlying structure or goals.	Tax rates, efficiency targets, emission limits	Low
	Feedbacks	Modifications to feedback mechanisms that regulate the system's behavior over time. They can dampen or reinforce systemic patterns.	Environmental fines, subsidies, performance incentives	Moderate
Deep	**System Design**	Changes to the institutional architecture, decision-making rules, and power relations that shape how the system functions.	Multi-level governance, participatory platforms	High
	System Intent (Goals & Paradigms)	Shifts in the overarching purpose, values, or dominant paradigms that define what the system is for and how success is measured.	From GDP growth to wellbeing, degrowth narratives	Very High

2.3. Resilience as a property of governance networks

The concept of resilience has become central to the analysis of socio-ecological systems and the governance arrangements that shape their capacity to withstand, adapt to, and transform in response to shocks and long-term stressors. Originally rooted in ecological theory (Holling, 1973), resilience has evolved into a multi-dimensional concept encompassing the ability of systems not only to absorb disturbances and maintain function (*persistence*), but also to adapt their structure (*adaptability*) and even shift into new regimes when needed (*transformability*) (Folke et al., 2010; Walker et al., 2004).

When applied to governance systems, resilience entails more than technical robustness or institutional efficiency. It reflects the degree to which institutional configurations, actor relationships, and decision-making processes can respond flexibly and innovatively to emerging challenges—particularly those associated with climate change, resource scarcity, or socio-political conflict (Biggs et al., 2012; Pahl-Wostl, 2009). In this view, governance networks are not merely instruments of control or regulation, but dynamic arenas in which resilience is continuously negotiated, reproduced, or undermined.

A resilient governance network is characterized by features such as diversity of actors and knowledge systems, redundancy in roles and responsibilities, modularity to contain cascading failures, and the capacity for learning and self-organization (Berkes et al., 2003; Janssen et al., 2006). Polycentricity—the coexistence of multiple centers of authority—is also considered a key feature, as it enables more adaptive and context-sensitive responses across scales and sectors (Ostrom, 2010; Huitema et al., 2009).

Critically, resilience is not a neutral or universally beneficial property. Scholars have warned against uncritically celebrating resilience without examining *what* is being made resilient and *for whom* (Cote & Nightingale, 2012; Béné et al., 2012). Systems can be resilient in maintaining unsustainable or unjust arrangements, such as elite capture of resources, exclusionary institutions, or maladaptive dependencies.

Therefore, assessing resilience in governance networks requires a normative lens—one that interrogates not only the system's capacity to endure, but also its ability to evolve toward more equitable, democratic, and sustainable configurations (Westley et al., 2011; Chaffin et al., 2014).

In the context of climate adaptation and water governance, resilience is increasingly conceptualized as a relational property that emerges from the interactions among actors, institutions, and ecological processes (Pahl-Wostl, 2009; Bixler et al., 2016). The structure and quality of relationships—trust, accountability, shared visions—are essential to understanding how governance systems mobilize collective action, coordinate across fragmented mandates, and navigate uncertainty. It is within this relational perspective that the integration of resilience thinking with network-based approaches finds its relevance: not as a static attribute of institutions, but as a dynamic, distributed, and contested capacity that is embedded in governance configurations.

3.Murcia As Case study

The Region of Murcia is one of Europe's most water-stressed agricultural areas, with irrigation withdrawals totaling nearly 1.7 billion m³ per year—over 80 % of regional use—and a structural deficit of roughly 20 % covered by the Tagus–Segura inter-basin transfer and advanced wastewater reuse schemes (FAO, 2021; Confederación Hidrográfica del Segura, 2021). Remarkably, Murcia reclaims and reuses approximately 98 % of treated wastewater for irrigation—well above the EU average—underscoring its position at the forefront of agricultural water reuse (Regional Government of Murcia, 2018; European Commission, 2020).

Despite these innovations, water quality remains a critical concern: nitrate concentrations in Segura-basin aquifers frequently exceed the 50 mg/L limit of the Nitrates Directive (91/676/EEC), while phosphate runoff drives eutrophication events in the Mar Menor coastal lagoon, fueling stakeholder conflicts between irrigation communities seeking expanded transfers and desalination and environmental groups demanding stricter fertilizer controls and reuse quality standards (Confederación Hidrográfica del Segura, 2021). This combination of extreme scarcity, pioneering reuse, and contested water-quality challenges makes Murcia an ideal case for exploring how governance networks and technological interventions co-evolve under these constraints.

