Integrated Environmental Assessment and Management, 2026, **00**, 1–18
https://doi.org/10.1093/inteam/vjag093
Published: June 5, 2026
Original Article | Environmental Management

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag093/8703276 by Orta Dogu Teknik University Library (ODTU) (Inactive) user on 29 September 2026

Enhancing the governance of the Water–Energy–Food–Ecosystem (WEFE) nexus in watersheds through combined stakeholder and social network analysis

Ece Demir[1], Ezgi Özdemir[1], B. İrem Yapan[1], Buse B. Kart[1], Esin Yandımata[1], Yasemin Demir[2], Pınar D. Güre[3], Gülser Köksal[4,†], and Emre Alp[1,*]

[1]Department of Environmental Engineering, Middle East Technical University, Ankara, Türkiye
[2]Soil, Fertilizer and Water Resources Central Research Institute, Republic of Türkïye Ministry of Agriculture and Forestry, Ankara, Türkiye
[3]Department of Economics, Middle East Technical University, Ankara, Türkiye
[4]Department of Industrial Engineering, TED University, Ankara, Türkiye
[†]Deceased.
*Corresponding author: Emre Alp, Email: emrealp@metu.edu.tr.

Abstract

The multifunctional role of water resources and their interconnections with the broader Water–Energy–Food–Ecosystem (WEFE) nexus necessitate a deeper understanding of complex governance structures involving diverse stakeholders. In this study, an integrated approach was developed in which stakeholder analysis and social network analysis were supported by the water value chain framework to categorize the key actors in watershed management, analyze network cohesion, and identify opportunities for cross-sectoral collaboration within the WEFE nexus. The Porsuk Watershed, located in a semi-arid region with growing resource challenges, offers a compelling case for exploring these governance dynamics. The findings revealed a fragmented water management structure with overlapping responsibilities, leading to inefficiencies and coordination challenges. Governmental bodies, national actors, and stakeholders in the "Manage Closely" quadrant of the interest–influence matrix exhibited strong internal collaboration within their respective groups but engaged less with other groups. Similarly, stakeholders within WEFE components showed stronger in-group collaboration than cross-group interactions, which exacerbated resource inefficiencies, increased trade-offs, and restricted synergies, thereby emphasizing the need for improved inter-sectoral coordination. Downstream actors demonstrated a higher interest in water governance than upstream actors due to their vulnerability to upstream decisions, while upstream actors showed a lower interest as they are less directly affected by the externalities they create. The information network exhibited fragmented information flow dominated by central actors, while academics, research institutions, and nongovernmental organizations remained underutilized, limiting their influence despite their expertise. These findings demonstrate the effectiveness of this integrated approach in understanding the social dynamics of WEFE nexus governance in watersheds.

Keywords Water–Energy–Food–Ecosystem (WEFE) nexus, stakeholder analysis, social network analysis, water value chain, circular economy

Introduction

Water governance faces the critical challenge of navigating the interdependencies of water, food, and energy systems (Ghafoori Kharanagh et al., 2020). By integrating social, economic, environmental, and technological processes, the Water–Energy–Food–Ecosystem (WEFE) nexus approach seeks to mitigate conflicts, minimize problem transfers across sectors, and maximize reciprocal advantages, positioning itself as a pivotal framework for sustainable watershed management (Benites-Lazaro et al., 2021; Jones & White, 2021; Stein et al., 2011). Similar to the WEFE nexus, the circular economy is an increasingly influential approach in resource management, emphasizing a closed-loop model of production and consumption over traditional "end-of-life" approaches (Kirchherr et al., 2017; Korhonen et al., 2018).

The water crisis in watersheds often stems from a limited understanding of interconnected social, economic, political, and physical factors (Nabiafjadi et al., 2021). Social factors are particularly important since watershed and administrative boundaries often differ, resulting in stakeholders with conflicting goals for resource management (Salajegheh et al., 2020). Moreover, poor sectoral coordination and the implementation of

Received: November 7, 2025. **Revised:** March 18, 2026. **Accepted:** May 26, 2026
© The Author(s) 2026. Published by Oxford University Press on behalf of the Society of Environmental Toxicology and Chemistry.
This is an Open Access article distributed under the terms of the Creative Commons Attribution License (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted reuse, distribution, and reproduction in any medium, provided the original work is properly cited.

nonparticipatory and top-down decision-making processes further contribute to the mismanagement of resources (Ghafoori Kharanagh et al., 2020). Effective management, therefore, requires an integrated approach that considers cross-sectoral interactions and all relevant subsystems, achievable through the WEFE nexus approach and collaborative governance between cross-sectoral actors (Benites-Lazaro et al., 2021). Collaborative governance plays a key role in developing coherent WEFE nexus policies and can be fostered by analyzing stakeholder dynamics and existing institutional arrangements (Demir, 2025). A failure to understand these dynamics can undermine efforts to resolve conflicts in natural resource governance (Ahmadi et al., 2019).

Incorporating social approaches into natural resource management can mitigate the limitations of relying solely on quantitative assessments by accounting for institutional and stakeholder considerations that are not captured by quantitative indicators alone (Lienert et al., 2013). In this context, value chain thinking, stakeholder analysis (SA), and social network analysis (SNA) offer complementary perspectives for examining governance and coordination challenges in multi-actor systems.

The integration of SA and SNA has the potential to address the limitations of both methodologies by creating a complementary approach that leverages SA's focus on actor traits and SNA's emphasis on interaction patterns (Narayan et al., 2020; Wu et al., 2020). The application of SNA can be enriched by SA findings while also addressing SA's tendency to overlook stakeholder relationships and treat actors as isolated units (Dos Muchangos et al., 2017). The integration of SA and SNA is a well-established approach that has been widely used across diverse disciplines, including environmental management (Ahmadi et al., 2019; Reyhani & Grundmann, 2021; Sharifian et al., 2022). Methodological integration is increasingly prominent in WEFE nexus research, as illustrated by efforts that combine stakeholder-oriented and network-based approaches to examine collaborative governance (Jones & White, 2021), embed decision-analytic techniques within network assessments to characterize actor power (Ghafoori Kharanagh et al., 2020), and link value chain perspectives with institutional analysis to interpret how rules and incentives shape nexus outcomes (Villamayor-Tomas et al., 2015).

This study aims to categorize the key actors in watershed management and analyze their interactions, proposing strategies to enhance network cohesion and promote cross-sectoral collaboration within the WEFE nexus. An integrated SA and SNA framework that incorporates the water value chain (WVC) is used to examine stakeholder dynamics, helping address the methodological limitations of SA and SNA. The analysis is applied in the Porsuk Watershed, a semi-arid region facing persistent water management challenges, where rising industrial and urban demand, upstream abstractions, and pollutant loads from domestic, industrial, and agricultural sources have intensified water quantity and quality pressures and amplified upstream–downstream tensions (see *Materials and methods*/*Study area* section).

This research is undertaken as part of the TÜBİTAK 121R014 project, which is dedicated to establishing a methodological framework for the assessment of circular water economy models within the WEFE nexus to facilitate sustainable watershed management (Alp et al., 2024). As a key element of this initiative, the research generates insights to support the formulation of water management strategies, the promotion of circular practices, and the creation of an integrated roadmap for the WEFE nexus.

In this study, the WVC serves as a structured framework to elucidate stakeholder roles and interactions and to facilitate stakeholder characterization in SA and relationship identification in SNA. The SA component evaluates stakeholder interest and influence to support coordination and engagement in decision-making processes, while the SNA component examines stakeholder interactions to identify structural deficiencies and collaborative opportunities. Advancing the literature, this study introduces sectoral WVCs at the watershed level to enhance system insights, develops a novel interest–influence assessment within SA to resolve longstanding inconsistencies, and integrates WVC into SNA for a more nuanced analysis of stakeholder relationships. By doing so, the study provides meaningful contributions to watershed management research.

Materials and methods

This study is organized into three main phases: system definition, data collection, and data analysis (Figure 1). The system definition involves the selection of a watershed with diverse stakeholders and conflicts in water management (*Materials and methods*/*Study area* section), the identification of relevant actors (*Materials and methods*/*Data collection* section), and the development of sectoral WVCs (*Materials and methods*/*Water value chain* section). Data collection includes semi-structured interviews and the processing of interview data (*Materials and methods*/*Data collection* section). Finally, the data analysis phase utilizes SA (*Materials and methods*/*Stakeholder analysis* sections) and SNA (*Materials and methods*/*Social network analysis* sections).

Study area

The Porsuk Watershed, spanning 10,825 km^2, is characterized by a semi-arid Mediterranean climate and receives an average annual rainfall of 494 mm (ÇŞİDB, 2021). The land use includes agricultural lands (51.4%), forests (45.3%), and artificial areas (2.9%), with minor contributions from water bodies and wetlands (Copernicus, 2018). The watershed is situated in the Eskişehir and Kütahya provinces, serving 1,002,397 people and distributing water resources predominantly to agriculture (60.2%), urban use (23.4%), and industry (16.4%) (DSİ, 2017). The economic landscape of Eskişehir and Kütahya reflects the diverse uses of the Porsuk Watershed's resources, with Eskişehir focused on services (52.1%), industry (32.4%), and agriculture (15.5%), while Kütahya shows a more balanced distribution across agriculture (39.0%), services (35.3%), and industry (25.7%) (TÜİK, 2012). In the watershed, surface water pollution arises from industrial discharges, domestic wastewater, and agricultural runoff, disrupting irrigation for key crops such as grains and sugar beets. Key contributors to pollution include two major domestic wastewater treatment plants and industrial

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag093/8703276 by Orta Dogu Teknik University Library (ODTU) (Inactive) user on 29 September 2026

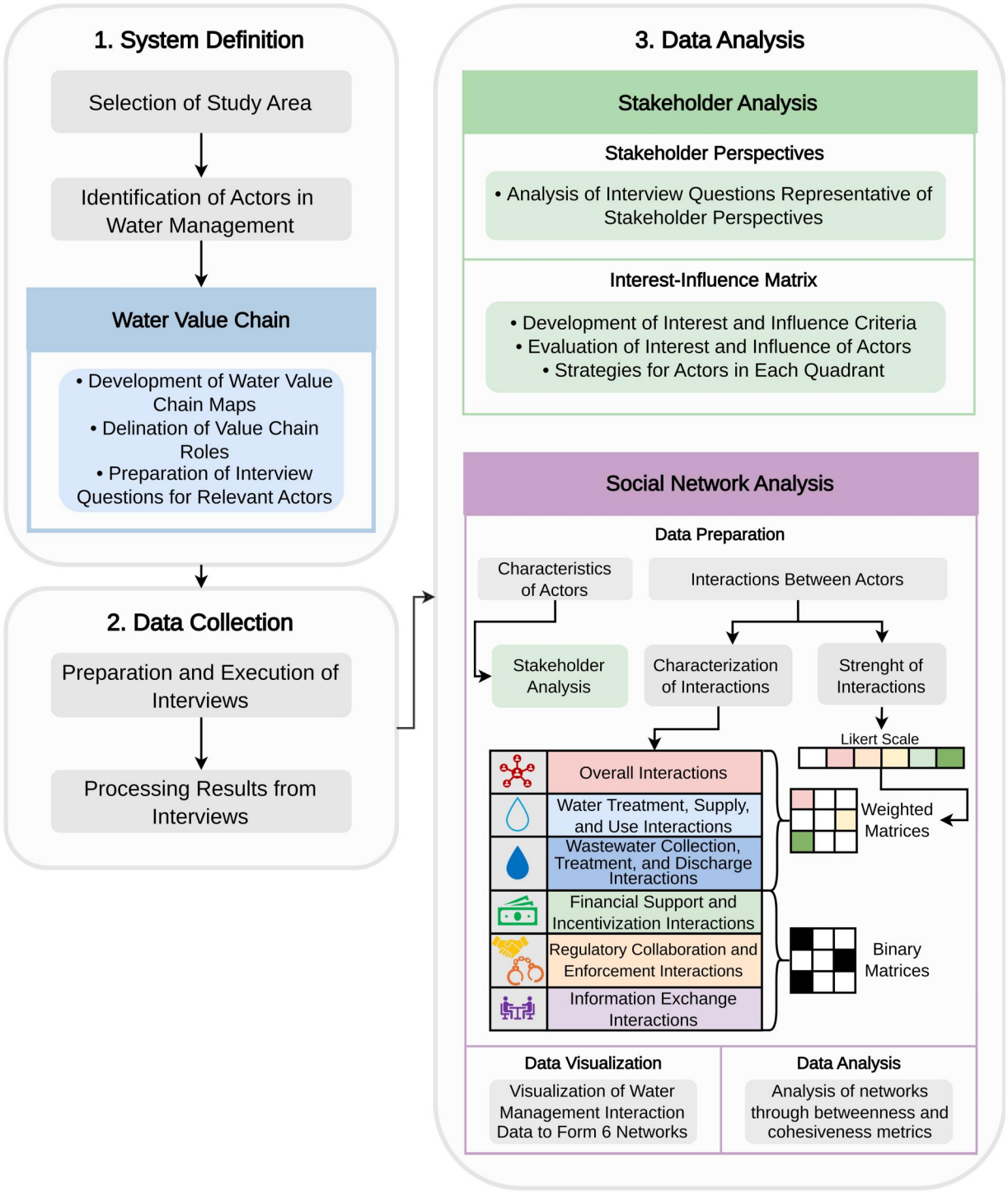

Figure 1 Methodology for enhancing WEFE nexus governance: a combined stakeholder and social network analysis for managing conflicting agendas in watersheds.

zones, notably Kütahya Organized Industrial Zones (OIZs) 1 and 2 and Eskişehir OIZ, alongside smaller industries.

