Using Social Network Analysis (SNA) to assess governance issues in the implementation of Nature-based Solutions (NbS)

Hosted by:

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Presentation Layout:

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   - Key Outcomes in SNA, their Description, and Examples of Applicability for NBS

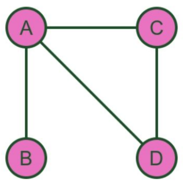
1. What is SNA

Representation of social networks

Social Network Analysis (SNA) is a methodology used to analyse social networks in addition to the usual statistical techniques for data analysis. SNA is often used to assess NbS Governance inputs such as (i) information exchange between social actors, (ii) technical connections between technical elements, (iii) operation from social actors to technical elements, and (iv) data transfer among actors. The approach is useful for representing and analysing practice-oriented and scientific gaps in the socio-technical network, such as information fragmentation among stakeholders (Manny, 2023).

SNA can highlight aspects of the interaction between stakeholders namely: connectedness and power of actors, and assess actor (i) authority, (ii) coordination ability, (iii) power and, (iii) information accessibility of various key stakeholders (Halder, 2024).

Representation - Social Networks are plotted as a set of nodes (sometimes referred to as actors or vertices in graph theory) connected by some type of relation, which are called ties, arcs, or edges.

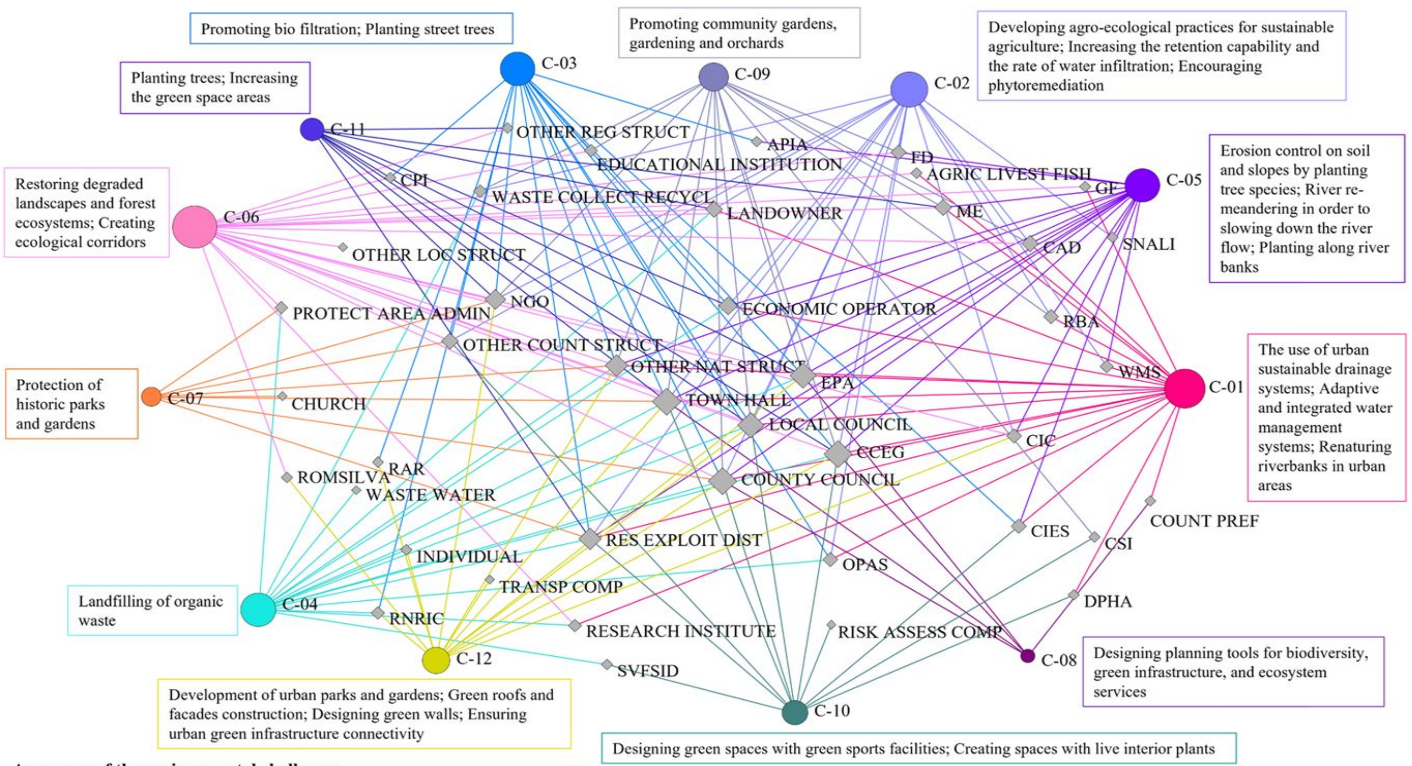


	A	B	C	D
A	0	1	1	1
B	1	0	0	0
C	1	0	0	1
D	1	0	1	0

Figure 1- Representation of a SN with actors A, B, C and D, and the respective adjacency matrix,