This analysis will be complemented by comparative case studies in the Netherlands, Poland, the United Kingdom, Sweden, Finland, Italy, and Ukraine, in future stages of the study.

4.Methodology

The methodology of this study is supported by COSMIC1, an open-access, interactive virtual platform that integrates data collection, actor-network visualization, and social network and leverage point analysis. COSMIC serves as both an academic research resource and a practical tool for multi-actor governance, centralizing data from the eight FARMWISE case studies (ES, IT, FI, ND, UK, UKr, PO, SW). As introduced before, in this work in progress paper, only the Spanish case study, in the Murcia region, will be introduced.

The sampling universe varies according to each case study's territorial context, acknowledging that an innovation system may be either regional or national: in the Murcia region in Spain, stakeholders are selected at the autonomous-community level - NUTS2 (regional)[2].

The number of participants was established according to a qualitative representativeness criterion validated jointly by the pilot coordinator and relevant local organizations, rather than through a strict statistical sampling method. Respondent recruitment was based on lists provided by regional leaders, supplemented by contacts identified through the iterative interview process, with explicit recognition and assessment of potential snowball bias (a sampling bias in which participants refer to similar contacts; Bethlehem, 2010). The study employed a

1 https://sus.media.h-da.de/ Developed jointly with the Darmstadt University of Applied Sciences.

[2] NUTS1/2 (national/regional): in countries with smaller administrative subdivisions, such as the Netherlands, where the study is conducted at the national level. / NUTS1 (national): in contexts covering one or more NUTS2 regions within a larger administrative framework, such as those used in Italy.

bottom-up mapping approach, progressively incorporating new stakeholders as they emerged during the interviews. Specifically, representatives of organizations such as irrigation communities, water-and-agriculture innovation firms, public research bodies, agricultural development agencies, farming cooperatives and federations, and journalists and media outlets specialized in environment and agriculture, among others, were surveyed. This iterative process continued until theoretical saturation was reached, ensuring the capture of the diverse perspectives essential for the analysis without relying on formal probabilistic estimates.

Using a multilingual questionnaire through the COSMIC platform, that will be available in eight languages, we collected three types of data structured in three sections: (1) nodes: general organizational information (10 items); (2) edges: description of key interactions among actors (7 items); and (3) leverage points: assessment of water-management leverage points (12 items) using a Likert scale. The main objective of the survey is to provide a robust database for analyzing both social networks under the Social Network Analysis framework (SNA; Wasserman & Faust, 1994) and leverage points from a systems perspective (Abson et al., 2017), thereby visualizing the complexity of the innovation and water-management ecosystem across the FARMWISE regions. Information about the actor network allows the researchers to get qualitative information about the actor network.

This survey was reviewed in a pilot phase by experts in agriculture, sustainability, and governance at the Polytechnic University of Valencia, ensuring coverage of the hydric innovation system's dimensions and internal consistency of the scales, and validating linguistic adaptation with each case-study leader (Dillman, Smyth & Christian, 2014).

Data collection is currently underway only for the FARMWISE Case Study in Spain, specifically in the Murcia region, carried out between February and April 2025. Surveys are administered by telephone during business hours, while simultaneously introducing the data in the COSMIC platform, with an average completion time of 15–18 minutes.

Raw data is stored in a JSON file feeding COSMIC's visualizations. This workflow enables calculation of key metrics—degree, betweenness, density, and modularity—and the creation of force-directed layouts that highlight the most significant interactions (Wasserman & Faust, 1994). All procedures comply with ethical and data protection regulations: participants sign informed consent under the GDPR, with advice from the UPV Data Protection Delegation.

5.Results (under construction

As the network remains under development, the following serves as a provisional illustration of the conclusions that may emerge.

5.1 The use of COSMIC platform

Data collection and preliminary social network computation were executed through the COSMIC (Collaborative Stakeholder Mapping of Interactions and Collaborations) platform, which implements a semi-automated pipeline from survey dissemination to metric extraction:

- **Questionnaire distribution**

A unique, multilingual survey link is generated for each case study and disseminated to identified stakeholders. Respondents provide organizational attributes and enumerate inter-organizational ties via structured fields. This standardized digital instrument reduces measurement error and enhances comparability across contexts (Dillman et al., 2014).

- **Automated data parsing and validation**

Submitted responses are encoded in JSON format. The platform performs syntactic and consistency checks—flagging incomplete metadata or implausible tie entries—and prompts researchers to resolve discrepancies, thus preserving data integrity.