Various regulatory and infrastructural interventions have been introduced to address these pressures, including the expansion of centralized wastewater treatment facilities, watershed-level monitoring programs, and stricter discharge standards aligned with national and European water legislation. In addition, spatial planning instruments such as the "Special Regulations for the Porsuk Dam Lake Basin" have defined protection zones, land-use restrictions, and development constraints intended to protect surface and groundwater resources (Demir, 2025). However, despite these measures, water stress and quality degradation remain persistent challenges, partly due to fragmented institutional responsibilities and uneven

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag093/8703276 by Orta Dogu Teknik University Library (ODTU) (Inactive) user on 29 September 2026

enforcement capacity. These dynamics also reinforce upstream–downstream tensions, as downstream users are directly affected by upstream withdrawals and pollution externalities.

Data collection

Stakeholders were initially identified through a document-based screening of watershed-specific planning and management materials for the Porsuk Watershed, including master plan documents and drought watershed management plans, from which organizations explicitly referenced as water users or management actors were compiled into a preliminary list (e.g., municipalities, agricultural cooperatives, and key industrial sectors). To ensure adequate representation of major industrial water users (IWUs), this list was expanded using The Union of Chambers and Commodity Exchanges of Türkiye database by screening facilities based on Statistical Classification of Economic Activities in the European Community (NACE) codes and capacity reports to identify actors with potentially significant water use or watershed-level impacts. The stakeholder pool was refined and supplemented through snowball sampling, and the final sample consisted of stakeholders who were identified through these steps and agreed to participate in the interviews.

Following site selection and stakeholder identification, semistructured interviews were designed to collect data. The development of the interview questions began with stakeholder segmentation, examining the position of institutions within the circularity framework using the 5W1H approach (detailed in online supplementary material Table A.1). The interview structure comprised three sections: The first section focused on institutional information, the second on sustainable water management and the institution's roles within the WVC, and the third on the circular economy. While the third section, addressing circular economy questions, remained consistent across all forms, the other sections were revised in accordance with the responsibilities of each institution.

The interviews were tailored to a diverse range of stakeholders, including representatives from OIZs, industrial producers, farmers, development agencies, State Hydraulic Works (DSİ), thermal power plants, nongovernmental organizations (NGOs), chambers of industry and agriculture, as well as various ministries and their provincial and district directorates. To explicitly incorporate the WEFE nexus into the interview design, WEFE nexus framing and WVC-based actor classes were used to tailor interview prompts and guide discussions with stakeholders, including those whose responsibilities relate to food, energy, and ecosystem dimensions of water management. Interview discussions therefore addressed cross-sector linkages, trade-offs, and synergies in relation to sustainability, circularity, and water circularity practices, rather than focusing solely on water-sector dynamics. Detailed information on interview question development is provided in online supplementary material Appendix A. Differences in interview sections across stakeholder groups are illustrated in online supplementary material Figure A.4, and the full set of questions is provided in Demir (2025). The distribution of interviewed actors across WEFE components, including overlaps between components, is summarized in online supplementary material Figure A.3.

Between July 6 and October 21, 2022, 50 face-to-face interviews were conducted, each lasting approximately 1.5 hr, with support from a team of three to five researchers who carefully documented the discussions. Regional maps and sectoral WVCs were provided to facilitate these discussions. Representation across key dimensions was ensured, including operational area (e.g., upstream/downstream), institution type, sector involvement, NACE codes, WEFE nexus component involvement, main WEFE nexus component, hierarchical rank (1: highest to 4: lowest), water pricing entitlements, water withdrawal points, wastewater discharge environments, alternative water sources, and project completion timelines. Stakeholder selection was designed to ensure broad representation across sectors and adequate geographic coverage within the study area. The spatial and sectoral distribution of interviewed stakeholders is presented in Figure 2, while the distribution of interviewed stakeholders across WVC classes is summarized in Table 1. Further detail on the distribution of all analyzed stakeholder attributes relevant to resource management is provided in online supplementary material Figure A.2.

After data collection, interview notes recorded by multiple researchers were consolidated and refined through iterative research-team discussions to ensure consistent interpretation across interviews. The consolidated interview data were compiled into actor-level tables and analyzed using open and axial coding to identify recurring concepts, which were subsequently grouped into higher-level categories and subcategories relevant to water management and used to synthesize stakeholder perspectives. Further qualitative detail on these stakeholder perspectives is reported in Demir (2025).

These interview-derived outputs were then used as the main input for the integrated WVC, SA, and SNA analyses. First, interview responses were used to identify each stakeholder's primary role within the WVC and to support consistent actor classification in Table 2. Second, qualitative data were translated into quantitative interest and influence scores based on the predefined criteria described in the *Materials and methods*/*Interest–influence matrix* sections. In parallel, interview statements describing collaboration, coordination, regulatory enforcement, information exchange, and financial support were extracted, coded by interaction type, direction, and strength, and transformed into the adjacency matrices used to construct the six interaction networks analyzed in the *Materials and methods*/*Analysis of network data* sections.

To address practical challenges associated with interview-based data generation, including uneven access across stakeholder groups, differences in willingness to disclose information, and variability in the level of detail provided, the interview notes were reviewed through structured research-team discussions and subjected to participatory validation. Feedback from the TÜBİTAK 121R014 Project Closing Workshop (April 29, 2024) was incorporated into the synthesis to strengthen the consistency and interpretability of the interview data and the resulting SA and SNA outputs.

Stakeholder analysis

The SA process identifies significant stakeholders, explores their perspectives, and determines which stakeholders should be prioritized in decision-making (Bendtsen et al., 2021; Pereira et al., 2025). A comprehensive understanding of social dynamics through SA can enhance the implementation of the WEFE nexus by improving stakeholder representation, fostering dialogue,

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag093/8703276 by Orta Dogu Teknik University Library (ODTU) (Inactive) user on 29 September 2026

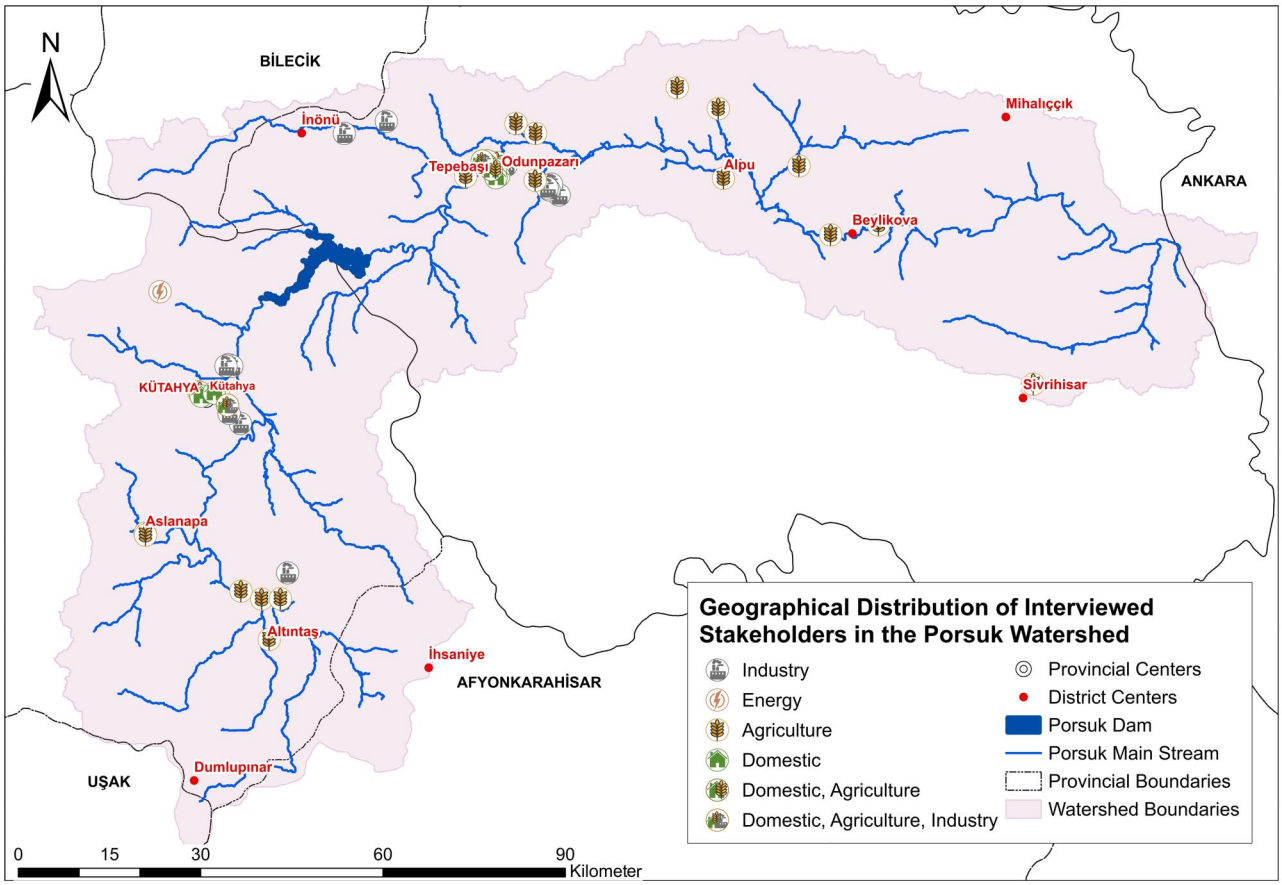

Figure 2 Geographical distribution of interviewed stakeholders by sector in the Porsuk Watershed.

Table 1 Number and percentage of stakeholders interviewed across water value chain classes.

Water value chain classes	Number of interviewed stakeholders per category	Proportion of total interviewed stakeholders per category (%)
Agricultural water user (AWU)	10	20.00
Industrial water user (IWU)	9	18.00
Agricultural water supply (WS)	2	4.00
Water supply/wastewater treatment (WS/WT)	7	14.00
Legislation provider/implementer (LPI)	10	20.00
Occupational organization (OO)	4	8.00
Incentive/support provider (I/S)	3	6.00
Information provider/research and development (R&D)	3	6.00
Nongovernmental organization (NGO)	2	4.00

and facilitating consensus-building among diverse groups to develop widely accepted, practical solutions for resource management, thereby supporting decision-making processes (Bendtsen et al., 2021; Lienert et al., 2013).

Despite the literature recognizing the benefits and varied applications of SA, the effectiveness of some components remains debated (Reed et al., 2009). Questions persist regarding the consistency of SA, its reliance on subjective assessments, the validity of data sources, and the fragmented perspectives it produces (Dos Muchangos et al., 2017; Reed et al., 2009). Additionally, unclear theoretical foundations and a tendency toward ad hoc approaches in SA contribute to ongoing uncertainty (Bendtsen et al., 2021; Lienert et al., 2013; Reed et al., 2009).

As outlined in Figure 1, the SA methodology encompasses the development of WVCs before the interviews (*Materials and methods*/*Water value chain* sections) and the construction of the interest–influence matrix based on interview outputs (*Materials and methods*/*Interest–influence matrix* sections).

Water value chain

The value chain approach is used to examine a product's lifecycle and provide insights into organizational relationships by

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag093/8703276 by Orta Dogu Teknik University Library (ODTU) (Inactive) user on 29 September 2026

Table 2 Responsibilities associated with water value chain classes.

Water value chain classes	Water value chain responsibility/role
Agricultural water user (AWU)	Production of goods, water supply, and providing knowledge and experience related to agricultural activities.
Industrial water user (IWU)	Production of goods.
Agricultural water supply (WS)	Irrigation water supply, crop pattern recommendation, organizing training, providing knowledge and expertise on agricultural activities, and maintenance and repair activities.
Water supply/wastewater treatment (WS/WT)	Process water supply, providing information and/or technical support, water supply, control of discharges, wastewater treatment, water treatment and distribution, and collection and treatment of wastewater, interinstitutional coordination, project development, drinking water supply, water quality monitoring, planning/project design, sampling from wastewater treatment plants, water storage, and reservoir operations.
Legislation provider/implementer (LPI)	Product pattern recommendations, interinstitutional coordination, organizing trainings, strategic planning, water supply, project development, control of discharges, environmental impact assessment (EIA) processes, coordination between farmers and institutions, providing information and expertise on agricultural activities, preparation of agricultural inventory, water quality monitoring, environmental management with sustainable principles, providing incentives, planning/project design, sampling from wastewater treatment plants, conducting inspections related to polluted surface waters, reviewing and approving water reuse projects, conducting inspections upon complaints, legislative studies, inspection activities, financial support, providing information and/or technical support, and supplying irrigation water.
Occupational organization (OO)	Interinstitutional coordination, organizing training, providing information and/or technical support, coordination between farmers and institutions, crop pattern recommendation, industrial development, and training qualified personnel.
Incentive/support provider (I/S)	Financial support, providing information and/or technical support, organizing training, conducting R&D studies, strategic planning, project development, wastewater collection and treatment, industrial development, and providing incentives.
Information provider/research and development (R&D)	Organizing training and conducting R&D activities, crop pattern recommendation, providing information and/or technical support, compliance with the Green Deal, providing knowledge and expertise on agricultural activities, environmental management with sustainable principles, and raising awareness.
Nongovernmental organization (NGO)	Raising awareness, interinstitutional coordination, and organizing trainings.

tracing key stages and exchanges (Chofreh et al., 2019; Neri et al., 2025). It is widely applied to industrial products but remains underutilized in water resource management (Maaß & Grundmann, 2018; Villamayor-Tomas et al., 2015).

This research develops sectoral WVCs for the Porsuk Watershed to delineate stakeholder roles and key interactions in water management, addressing a critical gap in watershed-scale analyses. The development process includes (a) identification of water sources and discharge bodies, (b) definition of water management stages (e.g., extraction, treatment, distribution, and discharge), (c) specification of sectoral processes (e.g., irrigation for agriculture, recycling for industry, and cooling for energy), (d) identification of water losses (e.g., leakage and evaporation) and additions (e.g., evapotranspiration and soil moisture), and (e) depiction of stakeholder roles across these stages.

In many cases, stakeholders fulfill multiple responsibilities across various WVC stages. For example, OIZ directorates manage water treatment, transmission, and wastewater disposal while also enforcing relevant standards, and development agencies provide financial support while contributing to knowledge dissemination. To maintain analytical clarity, stakeholders are categorized according to their primary roles within the WVC, with

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag093/8703276 by Orta Dogu Teknik University Library (ODTU) (Inactive) user on 29 September 2026

detailed responsibilities summarized in Table 2 and the corresponding abbreviations used throughout the text. At the same time, multifunctional and cross-sectoral roles are accounted for in the SNA by distinguishing interaction types, so that actors can be represented in different capacities across networks and their broader roles can be interpreted through network structure and centrality patterns rather than through multiple formal labels.

Interest–influence matrix

This research systematically evaluates stakeholder interest and influence by analyzing their attributes, categorizing them into four quadrants (Manage Closely, Keep Satisfied, Keep Informed, and Monitor) in the interest–influence matrix, and suggesting management strategies for each quadrant based on established literature to enhance engagement in decision-making processes. In the method developed in this study, interest is evaluated using knowledge of circularity practices, implementation efforts, and awareness of local drought conditions, while influence is assessed through six criteria: legitimate, expert, economic, positional, referent power, and environmental impact, all of which contribute to sustainable development. These criteria were developed by adapting concepts from existing literature, especially in relation to influence assessment (Cummings, 2019; Gabel, 2012; Khakhar & Ahmed, 2017; Lunenburg, 2012; Weber, 1993).

Interest–influence criteria are rated on a five-point scale ranging from 0 to 10, from indifferent to extremely interested and from minimal to great influence for interest and influence, respectively. The scores for each criterion were assigned through a structured interpretation of interview responses, in which qualitative evidence related to the indicator questions was evaluated by the research team and translated into numeric values according to the predefined scoring scale. To improve consistency and reduce individual bias, the scoring process was discussed iteratively among the researchers before final stakeholder positions in the matrix were determined. The final interest and influence scores for each stakeholder were determined by averaging the scores across their respective criteria, with equal weight assigned to each criterion. Figure 3 presents an overview of this assessment, while online supplementary material Figures C.1 and C.2 detail the definitions and interpretation of interest and influence levels for each criterion.

Social network analysis

The SNA approach focuses on relationships between actors and their interactions to reveal key individuals, groups, linkages, and structural patterns (Govender et al., 2025; Narayan et al., 2020; Ncube & Pittock, 2025). The use of SNA can be instrumental in enhancing system understanding, identifying areas for improvement, providing policy recommendations, and offering insights into actors' roles beyond traditional structures (Jones & White, 2021; Narayan et al., 2020). Additionally, SNA can identify key

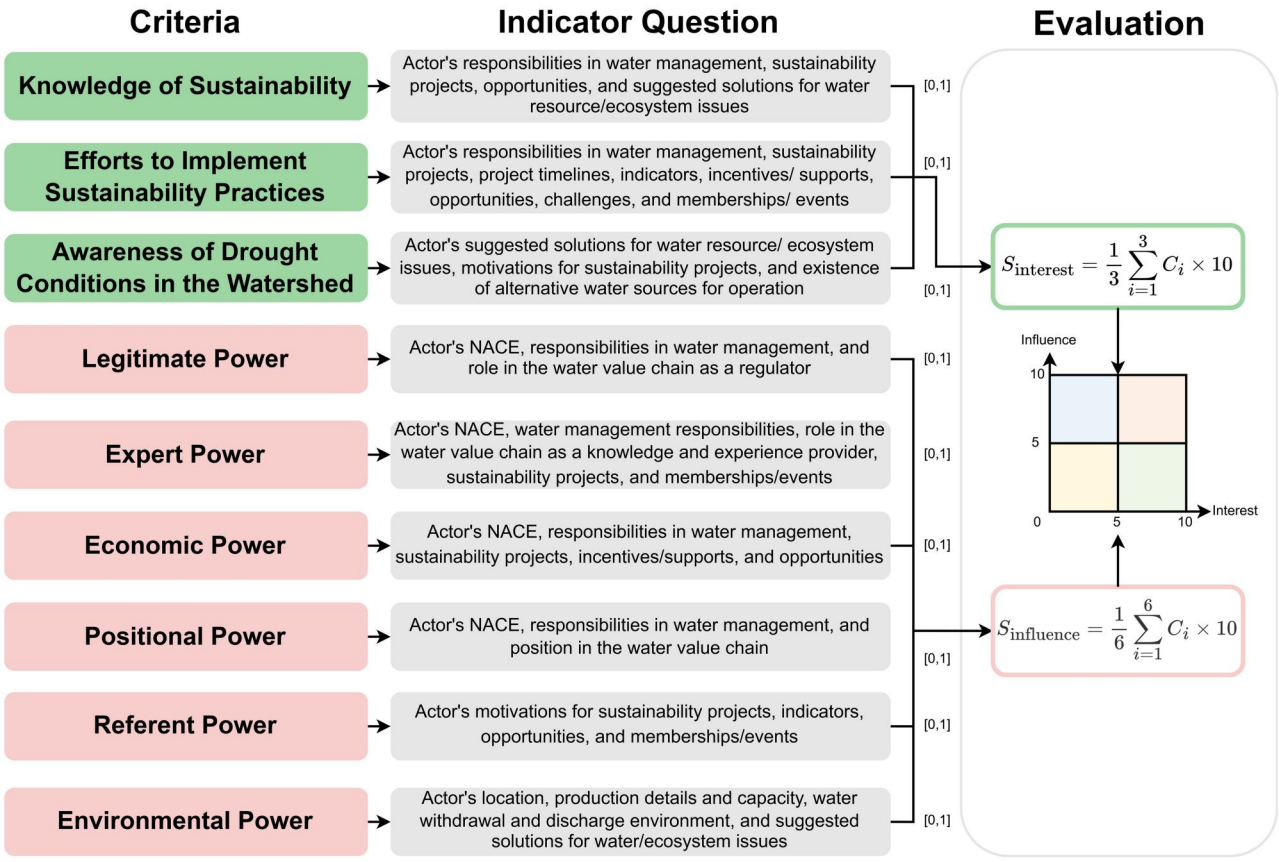

Figure 3 Criteria and indicator questions used to evaluate stakeholder interest and influence. NACE, Statistical Classification of Economic Activities in the European Community; $S_{interest}$, stakeholder interest score; $S_{influence}$, stakeholder influence score; C_i, criterion score.

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag093/8703276 by Orta Dogu Teknik University Library (ODTU) (Inactive) user on 29 September 2026

network actors who are best positioned to disseminate information and mediate disputes, further bolstering collaborative governance efforts (Ahmadi et al., 2019; Ghafoori Kharanagh et al., 2020).

However, there are limitations to the social network perspective, which assumes that actors are interconnected and that resource exchanges transmitted through their ties can enhance or hinder their ability to act, thereby influencing how coordination and collaboration unfold in resource management and governance (Wasserman & Faust, 1994). This can be limiting because ties may be inefficient or symbolic, and their number may not reflect meaningful coordination or decision-making influence. Moreover, SNA studies often struggle to define stakeholder linkages in a policy-relevant way, constraining their utility for WEFE governance (Jones & White, 2021).

As outlined in Figure 1, SNA employs a three-stage methodology, beginning with data preparation (*Materials and methods*/*Preparation of network data* sections), followed by network visualization, and concluding with analysis of communication at the network, subgroup, and actor levels using cohesiveness and embeddedness metrics (*Materials and methods*/*Analysis of network data* sections).

Preparation of network data

In social networks, nodes represent stakeholders, and edges represent their interactions. Node attributes are informed by SA, while this section defines actor interactions (edges) in terms of direction, weight, and type. Edge direction refers to the flow between two nodes, which can be directed (one-way, shown with arrows) or undirected (reciprocal, shown with lines) (Ghafoori Kharanagh et al., 2020). Edge weight represents the intensity or frequency of interactions, illustrated by edge thickness (Bellingeri et al., 2023). Edge type describes the characteristics of relationships within the network.