- **Network construction and visualization**

Upon validation, COSMIC automatically interprets the JSON edge list, instantiates an undirected graph, and generates a force-directed sociogram. This immediate visual feedback facilitates iterative sampling adjustments and early detection of structural anomalies.

- **On-the-fly metric computation**

Core SNA metrics at node/individual-level (degree, betwenness, closeness cenetralities) and at network level (node and edge counts, density, average degree, and modularity via the Louvain algorithm) are computed server-side and logged alongside raw data.

- **Data export for advanced analysis**

Processed networks and attribute tables can be exported in interoperable formats (e.g., GEXF, GraphML, CSV), enabling seamless integration with external analytic environments (e.g., Python's NetworkX, R's igraph).

- **Automated workflow with human intervention**

COSMIC transforms a single shared survey link into a parameterized network model with minimal manual intervention. Nevertheless, because stakeholder identification and response completeness rely on participant engagement, rigorous follow-up protocols—including reminder communications and targeted outreach—are required to achieve sufficient coverage, mitigate snowball bias, and satisfy theoretical saturation criteria.

5.2 Murcia's water and innovation social network

Rank	Degree Centrality	Betweenness	Closeness	Eigenvector
Explanation	Proportion of all possible direct ties an actor actually has; high values identify "hubs" with many immediate connections for rapid information/resource exchange.	Extent to which an actor lies on the shortest paths between others; high values flag "brokers" or gatekeepers controlling key communication channels.	Average proximity of an actor to all others (via shortest paths); high values mark those who can reach every stakeholder in a few steps, ideal for quick mobilization.	Influence via association: actors connected to other well-connected peers score highly, marking them as indirect opinion leaders whose reach is amplified by powerful neighbors.
Notes	Identifies actors with the most direct ties, key hubs for transmitting information or resources.	Pinpoints actors that bridge otherwise disconnected groups—critical brokers for cross-cluster coordination.	Highlights actors best positioned for rapid outreach—efficient conduits for time-sensitive communication.	Reveals actors whose influence is amplified by connections to other influential peers—ideal targets for indirect opinion-leader interventions.
1	CEBAS-CSIC	CEBAS-CSIC (171.67)	COBET Tratamientos del Agua SL (1.00)	Universidad Politécnica de Cartagena (1.00)
2	ESAMUR	ESAMUR (100.33)	ESAMUR (0.607)	CEBAS-CSIC (0.954)
3	Confederación Hidrográfica del Segura	Confederación Hidrográfica del Segura (72.00)	CEBAS-CSIC (0.595)	ESAMUR (0.944)
4	Comunidad de Regantes Campo Cartagena	Comunidad de Regantes Campo Cartagena (64.00)	Confederación Hidrográfica del Segura (0.565)	Comunidad de Regantes Campo Cartagena (0.835)
5	AZUD	AZUD (40.67)	SAT #557 (0.554)	Confederación Hidrográfica del Segura (0.760)

Concerning degree centrality, which represents the proportion of all possible direct ties that an organization actually has (i.e., a measure of its immediate interconnectedness), the five highest-scoring actors were CEBAS-CSIC, ESAMUR, Confederación Hidrográfica del Segura, Comunidad de Regantes Campo Cartagena, and AZUD.

This means that these organizations maintain the greatest number of direct relationships within the Murcia governance network, positioning them as key conduits for exchanging information, coordinating activities, and mobilizing resources across stakeholders.

Concerning betweenness centrality, which captures how often an organization lies on the shortest paths linking other pairs of actors (i.e., its potential to broker or gatekeep information flows), the top five and their scores were: CEBAS-CSIC (171.67), ESAMUR (100.33), Confederación Hidrográfica del Segura (72.00), Comunidad de Regantes Campo Cartagena (64.00), and AZUD (40.67). This indicates that these organizations occupy pivotal intermediary positions in the network, controlling key channels through which information and resources traverse between otherwise disconnected stakeholders.

Concerning closeness centrality, which quantifies an organization's average proximity to all other actors in the network (i.e., its capacity for rapid outreach), the highest values were observed for COBET Tratamientos del Agua SL (1.00), ESAMUR (0.607), CEBAS-CSIC (0.595), Confederación Hidrográfica del Segura (0.565), and SAT #557 (0.554). This means that these organizations are, on average, fewer steps away from all other stakeholders, enabling them to disseminate information or coordinate actions across the network more quickly than their peers.