In this study, the definition of edge type follows a WVC approach, resulting in the formation of six networks detailed below. (a) *Water Treatment, Supply, and Use Interactions* and (b) *Wastewater Collection, Treatment, and Discharge Interactions* involve exchanges essential for water access and wastewater disposal (directed to reflect mass flow, weighted by water volume and the corresponding coordination needs, with nonhuman actors included). (c) *Financial Support and Incentivization Interactions* represent stakeholder efforts to secure financial resources for circular practices (directional, unweighted, reflecting the flow of funds). (d) *Regulatory Interactions* are divided into two types: regulatory collaboration involving exchanges under collaborative governance that reflect shared authority, partnerships, and consensus-based decisions (unweighted, undirected), and regulatory enforcement interactions to ensure compliance with environmental regulations (directed from higher to lower authority) (Carlsson & Berkes, 2005). (e) *Information Exchange Interactions* include meetings, collaborative planning, data sharing, and resource exchange (undirected and unweighted). Finally, (f) *Overall Interactions* encompass all the previously described interactions (undirected, weighted by their frequency and type).

Social networks are modeled using adjacency matrices, square matrices that detail node interactions. This study utilizes six matrices (three weighted and three binary), which are visualized in *Gephi 0.10* (Bastian et al., 2009). Details on the validation of network data are provided in online supplementary material Appendix D.

Analysis of network data

This study employs metrics for cohesiveness and embeddedness to examine network structures using UCINET 6.775 (Borgatti et al., 2002). At the network and subgroup levels, cohesiveness metrics, such as the external–internal (E–I) index, network density, core–periphery structure, and clustering, evaluate unity and interconnectedness, which are essential for fostering cross-sector governance and collaboration among groups (Jones & White, 2021). At the node level, embeddedness metrics, including degree centrality, betweenness centrality, and eigenvalue centrality, measure the integration of individual nodes within the network, highlighting key actors and potential communication pathways. High embeddedness indicates strong resource access and efficient connectivity within the WEFE system (Jones & White, 2021). A detailed explanation of these metrics and their relevance is provided below.

Cohesiveness measures

The External–Internal Index evaluates the tendency for in-group versus cross-group interaction on a scale from −1.0 (in-group) to +1.0 (cross-group), supporting the evaluation of intergroup collaboration in this study (Jones & White, 2021). *Network Density* quantifies the proportion of actual connections relative to possible connections, with higher values often interpreted as indicators of stronger cohesion, trust, and enhanced cooperation and resource flow (Dos Muchangos et al., 2017; Ghafoori Kharanagh et al., 2020). *Core and Periphery Fit* distinguishes between central, influential stakeholders and peripheral ones, highlighting power dynamics within the network, with fit values approaching 1 indicating a closer alignment with the theoretical core–periphery structure (Geneson & Tsai, 2022; Narayan et al., 2020). *Clustering* measures the formation of tightly connected groups within communities (Ghafoori Kharanagh et al., 2020).

Embeddedness measures

Degree Centrality quantifies an actor's direct connections, with higher values signifying leadership roles and influence in decision-making and policy development (Ahmadi et al., 2019). In-degree centrality reflects the number of incoming connections, indicating access to resources, while out-degree centrality represents outgoing connections, highlighting influence in knowledge dissemination and resource allocation (Ghafoori Kharanagh et al., 2020). *Betweenness Centrality* identifies actors serving as intermediaries that link clusters, potentially regulating the flow of information and resources (Jones & White, 2021). *Eigenvalue Centrality* evaluates an actor's influence by analyzing their connections to other highly central nodes (Powell & Hopkins, 2015).

Results and discussion

This section details the outcomes of the integrated methodology, encompassing SA in the *Results and discussion*/*Stakeholder*

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag093/8703276 by Orta Dogu Teknik University Library (ODTU) (Inactive) user on 29 September 2026

analysis sections and SNA in the *Results and discussion*/*Social network analysis* sections.

Stakeholder analysis

This section presents findings from SA, starting with preliminary insights from WVCs (*Results and discussion*/*Water value chain* sections), followed by evaluations of stakeholder interest and influence (*Results and discussion*/*Interest–influence matrix* sections).

Water value chain

The watershed-scale sectoral WVCs developed for the Porsuk Watershed (Figure 4) illustrate water flows from sources such as groundwater, streams, and rainwater to end-users and eventual discharge. Detailed sector-specific WVCs for agriculture, urban systems, industry, and energy are provided in Supplementary Appendix B (see online supplementary material Figures B.1–B.4). Figure 4 presents an integrated representation of the WVC four main sectors in the watershed, namely agriculture, urban systems, industry, and energy. The integrated WVC is organized along sequential stages that include water sources, ecosystem requirements, transmission, water treatment and distribution, end uses, wastewater collection and treatment, production, and final discharge. This structure allows for the visualization of how water is abstracted, conveyed, used, and returned to the environment across multiple sectors of the watershed. Overall, Figure 4 and Supplementary Appendix B (see online supplementary material Figures B.1–B.4) reveal that water governance in the Porsuk Watershed is shaped by a complex institutional structure in which multiple actors operate across interconnected stages and often assume overlapping responsibilities. This complexity was also emphasized during stakeholder interviews, where the DSİ third Regional Directorate identified overlapping roles between provincial administrations and metropolitan municipalities as a source of conflict.

As outlined in the methodology, the interviewed stakeholders were categorized by their primary roles within the WVC to enhance clarity, resulting in the following distribution: agricultural water user (AWU) (20%), legislation provider/implementer (LPI) (20%), IWU (18%), water supply and wastewater treatment (WS/WT) (14%), occupational organization (OO) (8%), incentive/support provider (I/S) (6%), research and development (R&D) (6%), NGO (4%), and WS (4%). The interviews also explored stakeholders' preferred future roles within the WVC. While most stakeholders expressed a preference to maintain their current positions, the R&D class indicated a desire for greater involvement in regulatory governance, and the I/S group expressed interest in taking a more active role in knowledge dissemination.

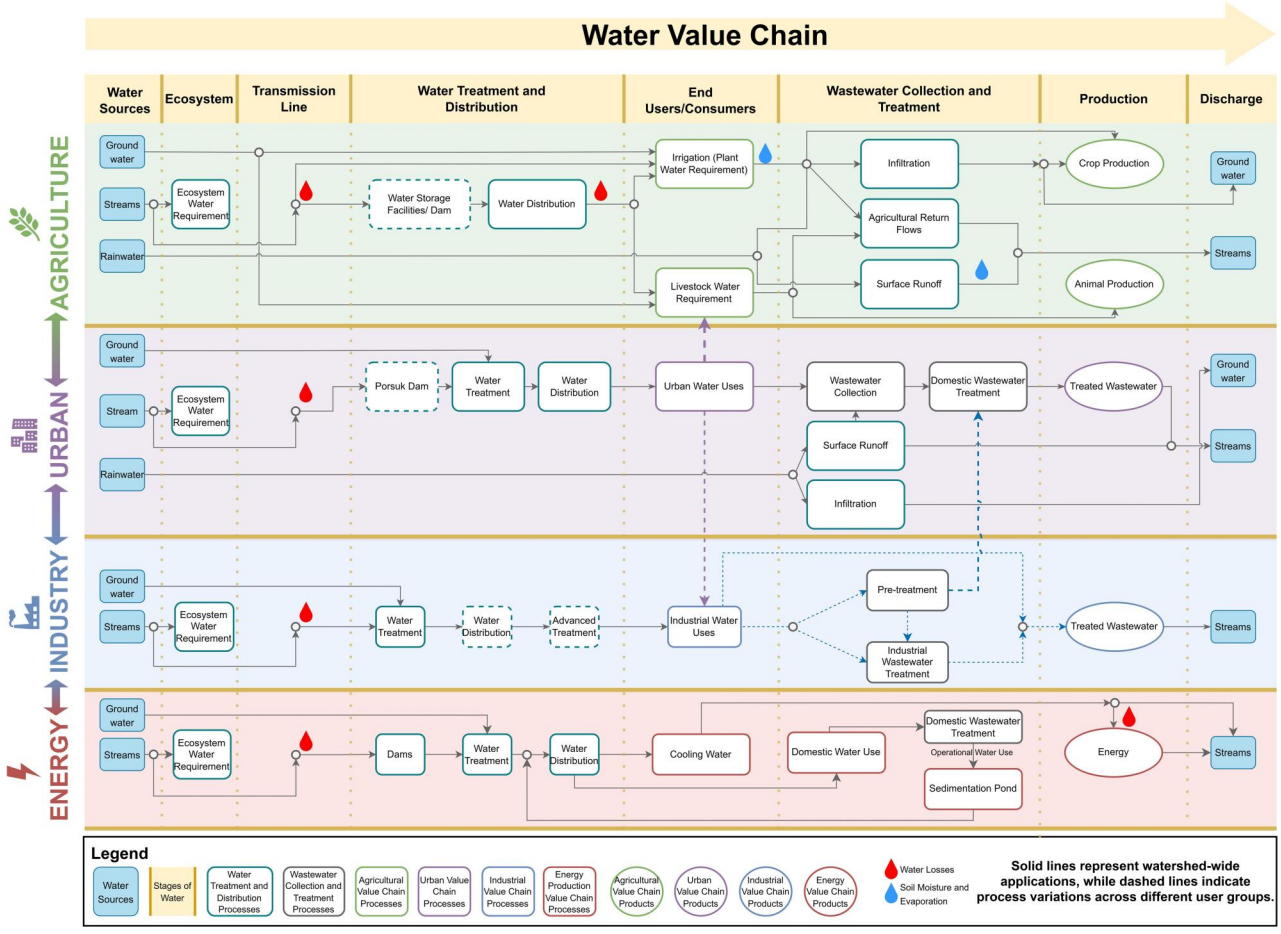

Figure 4 Water value chains across agriculture, urban, industrial, and energy sectors.

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag093/8703276 by Orta Dogu Teknik University Library (ODTU) (Inactive) user on 29 September 2026

Interest–influence matrix

Figure 5 illustrates stakeholders' interest–influence levels, with 36% classified as "Manage Closely," 48% as "Keep Informed," 4% as "Keep Satisfied," and 12% as "Monitor." Overall, high interest is observed in 84% of stakeholders, while 40% exhibit high influence in water management. Research organizations (R&D), irrigation unions (WS), and governmental bodies (LPI) demonstrate the highest levels of interest, whereas OOs, farmers (AWU), and NGOs exhibit the lowest. Similarly, influence levels reveal significant disparities, with municipalities and OIZs (WS/WT) alongside governmental bodies (LPI) exerting considerable influence, while OOs, farmers (AWU), and NGOs have relatively limited influence.

Figure 6 presents a box-and-whisker plot illustrating the distribution of stakeholder interest and influence within the WVC. Figure 6 reveals that governing bodies (LPI), encompassing public institutions with varying hierarchical roles, experience notable variability in influence, primarily shaped by institutional size and geographic positioning. Occupational organizations display a wide range of values for both interest and influence, with chambers of industry holding greater influence and chambers of agriculture exhibiting higher interest. Interest levels among NGOs vary according to their focus on circularity, while their influence remains stable. Irrigation unions show minimal variability, maintaining consistently moderate influence; this outcome also reflects the limited sample of two irrigation unions included in the study.

Figure 7 illustrates distinct patterns in stakeholder interest and influence. Regarding interest, sustainability knowledge is most prominent among funding agencies (I/S), research institutions (R&D), and OOs, while municipalities and OIZs (WS/WT) demonstrate the strongest efforts to implement sustainability practices. Drought awareness is particularly notable among NGOs, research institutions, farmers, and industries. In terms of influence, governmental bodies (LPI), municipalities, OIZs, and irrigation unions exhibit the highest levels of positional and legitimate power. Conversely, research institutions, funding agencies, and NGOs hold expert power. Economic power is concentrated within funding agencies, ministries, municipalities, and OIZs, while referent power is strongest among funding agencies, NGOs, research institutions, and OOs. Occupational organizations show limited positional, legitimate, and expert power, while NGOs possess the least economic power. These findings highlight opportunities to leverage stakeholder strengths while addressing existing gaps.

Across the interest–influence quadrants, distinct trends emerge. "Manage Closely" actors, mostly municipalities and OIZs (33%) and governmental bodies (27%), are primarily public-sector actors (61%). "Keep Informed" stakeholders, encompassing farmers (29%) and industries (25%), governmental bodies (16%), and research institutions (12%), align with the food component (66%) and are primarily downstream (62%). "Monitor" stakeholders, largely farmers (66%), occupy lower hierarchical positions. Stakeholders associated with the food component generally exhibit lower influence compared to other WEFE components. Stakeholders with broader geographic coverage, such as watershed (interest: 8.33) and national (interest: 7.77) levels, show higher interest due to their role in policy formulation, while localized stakeholders (upstream and downstream) exhibit lower interest, focusing more on operational

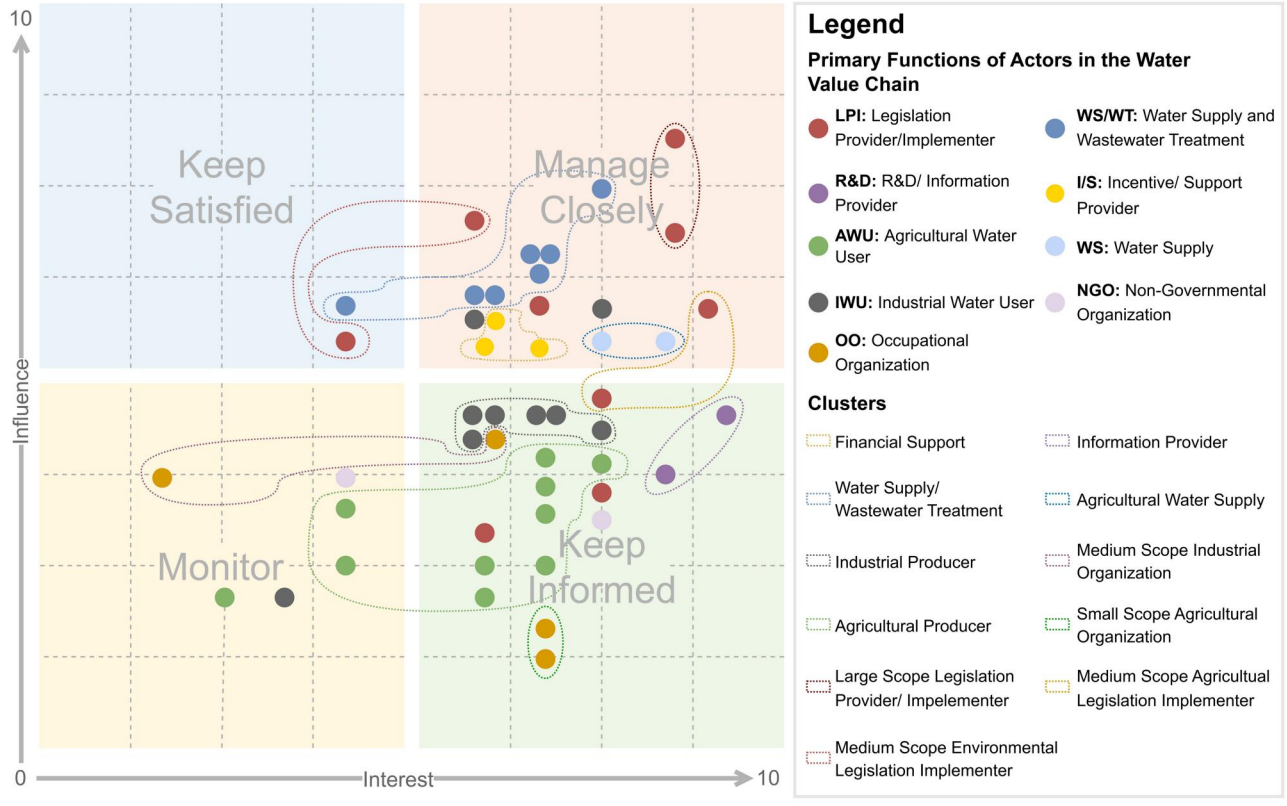

Figure 5 Distribution and clustering of stakeholders across the interest–influence matrix.

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag093/8703276 by Orta Dogu Teknik University Library (ODTU) (Inactive) user on 29 September 2026

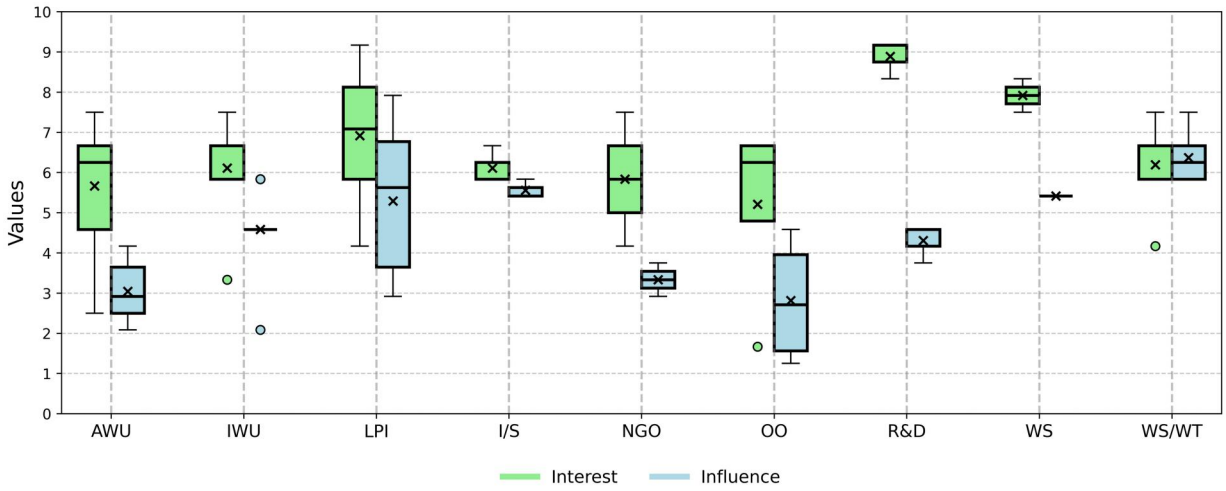

Figure 6 Distribution of stakeholder interest–influence scores across water value chain classes. AWU, agricultural water user; IWU, industrial water user; LPI, legislation provider/implementer; I/S, incentive/support provider; NGO, nongovernmental organization; OO, occupational organization; R&D, research and development/information provider; WS, water supply; WS/WT, water supply and wastewater treatment.

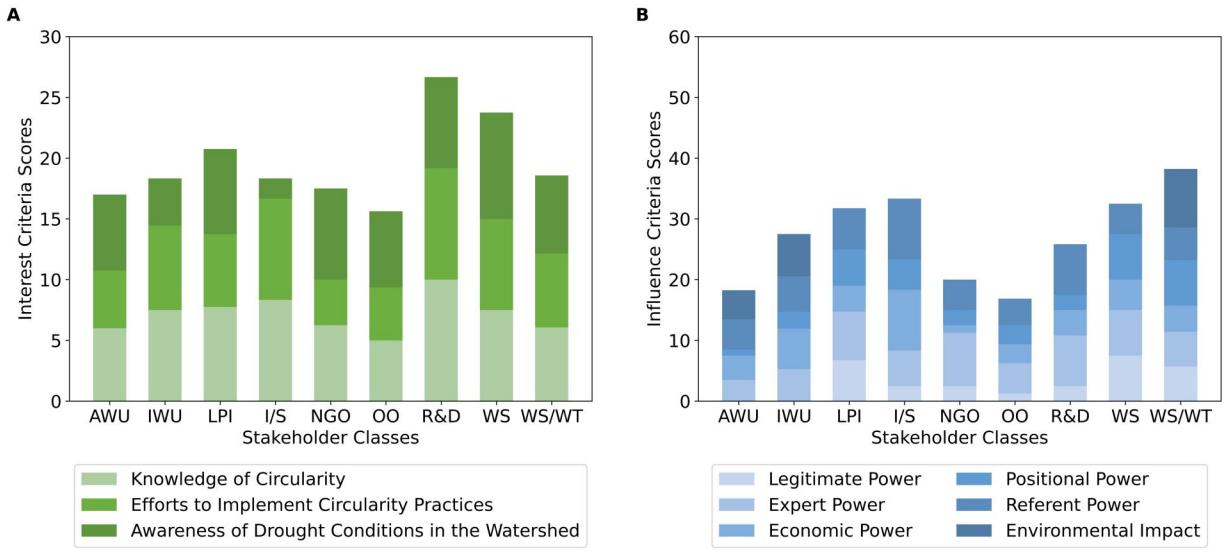

Figure 7 Criteria-level analysis of stakeholder (A) interest and (B) influence scores across water value chain classes. AWU, agricultural water user; IWU, industrial water user; LPI, legislation provider/implementer; I/S, incentive/support provider; NGO, nongovernmental organization; OO, occupational organization; R&D, research and development/information provider; WS, water supply; WS/WT, water supply and wastewater treatment.

concerns. At the local scale, downstream actors (interest: 6.42) exhibit greater interest in water governance than upstream actors (interest: 5.75) due to their vulnerability to upstream decisions, while upstream actors show lower engagement as they are less directly affected by the externalities they create. These findings suggest the need to enhance upstream–downstream collaboration through the application of participatory decision-making processes, the implementation of incentive structures to engage upstream actors, the initiation of awareness campaigns on shared responsibilities, and the enforcement of stricter regulations to mitigate negative externalities.

The WVC classes within each quadrant correspond closely to stakeholder profiles identified in the literature. Tailored strategies recommended in the literature to manage these stakeholders include prioritizing "Manage Closely" stakeholders (WT/WS, WS, I/S, LPI) to facilitate policy change, consulting "Keep Informed" stakeholders (AWU, IWU, R&D, OO) to ensure continued engagement, collaborating with "Keep Satisfied" stakeholders (LPI, WS/WT) to maintain their support, and educating "Monitor" stakeholders (AWU) to enhance awareness (Brouwer & Brouwers, 2014; Eden & Ackermann, 2021; ESCAP, 2018).

Social network analysis

This section outlines the findings of SNA at three levels: the entire network (*Results and discussion/Network-level findings*

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag093/8703276 by Orta Dogu Teknik University Library (ODTU) (Inactive) user on 29 September 2026

sections), subgroups (*Results and discussion/Subgroup level findings* sections), and individual actors (*Results and discussion/Actor-level findings* sections).

Network-level findings

At the network level, this study explores the number of actors, linkages, network density, core/periphery configuration, and clustering within six WVC interaction networks, as visualized in Figure 8. As Figure 8 depicts, participation, measured by the number of actors and connections, varies considerably across value chain interactions. The overall network, comprising 75 actors and 619 connections, emerges as the largest. In contrast, more specialized or localized networks, such as water (35 actors, 38 connections) and wastewater (18 actors, 17 connections), demonstrate significantly lower levels of participation. Density, reflecting network cohesion, is highest in the overall (0.341), wastewater (0.258), and water (0.097) networks. In contrast, lower densities are observed in the information (0.084), regulatory (0.063), and financial (0.031) networks.

Notably, the regulatory and information networks demonstrate increased density and participation, particularly among regional LPIs operating under the "Special Regulations for the Porsuk Dam Lake Basin." This initiative, led by downstream urban WS/WT and involving eight key stakeholders, including provincial directorates, regional hydraulic works, and governorships, not only establishes water body-specific pollutant discharge standards for drinking water sources but also enhances opportunities for collaboration through improved communication among stakeholders.