Concerning eigenvector centrality, which reflects influence via connections to other well-connected actors (i.e., indirect prestige or endorsement power), the leading organizations were Universidad Politécnica de Cartagena (1.00), CEBAS-CSIC (0.954), ESAMUR (0.944), Comunidad de Regantes Campo Cartagena (0.835), and Confederación Hidrográfica del Segura (0.760). This indicates that these organizations are not only well-connected themselves but are also linked to other highly connected stakeholders, granting them enhanced indirect influence and prestige within the governance network.

Together, these centrality measures paint a consistent picture of Murcia's water-governance network as a polycentric yet hub-driven system. A small group of organizations—most notably CEBAS-CSIC, ESAMUR, and the Confederación Hidrográfica del Segura—occupy the most direct ties, broker the majority of indirect exchanges, and sit closest on average to all other actors, making them essential for coordination, information flow, and rapid outreach. Meanwhile, the Universidad Politécnica de Cartagena and CEBAS-CSIC extend their reach even further by connecting to other highly central stakeholders, amplifying their indirect influence across the network. This overlap of high-degree hubs, high-betweenness brokers, high-closeness disseminators, and high-eigenvector influencers underscores the critical role of a core group in maintaining network cohesion, facilitating cross-cluster links, and accelerating the spread of innovations or policy directives. At the same time, it points to potential vulnerabilities should any of these central organizations be disrupted, as well as to strategic opportunities for leveraging their positions to achieve system-wide impact.

5.3 Murcia's stakeholders perception about the about their network

Stakeholders from five sectors provided Likert-scale ratings (1 = "completely disagree" to 5 = "completely agree") on three dimensions of network leverage points. Table 6 summarizes, for each sector, the number of respondents (N), mean score, and standard deviation (SD) for each survey item. In each sector, all items received between 1 and 5 ratings, with most sectors providing 2–4 responses per item.

Sector-specific descriptive statistics for network perception items

SECTOR	ITEM	N	MEAN	SD
Surface level				
Academia	The network is strong and cohesive.	2	4.50	0.71
	The network is very diverse.	2	4.00	0.00
	Efficient coordination mechanisms exist.	2	3.50	0.71
Comunicación	The network is strong and cohesive.	1	5.00	–
	The network is very diverse.	1	4.00	–
	Efficient coordination mechanisms exist.	1	4.00	–
Private sector	The network is strong and cohesive.	4	3.50	1.73
	The network is very diverse.	4	4.00	0.82
	Efficient coordination mechanisms exist.	4	3.25	1.50
Sector Público	The network is strong and cohesive.	3	4.00	1.00
	The network is very diverse.	3	4.33	0.58
	Efficient coordination mechanisms exist.	3	3.67	0.58
Sociedad Civil	The network is strong and cohesive.	2	2.50	0.71
	The network is very diverse.	2	3.00	1.41
	Efficient coordination mechanisms exist.	2	3.00	1.41
Intermediate level				
Academia	I would like to collaborate more.	2	4.00	0.00
	Influential actors facilitate sustainable practices.	2	3.50	0.71
	Conflicts impede innovation.	2	2.50	0.71
Communication	I would like to collaborate more.	1	3.00	–
	Influential actors facilitate sustainable practices.	1	3.00	–
	Conflicts impede innovation.	1	2.00	–
Private sector	I would like to collaborate more.	4	4.25	0.96
	Influential actors facilitate sustainable practices.	4	3.50	0.58
	Conflicts impede innovation.	4	3.25	1.50
Public sector	I would like to collaborate more.	3	4.33	0.58
	Influential actors facilitate sustainable practices.	3	3.67	0.58
	Conflicts impede innovation.	3	3.00	0.00
Civil society	I would like to collaborate more.	2	3.50	0.71
	Influential actors facilitate sustainable practices.	2	3.00	1.41
	Conflicts impede innovation.	2	3.00	0.00

Deep level				
Academia	Network prioritizes sustainability over productivity.	2	2.50	0.71
	Ecosystem ready for collaborative governance.	2	4.00	0.00
Communication	Network prioritizes sustainability over productivity.	1	3.00	–
	Ecosystem ready for collaborative governance.	1	4.00	–
Private sector	Network prioritizes sustainability over productivity.	4	2.25	0.83
	Ecosystem ready for collaborative governance.	4	2.25	0.83
Public sector	Network prioritizes sustainability over productivity.	3	2.67	0.58
	Ecosystem ready for collaborative governance.	3	3.67	1.15
Civil society	Network prioritizes sustainability over productivity.	2	3.00	0.00
	Ecosystem ready for collaborative governance.	2	3.50	0.71

Stakeholder groups differed in how they rated the cohesion, diversity, and coordination of the Murcia governance network ("surface level"). Academic and Public Sector respondents consistently rated network strength and diversity highly (mean scores ≥ 4.0 out of 5) and judged coordination mechanisms to be moderately efficient (3.5–4.0). Private Sector actors provided more varied answers, with average scores of 3.5 for cohesion, 4.0 for diversity, and 3.25 for coordination. Civil Society gave the lowest surface-level ratings (2.5–3.0), while the sole Communications respondent rated all three dimensions between 4 and 5.

On the "intermediate level," which addresses actors' willingness to collaborate, the role of influential organizations, and the impact of conflicts, Public and Private Sector participants expressed the strongest desire to work more closely with the network (means slightly above 4.0). Academics' willingness to collaborate was similarly high (4.0), whereas Civil Society and Communications scored this item at 3.5 and 3.0, respectively. Across sectors, opinions were moderate on whether key actors facilitate sustainable practices (means around 3.5) and on whether conflicts obstruct innovation (means ranging from 2.5 to 3.25).

At the "deep level," concerning the network's underlying goals and readiness for new governance models, all groups gave lower ratings on whether sustainability takes priority over productivity (means between 2.25 and 3.0). In contrast, perceived readiness for a more collaborative, sustainable governance approach was rated highest by Academia and Communications (4.0) and lowest by the Private Sector (2.25), with Public Sector and Civil Society falling in between (3.5–3.7).

6.discussion: qualitative integration of stakeholder's network perceptions (under construction)
Drawing on resilience theory and leverage-point concepts, stakeholder perceptions help us understand Murcia's governance network in three ways: its ability to absorb shocks, to adapt over time, and to transform fundamentally.

Absorptive capacity (surface-level perceptions & parameter levers)
High ratings of network cohesion and diversity among Academia and Public Sector actors align with a capacity to absorb disturbances through redundant ties and multiple information channels (Berkes et al., 2003). These perceptions corroborate the high-degree centrality of CEBAS-CSIC and ESAMUR, suggesting that immediate "parameter" interventions—such as enhanced data-sharing protocols—can be readily deployed via these hubs to buffer short-term shocks. In contrast, Civil Society's lower ratings suggest some groups may be left out, pointing to areas where we need focused outreach to strengthen these weaker points.

Adaptive capacity (intermediate-level perceptions & feedback levers)
Strong expressed willingness to collaborate (especially in Public and Private sectors) reflects a positive feedback orientation—actors are ready to adjust practices in response to evolving conditions (Pahl-Wostl, 2009). This theme resonates with high-betweenness metrics: brokers like ESAMUR occupy positions to catalyze adaptive loops by convening multi-stakeholder working groups or piloting iterative policy-learning exercises. However, moderate

concern about conflicts suggests that without clear feedback mechanisms—like performance-based incentives or mediation forums—adaptation may stall.

Transformative capacity (deep-level perceptions & intent levers)
Views diverged on whether sustainability goals outweigh productivity goals. Some actors remain focused on traditional mandates, while others are open to deeper change, despite both actors can be innovating and fostering paradigm shifts (Folke et al., 2010). These normative divergences correspond to Meadows' "intent" leverage points: changing goals and paradigms is inherently political and requires deliberate engagement of central institutions (e.g., Confederación Hidrográfica del Segura) to convene reflexive dialogues. The relatively higher readiness perceived by Academia and Communications suggests pockets of transformative potential that can be activated through strategic framing exercises and co-creation workshops.

7.Preliminary conclusıons

The COSMIC platform was pivotal in this research, providing an end-to-end, semi-automated pipeline from survey deployment to network visualization and metric extraction. Its multilingual interface, real-time validation checks, and built-in SNA computations enabled rapid development of a fully parameterized network model from a single questionnaire link.
However, ensuring that peripheral actors were included—and thereby mitigating snowball bias—required diligent follow-up by the research team.

Overall, the combination of COSMIC-enabled network analytics and qualitative insights offers a scalable, replicable methodology for diagnosing resilience and guiding multi-level interventions: simple "parameter" fixes via data-sharing protocols, "feedback" instruments like incentives and demonstration projects, and "intent" dialogues to realign system goals. Future research should broaden stakeholder engagement, track network dynamics over time, and pilot the identified leverage-point interventions to assess their impact on adaptive capacity and transformative change.

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