The regulatory network exhibits the highest core–periphery fit (0.572), indicating a well-defined hierarchy where central actors hold dominant roles and peripheral stakeholders have limited connections. This is followed by the wastewater (0.480), information (0.409), water (0.395), overall (0.394), and financial (0.301) networks, which demonstrate moderate alignment with the core–periphery structure. In the financial network, resource distribution is more decentralized, spanning multiple administrative levels. Consistent with previous studies, regional and national public actors occupy central, well-connected positions, while local governments often remain on the periphery, particularly in regulatory and information networks (Ghafoori Kharanagh et al., 2020; Stein et al., 2011). The clustering

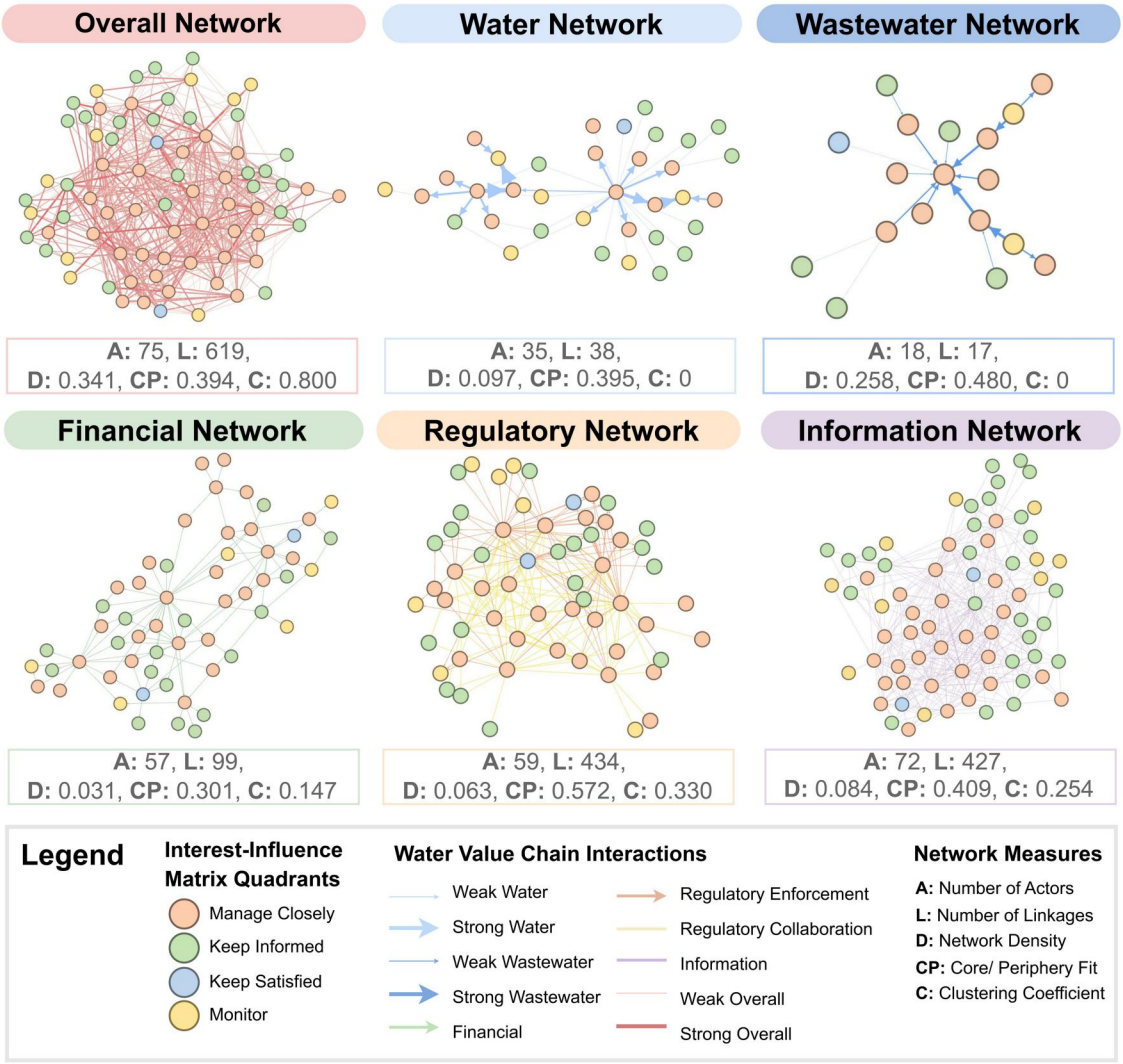

Figure 8 Social network diagrams and network-level measures for water value chain interactions.

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag093/8703276 by Orta Dogu Teknik University Library (ODTU) (Inactive) user on 29 September 2026

coefficient is highest in the overall network (0.800), reflecting tightly connected groups, with lower values for the regulatory (0.330), information (0.254), and financial (0.147) networks. Consistent with the literature, clusters align with administrative boundaries, reinforcing the importance of geographic proximity in collaboration (Janssens De Bisthoven et al., 2022). Finally, the information network's low density (0.084), high clustering (0.254), and strong core–periphery fit (0.409) suggest fragmented information flow controlled by central actors.

From a WEFE nexus perspective, all nexus pillars are represented in both the core and peripheral positions of the overall interaction network, although clearer patterns emerge when the interaction types are examined separately. Water-related actors are more central in the water and wastewater networks, energy-related actors are more central in the financial network, and ecosystem-related actors are more central in the regulatory network. The information network exhibits the greatest diversity, with all nexus pillars represented in central positions. Across these networks, food-sector actors tend to remain more peripheral, likely due to their smaller operational scale and predominantly user-oriented roles. A more detailed discussion of WEFE nexus representation is provided in the *Results and discussion/Sub-group level findings* sections.

Subgroup level findings

Figure 9 presents trends in the total number of internal and external linkages, network density, and the E–I index for stakeholder groups across value chain interaction networks, categorized into high (≥67%), moderate (≥33% and <67%), and low (<33%) percentiles. Figure 9 reveals distinct patterns in stakeholder communication levels (total number of linkages), in-group collaboration (density), and cross-group collaboration (E-I index). These patterns are discussed below.

Water value chain

Communication levels are highest for governmental bodies (LPI), indicating significant engagement across value chain interactions. Similarly, density is highest for LPI, reflecting strong in-group collaboration. However, the E–I index highlights limited external interaction for LPI, coupled with internal densities being 3–5 times higher than network averages. This suggests a strong reliance on in-group interactions (Janssens De Bisthoven et al., 2022). These findings align with Nabiafjadi et al. (2021), who observed that actors like LPI often prioritize internal networks due to centralized decision-making structures. While this ensures operational efficiency, it limits external engagement and reduces opportunities for diverse collaboration, which are both critical for addressing complex challenges and implementing effective policies (Sagie & Orenstein, 2022).

Geographical scope

Higher density values correlate with broader geographical scopes, with national actors demonstrating densities 3–4 times above network averages, consistent with Nabiafjadi et al. (2021). Watershed actors, despite their intermediary role in bridging local and national stakeholders, exhibit relatively high E–I indices but are weak in in-group collaboration. According to Janssens De Bisthoven et al. (2022) and Stein et al. (2011), this issue can be addressed by reinforcing vertical relationships, which are essential for improving coordination in decision-making and effectively implementing nexus approaches in watershed management.

The WEFE nexus

Water and food components of the WEFE nexus exhibit stronger in-group collaboration compared to cross-group collaboration (E–I index), consistent with the findings of Ghafoori Kharanagh et al. (2020). Furthermore, our findings reveal that the strongest cross-group collaboration is observed between ecosystem and water actors, consistent with the findings of Jones and White (2021). However, the observed pattern may be partly attributed to smaller sample sizes in these components.

It should also be noted that cohesion (density) within all WEFE nexus components in financial, information, and regulatory interactions remains low. According to Jones and White (2021), such low cohesion may constrain the capacity of these components to support coordinated decision-making, reinforcing the argument that strong in-group collaboration may also be a prerequisite for effective cross-group engagement.

Interest–influence matrix

The "Manage Closely" quadrant exhibits low cross-group collaboration (E–I index) and in-group collaboration (density) that is 2–3 times above network averages, making it the most insulated quadrant. This isolation undermines system effectiveness by restricting bottom-up approaches, defined as processes initiated at the local or community level, and limiting the integration of diverse perspectives, leading to outdated, homogenous information (Dos Muchangos et al., 2017). In contrast, the "Keep Informed" and "Monitor" quadrants exhibit low density but high E–I indices, reflecting openness to partnerships despite limited internal cohesion/trust. These findings suggest the need to strengthen collaboration between the "Keep Informed" and "Manage Closely" quadrants for effective policymaking, which can be achieved through collaborative discussions and renewed stakeholder connections (Dos Muchangos et al., 2017; Zhakenova, 2017).

Hierarchical position

Findings reveal that higher hierarchical levels (e.g., Level 1) are characterized by limited cross-group collaboration and heightened in-group collaboration, while lower levels (e.g., Levels 3 and 4) exhibit the reverse pattern. This is evident in Levels 1 and 2, which exhibit internal densities 3–8 times above network averages, underscoring their insulated structures. These results align with Nabiafjadi et al. (2021), who reported that cohesive decision-making is concentrated at the highest levels and subsequently delegated to lower authorities. Similarly, our findings parallel those of Stein et al. (2011), who observed that vertical (hierarchical) interactions often overshadow horizontal interactions across WEFE nexus components.

Actor-level findings

This section examines the distribution patterns of degree centrality, betweenness centrality, and eigenvalue centrality within WVC interactions. In the water network, intermediaries such as OIZs, municipalities, and irrigation cooperatives exhibit the highest betweenness centrality, serving as critical connectors between users and diverse sources. In the wastewater network, centralized industrial wastewater management downstream is

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag093/8703276 by Orta Dogu Teknik University Library (ODTU) (Inactive) user on 29 September 2026

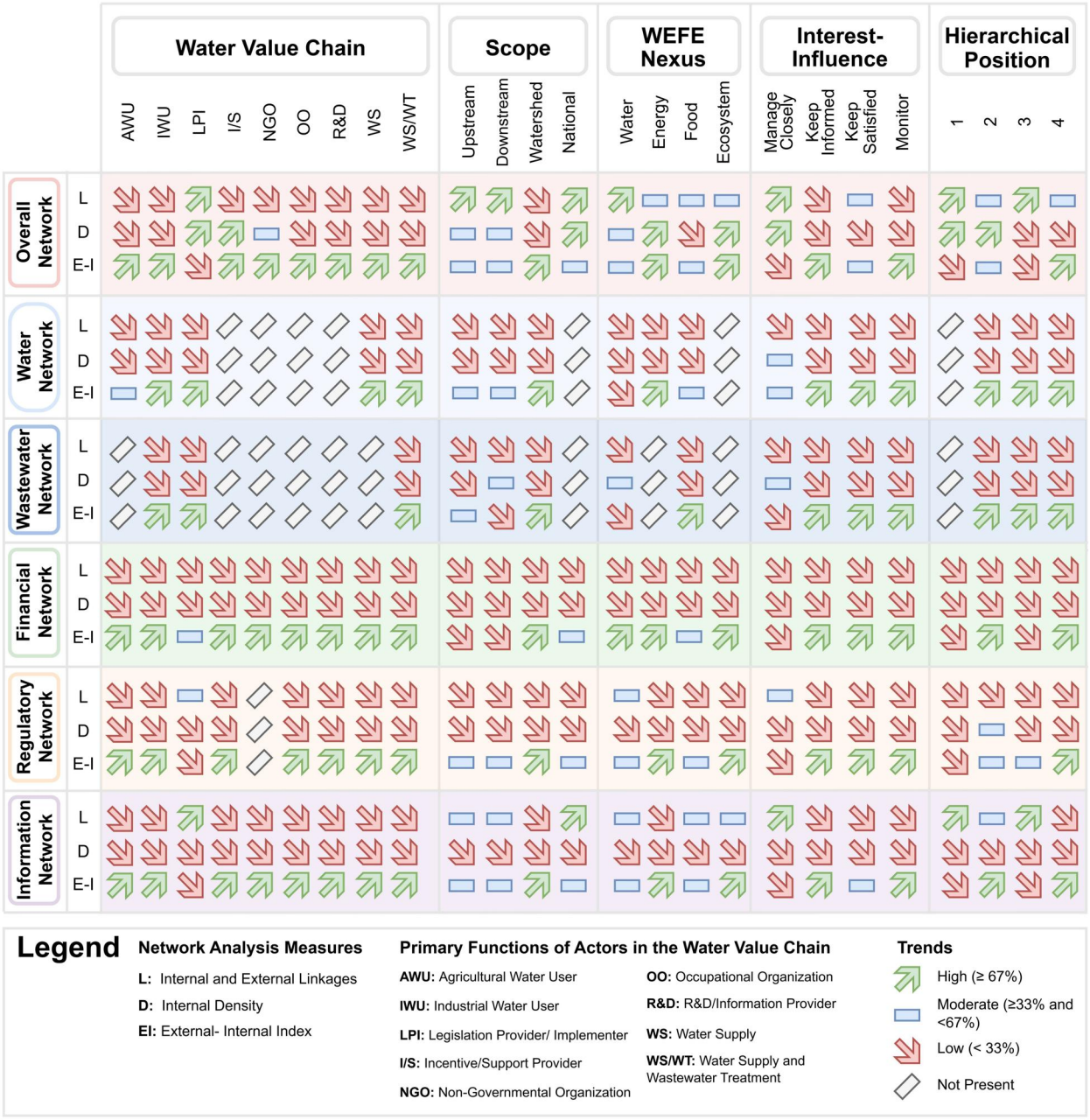

Figure 9 Percentile trends for internal and external linkages (L), internal density (D), and external–internal (E–I) index across WVC, scope, WEFE nexus, interest–influence, and hierarchical position attributes for WVC interactions. WVC, water value chain; WEFE, Water–Energy–Food–Ecosystem.

found to be associated with reduced clustering. Water and wastewater interactions, by necessity, show higher cross-group collaboration (E–I index), as all water users and wastewater producers from different WEFE components must coordinate with water-related stakeholders.

In the financial network, international funds, development agencies (I/S), municipalities (WS/WT), and governmental bodies (LPI) stand out with the highest out-degree and betweenness centrality, underscoring their influence in directing funding and regulating resource flows. The high betweenness centrality of national actors suggests that financial capital remains concentrated and predominantly controlled by public-sector actors at the national level, consistent with the findings of Ghafoori Kharanagh et al. (2020). A clear connection between financial and information networks emerges, reflected in stakeholder statements such as an upstream farmer's acknowledgment of "no information mechanism (on funding)" and a watershed research institution's comment on decreased government support, which limited conference attendance.

The regulatory network is predominantly led by the DSİ third Regional Directorate, a watershed governing body overseeing well permits and enforcement activities, with 57% of its connections dedicated to regulatory enforcement. The high betweenness centrality of ministries, governorships, and provincial

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag093/8703276 by Orta Dogu Teknik University Library (ODTU) (Inactive) user on 29 September 2026

directorates underscores their potential as key connectors, facilitating more effective regulatory coordination, information dissemination, and enforcement within the WEFE nexus.

Within the information network, ministries at the national level hold the highest centrality, mainly interacting with local directorates and financial institutions. Locally, development agencies, governorships, and DSİ are key contributors to knowledge dissemination. External collaboration across WEFE components is least observed among actors in information interactions, followed by regulatory interactions, and is most prominent in financial interactions. Betweenness centrality is highest within the information network, underscoring the essential roles of ministries, consultancy firms, and provincial directorates in bridging stakeholders and enabling connections across the network. Conversely, academics, research institutions, and NGOs exhibit low centrality despite their capacity to enhance the dissemination, accessibility, and quality of information.

Stakeholder feedback and governance implications

To strengthen interpretive robustness and practical relevance, preliminary findings from this study were shared and collectively discussed with watershed stakeholders at the TÜBİTAK 121R014 Project Closing Workshop on April 29, 2024. Participants reviewed the preliminary actor landscape and relationship patterns, noted minor revisions and classification refinements, and broadly confirmed the diagnosis of institutional fragmentation, limited cross-sector information flow, and persistent upstream–downstream tensions that complicate conflict resolution. The analysis was received as a useful diagnostic that provides a shared evidence base for developing feasible, win–win solutions across provinces and sectors, and the discussion helped refine the interpretation and governance implications reported in this study.

In line with the synthesis, the workshop discussion emphasized the need to (a) clarify overlapping roles and mandates through institutional mapping and role delineation; (b) strengthen science–policy interfaces by formalizing the participation of technical experts and researchers in planning and coordination bodies; (c) institutionalize iterative stakeholder feedback mechanisms to better integrate contextual knowledge and improve compliance; and (d) operationalize watershed-scale coordination mechanisms, including by leveraging bridging actors identified by high betweenness centrality and expanding watershed-specific spatial provisions and special regulations beyond drinking water protection to cover other critical water bodies and pressures.

While the recommendations above are grounded in the Porsuk Watershed case, the underlying analytical logic is applicable to other watersheds when tailored to local conditions. The WVC provides a consistent analytical structure that can be implemented by identifying the relevant actors and governance processes across WEFE components and by ensuring that interview questions and interpretation focus on the dominant points of tension shaping coordination dynamics and governance priorities. In the Porsuk Watershed, the central tension is largely user-oriented, as upstream withdrawals and pollutant loads translate into downstream vulnerability and persistent upstream–downstream tensions. In other watersheds, the focal tension may instead be ecosystem-oriented or may be shaped by different sectoral profiles that make certain trade-offs and constraints more prominent.

Based on the lessons derived from this application, future implementations would benefit from identifying the dominant coordination tensions at an early stage and aligning the interview design accordingly. Methodological robustness would further depend on clear boundary setting and actor categorization, transparent documentation of data synthesis and coding procedures, and triangulation of interview findings with secondary sources. Equally important, preliminary interpretations should be validated with stakeholders and informed by adequate representation across sectors and administrative scales, as these steps improve contextual accuracy and enable a more integrated assessment of institutional roles, interdependencies, and coordination gaps.

Although this study is primarily diagnosis-led, its findings provide a structured evidence base for identifying potential governance improvements in the Porsuk Watershed. Building on this diagnostic foundation, Demir and Alp (2026) further develop solution pathways and governance design options by using the institutional relationships, coordination gaps, and stakeholder interaction patterns identified in this study as key inputs for an adapted Institutional Analysis and Development framework for policy analysis and institutional design.

Conclusion

The increasing pressure on water, food, and energy resources due to population and economic expansion highlights the critical need to examine water governance across the WEFE nexus components to foster sustainable development. The Porsuk Watershed exemplifies the governance challenges within the WEFE nexus, where excessive upstream withdrawals have reduced downstream water availability and quality. To address these issues, this study aims to map key stakeholders in watershed management and assess their interactions to devise strategies that strengthen network cohesion and foster cross-sectoral cooperation within the WEFE nexus.

The Porsuk Watershed's network-level SNA findings highlight that extending the scope of "Special Regulations for the Porsuk Dam Lake Basin" to cover a wider range of water resources could improve stakeholder coordination across regulatory networks. Its implementation has already increased engagement, particularly among regional governing bodies. At the same time, the WVC analysis identifies inefficiencies arising from overlapping responsibilities among governing bodies, leading to duplication of efforts and accountability gaps. It is advised that stakeholders in the Porsuk Watershed implement targeted governance reforms to enhance institutional coordination, clarify stakeholder roles, and harmonize regulations.

The interest and influence assessments indicate that downstream actors in the Porsuk Watershed show greater interest in integrated resource governance initiatives than upstream actors due to their higher vulnerability to upstream decisions. In the Porsuk Watershed, mitigating this disparity necessitates

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag093/8703276 by Orta Dogu Teknik University Library (ODTU) (Inactive) user on 29 September 2026

upstream engagement incentives and awareness campaigns on shared responsibilities, with their success relying on actors with substantial expert power. Despite their expertise, academics, research institutions, and NGOs in the "Keep Informed" quadrant have limited influence. Actor-level SNA findings reveal a fragmented information flow within the watershed, dominated by central actors, while knowledge-based stakeholders remain underutilized. To improve information accessibility and quality, fostering collaboration between "Keep Informed" and "Manage Closely" stakeholders is recommended. Furthermore, ministries and their provincial directorates, as intermediaries (betweenness centrality), can play a critical role in facilitating information exchange across fragmented groups.

Group-level SNA findings from the Porsuk Watershed show that governmental bodies, national actors, and high-hierarchy stakeholders in the "Manage Closely" quadrant, such as ministries, maintain strong internal collaboration (density) but weak cross-group engagement (E–I index). This centralized structure limits inclusivity, restricting participatory governance and adaptive decision-making. Similarly, the components of the WEFE nexus generally exhibit stronger internal collaboration than cross-sectoral engagement, thereby reinforcing existing inefficiencies and trade-offs. Addressing these governance challenges requires focused capacity-building within individual WEFE components and enhanced cross-sectoral engagement through advisory committees and interagency working groups.

The results emphasize the importance of integrated policies that foster stakeholder engagement, empower marginalized groups, clarify responsibilities, and implement flexible, context-specific strategies for cross-sector collaboration. This study advances watershed management by developing sectoral WVCs, refining SA through a novel interest–influence assessment, and integrating WVC into SNA for a nuanced analysis of stakeholder interactions. Future studies could expand actor sampling, apply dynamic network analysis within a value chain perspective, and integrate political economy considerations into SNA to strengthen system understanding.

Supplementary material

Supplementary material is available at *Integrated Environmental Assessment and Management* online.

Data availability

The data and methodological information are provided in the article and online Supplementary Material.

Author contributions

Ece Demir (Conceptualization, Data curation, Formal analysis, Methodology, Software, Validation, Visualization, Writing—original draft, Writing—review & editing), Ezgi Özdemir (Conceptualization, Data curation, Methodology), B. İrem Yapan (Conceptualization, Data curation, Formal analysis, Methodology, Writing—review & editing), Buse B. Kart (Data curation, Formal analysis, Methodology), Esin Yandımata (Conceptualization, Data curation, Formal analysis, Methodology), Yasemin Demir (Conceptualization, Methodology, Supervision), Pınar D. Güre (Conceptualization, Methodology, Supervision, Writing—review & editing), Gülser Köksal (Conceptualization, Methodology, Supervision), and Emre Alp (Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Writing—review & editing)

Funding

This work was supported by the Scientific and Technological Research Council of Türkiye (TÜBİTAK) under the project titled "A New Approach for Sustainable Water Management: Integration of the Circular Economy Approach to the Framework of Water-Energy-Food-Ecosystem Nexus" (Project No. 121R014).

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical statement

Prior to data collection, ethical approval was obtained from the METU Human Research Ethics Committee (HREC).

Acknowledgments

The authors wish to dedicate this work to the memory of Prof. Dr. Gülser Köksal, who passed away in January 2026. In the early stages of this study, Prof. Köksal played a pivotal role in shaping the direction of the work and encouraged us to develop what initially appeared to be a modest work package into a comprehensive and distinctive contribution to the literature. We remain deeply grateful for her insight, mentorship, and inspiration. We extend our sincere appreciation to the 50 stakeholders who participated in the interviews conducted between July 6, 2022 and October 21, 2022, as their time and engagement were invaluable to this study.

References

Ahmadi, A., Kerachian, R., Rahimi, R., & Emami Skardi, M. J. (2019). Comparing and combining social network analysis and stakeholder analysis for natural resource governance. *Environmental Development*, *32*, 100451. https://doi.org/10.1016/j.envdev.2019.07.001

Alp, E., Yetiş, Ü., Gündüz, O., Köksal, M. A., Uzal, N., Güre, P. D., Özeren, C., Demir, Y., Yurdakul, İ., Alkaya, E., Köksal, G., Özertan, G., Özcan, Z., Yapan, B. İ., Özdemir, E., Yandımata, E., Demir, E., Kart, B. B., Bingöl, E., … Şenocak, İ. (2024). *A new approach for sustainable water management: Integration of the circular economy approach to the framework of*

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag093/8703276 by Orta Dogu Teknik University Library (ODTU) (Inactive) user on 29 September 2026

water-energy-food-ecosystem nexus. Project No: 121R014. TÜBİTAK.

Bastian, M., Heymann, S., & Jacomy, M. (2009). Gephi: An open source software for exploring and manipulating networks. *Proceedings of the International AAAI Conference on Web and Social Media*, *3*, 361–362. https://doi.org/10.1609/icwsm.v3i1.13937

Bellingeri, M., Bevacqua, D., Sartori, F., Turchetto, M., Scotognella, F., Alfieri, R., Nguyen, N. K. K., Le, T. T., Nguyen, Q., & Cassi, D. (2023). Considering weights in real social networks: A review. *Frontiers in Physics*, *11*, 1152243. https://doi.org/10.3389/fphy.2023.1152243

Bendtsen, E. B., Clausen, L. P. W., & Hansen, S. F. (2021). A review of the state-of-the-art for stakeholder analysis with regard to environmental management and regulation. *Journal of Environmental Management*, *279*, 111773. https://doi.org/10.1016/j.jenvman.2020.111773

Benites-Lazaro, L. L., Nascimento, N., Urbinatti, A., Amaral, M., & Giatti, L. L. (2021). The social network analysis to study discourse on Water–Energy–Food Nexus. In S. S. Muthu (Ed.), *The Water–Energy–Food Nexus* (pp. 127–144). Springer Singapore. https://doi.org/10.1007/978-981-16-0239-9_5

Borgatti, S. P., Everett, M. G., & Freeman, L. C. (2002). *UCINET for Windows: Software for social network analysis (Version UCINET 6.775) [Computer software]*. Analytic Technologies.

Brouwer, H., & Brouwers, J. (2014). *The MSP tool guide (sixty tools to facilitate multi-stakeholder partnerships)*. Wageningen University & Research.

Carlsson, L., & Berkes, F. (2005). Co-management: Concepts and methodological implications. *Journal of Environmental Management*, *75*, 65–76. https://doi.org/10.1016/j.jenvman.2004.11.008

Chofreh, A. G., Goni, F. A., Zeinalnezhad, M., Navidar, S., Shayestehzadeh, H., & Klemeš, J. J. (2019). Value chain mapping of the water and sewage treatment to contribute to sustainability. *Journal of Environmental Management*, *239*, 38–47. https://doi.org/10.1016/j.jenvman.2019.03.023

Copernicus (2018). *Pan-European CORINE Land Cover 2018 (CLC2018)*. Copernicus Land Monitoring Service. https://land.copernicus.eu/pan-european/corine-land-cover

ÇŞİDB (2021). *Desertification and erosion in Turkey*. https://webdosya.csb.gov.tr/db/cem/icerikler/cemxbrosxingxmail-20211108120330.pdf

Cummings, A. R. (2019). *The effects of social power bases in varying organizational cultures: (509732019-001)* [Dataset]. https://doi.org/10.1037/e509732019-001

Demir, E. (2025). *A holistic framework for the governance of water resources to promote the circular water economy in the Porsuk Watershed within the context of the water-energy-food-ecosystem nexus*. Middle East Technical University.

Demir, E., & Alp, E. (2026). Advancing circular water transitions in the WEFE nexus with the Ostrom's institutional analysis and development framework. *Journal of Cleaner Production*, *552*, 147978. https://doi.org/10.1016/j.jclepro.2026.147978

Dos Muchangos, L. S., Tokai, A., & Hanashima, A. (2017). Stakeholder analysis and social network analysis to evaluate the stakeholders of a MSWM system—A pilot study of Maputo City. *Environmental Development*, *24*, 124–135. https://doi.org/10.1016/j.envdev.2017.04.005

DSİ (2017). *Sakarya Basin Master Plan Final Report*.

Eden, C., & Ackermann, F. (2021). Modelling stakeholder dynamics for supporting group decision and negotiation: Theory to practice. *Group Decision and Negotiation*, *30*, 1001–1025. https://doi.org/10.1007/s10726-021-09745-y

ESCAP (2018). *Training reference material: Effective stakeholder engagement for the 2030 agenda*. https://www.unescap.org/sites/default/files/Final.Effective%20Stakeholder%20Engagement%20for%20the%202030%20Agenda%20rev.pdf

Gabel, S. (2012). Perspective: Physician leaders and their bases of power. *Academic Medicine*, *87*, 221–225. https://doi.org/10.1097/ACM.0b013e31823f3b0c

Geneson, J., & Tsai, S.-F. (2022). Peripherality in networks: Theory and applications. *Journal of Mathematical Chemistry*, *60*, 1021–1079. https://doi.org/10.1007/s10910-022-01345-8

Ghafoori Kharanagh, S., Banihabib, M. E., & Javadi, S. (2020). An MCDM-based social network analysis of water governance to determine actors' power in water-food-energy nexus. *Journal of Hydrology*, *581*, 124382. https://doi.org/10.1016/j.jhydrol.2019.124382

Govender, M., Poti, M., Nijamdeen, T. W. G. F. M., Sunanda Kodikara, K. A., Dahdouh-Guebas, F., & Hugé, J. (2025). Mapping conservation conflicts by integrating social network analysis and Q methodology: A sea turtle case from Sri Lanka. *Scientific Reports*, *15*, 16658. https://doi.org/10.1038/s41598-025-99926-5

Janssens De Bisthoven, L., Vanhove, M., Rochette, A.-J., Hugé, J., & Brendonck, L. (2022). Stakeholder analysis on ecosystem services of Lake Manyara sub-basin (Tanzania): How to overcome confounding factors. *Environmental Management*, *69*, 652–665. https://doi.org/10.1007/s00267-021-01466-x

Jones, J. L., & White, D. D. (2021). A social network analysis of collaborative governance for the food-energy-water nexus in Phoenix, AZ, USA. *Journal of Environmental Studies and Sciences*, *11*, 671–681. https://doi.org/10.1007/s13412-021-00676-3

Khakhar, P., & Ahmed, Z. U. (2017). The concepts of power in international business negotiations: An empirical investigation. *Journal of Transnational Management*, *22*, 25–52. https://doi.org/10.1080/15475778.2017.1274613

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular economy: The concept and its limitations. *Ecological Economics*, *143*, 37–46. https://doi.org/10.1016/j.ecolecon.2017.06.041

Lienert, J., Schnetzer, F., & Ingold, K. (2013). Stakeholder analysis combined with social network analysis provides fine-grained insights into water infrastructure planning processes. *Journal of Environmental Management*, *125*, 134–148. https://doi.org/10.1016/j.jenvman.2013.03.052

Lunenburg, F. C. (2012). Power and leadership: An influence process. *International Journal of Management, Business, and Administration*, *15*, 1–9.

Maaß, O., & Grundmann, P. (2018). Governing transactions and interdependences between linked value chains in a circular economy: The case of wastewater reuse in Braunschweig

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag093/8703276 by Orta Dogu Teknik University Library (ODTU) (Inactive) user on 29 September 2026

(Germany). *Sustainability*, *10*, 1125. https://doi.org/10.3390/su10041125

Nabiafjadi, S., Sharifzadeh, M., & Ahmadvand, M. (2021). Social network analysis for identifying actors engaged in water governance: An endorheic basin case in the Middle East. *Journal of Environmental Management*, *288*, 112376. https://doi.org/10.1016/j.jenvman.2021.112376

Narayan, A. S., Fischer, M., & Lüthi, C. (2020). Social network analysis for Water, Sanitation, and Hygiene (WASH): Application in governance of decentralized wastewater treatment in India using a novel validation methodology. *Frontiers in Environmental Science*, *7*, 198. https://doi.org/10.3389/fenvs.2019.00198

Ncube, X., & Pittock, J. (2025). Application of social network analysis in determining innovation information exchange at irrigation schemes in Zimbabwe. *International Journal of Water Resources Development*, *41*, 447–465. https://doi.org/10.1080/07900627.2024.2443765

Neri, A., Rizzuni, A., Garrone, P., & Cagno, E. (2025). Barriers and drivers to the development of an effective water reuse chain: Insights from an Italian water utility. *Clean Technologies and Environmental Policy*, *27*, 1617–1637. https://doi.org/10.1007/s10098-024-02899-8

Pereira, C., Zarghami, A., Teixeira, E., & Araújo, E. (2025). Stakeholder mapping for a nature-based solutions project: a comprehensive approach for enhanced participation and co-creation. *Sustainability*, *17*, 8416. https://doi.org/10.3390/su17188416

Powell, J., & Hopkins, M. (2015). Social networks. In *A librarian's guide to graphs, data and the semantic web* (pp. 111–116). Elsevier. https://doi.org/10.1016/B978-1-84334-753-8.00014-2

Reed, M. S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C. H., & Stringer, L. C. (2009). Who's in and why? A typology of stakeholder analysis methods for natural resource management. *Journal of Environmental Management*, *90*, 1933–1949. https://doi.org/10.1016/j.jenvman.2009.01.001

Reyhani, M. N., & Grundmann, P. (2021). Who influences whom and how in river-basin governance? A participatory stakeholder and social network analysis in Zayandeh-Rud basin, Iran. *Environmental Development*, *40*, 100677. https://doi.org/10.1016/j.envdev.2021.100677

Sagie, H., & Orenstein, D. E. (2022). Benefits of stakeholder integration in an ecosystem services assessment of Mount Carmel Biosphere Reserve, Israel. *Ecosystem Services*, *53*, 101404. https://doi.org/10.1016/j.ecoser.2021.101404

Salajegheh, S., Jafari, H. R., & Pourebrahim, S. (2020). Modeling the impact of social network measures on institutional adaptive capacity needed for sustainable governance of water resources. *Natural Resource Modeling*, *33*, e12277. https://doi.org/10.1111/nrm.12277

Sharifian, H., Emami-Skardi, M. J., Behzadfar, M., & Faizi, M. (2022). Water sensitive urban design (WSUD) approach for mitigating groundwater depletion in urban geography; through the lens of stakeholder and social network analysis. *Water Supply*, *22*, 5833–5852. https://doi.org/10.2166/ws.2022.206

Stein, C., Ernstson, H., & Barron, J. (2011). A social network approach to analyzing water governance: The case of the Mkindo catchment, Tanzania. *Physics and Chemistry of the Earth, Parts A/B/C*, *36*, 1085–1092. https://doi.org/10.1016/j.pce.2011.07.083

TÜİK (2012). *Employment statistics by sector*. https://www.tuik.gov.tr/

Villamayor-Tomas, S., Grundmann, P., Epstein, G., Evans, T., & Kimmich, C. (2015). The water-energy-food security nexus through the lenses of the value chain and the institutional analysis and development frameworks. *Water Alternatives*, *8*, 735–755.

Wasserman, S., & Faust, K. (1994). *Social network analysis: Methods and applications* (1st ed.). Cambridge University Press. https://doi.org/10.1017/CBO9780511815478

Weber, M. (1993). Power, domination, and legitimacy. In M. E. Olsen, & M. N. Marger (Eds.), *Power in modern societies* (p. 11). Routledge.

Wu, W., He, F., Zhuang, T., & Yi, Y. (2020). Stakeholder analysis and social network analysis in the decision-making of industrial land redevelopment in China: The case of Shanghai. *International Journal of Environmental Research and Public Health*, *17*, 9206. https://doi.org/10.3390/ijerph17249206

Zhakenova, S. (2017). *Stakeholder analysis report: Central Asia nexus dialogue project: Fostering water, energy and food security nexus dialogue and multi-sector investment*. https://carececo.org/Nexus_Stakeholder%20analysis_2ver_SZH.PDF

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag093/8703276 by Orta Dogu Teknik University Library (ODTU) (Inactive) user on 29 September 2026