2. Representation of social networks

Illustration of a social network



Acronyms of the environmental challenges

C-01 - surface and groundwater pollution (including drinking water quality and quantity)
C-02 - soil and subsoil pollution
C-03 - air pollution
C-04 - improper waste management
C-05 - low degree of prevention/mitigation/elimination of natural and anthropogenic disaster effects
C-06 - affecting the natural and anthropogenic environment
C-07 - the impact of tourism and the need to promote sustainable tourism (including historical and cultural heritage)
C-08 - weak institutional capacity in the field of environmental protection
C-09 - low environmental education and public awareness
C-10 - poor quality of life of the population (including physical and mental health)
C-11 - low sustainable development (including climate change control and adaptation)
C-12 - urban development (including transport and green infrastructure)

*Figure 33-Two-mode network of stakeholders from LEAPs with responsibilities in solving environmental challenges and implicitly to diffuse NbS, From Cristina-Gabriela Mitincu (2023)- **Stakeholders' involvement in the planning of NBS: A network analysis approach***

Stakeholder's name	Acronyms of the stakeholders
Town hall	TOWN HALL
County Council	COUNTY COUNCIL
County Commissariat - National Environmental Guard	CCEG
Local council	LOCAL COUNCIL
Environmental Protection Agency	EPA
Other national structures	OTHER NAT STRUCT
Operator of resource exploitation and distribution of electricity, geothermal energy, water, and natural gas	RES EXPLOIT DIST
Non-governmental organization	NGO
Other country structures	OTHER COUNT STRUCT
Economic operator in agriculture, industry, and service	ECONOMIC OPERATOR
Landowner and landowners' association	LANDOWNER
County Agriculture Directorate	CAD
Ministry of Environment	ME
County Inspectorate for Constructions	CIC
County Inspectorate for Emergency Situations	CIES
Office of Pedological and Agrochemical Studies	OPAS
Protected area administration	PROTECT AREA ADMIN
Research institute	RESEARCH INSTITUTE
Forestry Department	FD
River Basin Administration	RBA
Educational institution	EDUCATIONAL INSTITUTION
Waste collector and recycler	WASTE COLLECT RECYCL
Romanian National Road Infrastructure Company	RNRIC
Water Management System	WMS
ROMSILVA	ROMSILVA
County Directorate of Public Health	DPHA
Sanitary, Veterinary, and Food Safety Inspection Directorate	SVFSID
Agriculture, livestock, and fishery association	AGRIC LIVEST FISH
Forest Guard	FG
County Police Inspect	
Agency for Payments	
Other regional structu	
Romanian Automotive	
Individual	
County Prefecture	
County School Inspec	
Subsidiary of Nationa	
Other local structures	
Waste landfill and was	
Transport company	
Risk assessment comp	
Church	

Example of the application of SNA to understand NBS governance structure – From the study done by Cristina-Gabriela *(Mitincu et Al.,2023)*, aiming to identify the key stakeholders within the environmental planning processes to be considered in NBS promotion, as well as to understand their actual position in a conceptual collaboration network. For that purpose, a sample of seven Local Environmental Action Plans (LEAPs) from Romania were used.

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3. SNA measures

Measurement of social networks and outcomes/implications:

Measures/ Formula	Measure interpretation	Outcome/Implication
1. Weight of the tie N/A	Measures the duration, frequency, or intensity of interaction, or the amounts involved in transactions.	Reflects the strength of the connection
2. Centrality of the graph N/A	How the position of a vertex is within the overall structure of the graph and, therefore,	High centrality means the network have playes that have core positions to the network, key players of the network
3. Degree K, or valency $k_i = \sum_{j=1}^{n} a_{ij}, 0 < k_i < n,$ a_{ij} is the entry of the i-th row and j-th column of the adjacency matrix	Usually denoted as k_v, is a measure of the immediate adjacency and the involvement of the node in the network and is computed as the number of edges incident on a given node or, similarly, as the number of neighbors of node v.	A higher degree represents a greater number of alternative sources of connection, information or resources.
4. Eccentricity of the vertex ε $\epsilon = \max_{i \in V(G) \setminus v} d(v, i).$ geodesic distance, or shortest path, between nodes i and j, is denoted as $d(i ; j)$	Is the greatest geodesic distance between a given vertex and any other in the graph.	High eccentricity means the node is further away from the most distant nodes, this indicates they may be isolated in the network, distant from other nodes, or less included in transaction.
5. Diameter D of the network $D = \max\{\epsilon : v \in V\}$	Is given by the maximum eccentricity of the set of vertices in the network	The diameter translates the overall spread of the actors, higher diameter means less connectivity among actors, more intermediates.
6. Radius R of the network $R = \min\{\epsilon : v \in V\}$	is defined as the minimum eccentricity of the set of vertices	The lower the radios, the more compact or tightly connected the network nodes are. Good flow of information and resources exchange occur in the radios path.
7. Density ρ $\rho = \frac{m(G)}{m_{max(G)}}, 0 < \rho < 1,$	Explains the general level of connectedness in a network. It is given by the proportion of edges in the network relative to the maximum possible number of edges	Higher density in an information-sharing SNA signifies more frequent information sharing among the actors. This is analogous to active interaction and transparency. Due to the large number of ties, high density is also analogous to difficulties in coordination
8. Degree Centrality C_D $C_D(n_i) = \frac{d(n_i)}{(N-1)}$ N - total nr. of network nodes; $d(n_i)$ - degree of node i	The number of immediate links directed to or given off by a node. It is sometimes normalized by diving by the number of other nodes in the network	A higher degree represents a greater number of alternative sources of connection. This reflects more power of the actor or higher significance of the actor in the network.
9. Closeness Centrality C_C $C_C(n_i) = \frac{(N-1)}{\sum_{j=1}^{N} d(n_i,n_j)}$ N - total nr. of network nodes; $d(n_i)$ - degree of node i	How far is a node to connect to every other node in the network. Distance is measured in terms of immediate links between two nodes	Higher closeness indicates the actor's ability to independently access information, knowledge or resources from other actors. This analogous to the efficiency and independence of the actors
10. Betweenness Centrality B_C $C_B(n_i) = \frac{\sum_{j<k} \frac{g_{jk}(n_i)}{g_{jk}}}{[(n-1)(n-2)]/2}$	How often a node fall in between two non-adjacent nodes based on the shortest path. Adjacent nodes are connected by a single link or arc. Non-adjacent nodes are connected by more than one arc or link	Higher betweenness signifies an actor's ability to control the flow of resources or information among other actors. This is analogous to gatekeeping/coordination (control of information) power

3. SNA measures

SNA Measures and Implications/output

SNA Measure	Category	Description	Implications/output
Degree Centrality	Node	Number of direct connections a node has.	High degree centrality indicates a node with many direct ties, suggesting influence or control in the network, such as key connectors or information hubs.
In-Degree / Out-Degree	Node	Number of incoming or outgoing connections in a directed network.	High in-degree indicates a node that is a popular recipient of connections, while high out-degree indicates a node that initiates many connections, possibly a leader or communicator.
Betweenness Centrality	Node	Frequency at which a node lies on the shortest path between other nodes.	Nodes with high betweenness are important for bridging different parts of the network, controlling or facilitating information flow across otherwise unconnected groups.
Closeness Centrality	Node	Average shortest path from a node to all other nodes.	A node with high closeness centrality can access the rest of the network more quickly, influencing its surroundings efficiently.
Eigenvector Centrality	Node	Influence of a node based on connections to other influential nodes.	Nodes connected to other well-connected or influential nodes hold higher power and importance in the overall network, acting as opinion leaders or key resources.
Hubs and Authorities	Node	Nodes that are authoritative (good sources of information) or hubs (important connectors).	Hubs connect many nodes, while authorities are reliable sources. High scores in both categories indicate critical nodes for either information dissemination or access.
Local Clustering Coefficient	Node	Proportion of a node's neighbors that are also connected to each other.	A high clustering coefficient indicates that the node is part of a tightly-knit group, suggesting strong local collaboration or community-building but potentially reducing exposure to new ideas.
Eccentricity	Node	The greatest distance between a node and any other node in the network.	Nodes with low eccentricity are closer to all other nodes, meaning they have more influence or faster access to others. High eccentricity implies a peripheral or isolated position in the network.
Reciprocity	Link	Measures the extent to which connections are bidirectional (in directed networks).	High reciprocity indicates a balanced, mutual relationship, fostering cooperation and trust. Low reciprocity may point to hierarchy or power imbalances.
Link Strength (Weight)	Link	Represents the strength or intensity of a connection between two nodes.	Stronger links imply stronger relationships, collaborations, or dependencies. Weaker links might represent occasional interactions, weak ties, or potential areas for growth in collaboration.
Link Symmetry	Link	Measures whether the strength of a link is equal in both directions.	Symmetric links suggest balanced relationships, whereas asymmetric links indicate unequal power dynamics, resource exchange, or influence between the two connected nodes.
Link Homophily	Link	Measures the similarity between two connected nodes based on their attributes.	High homophily suggests that similar nodes tend to connect, fostering trust and collaboration, but possibly reducing diversity of perspectives. Low homophily encourages diversity and innovation through cross-group connections.
Edge Betweenness	Link	Frequency at which a link lies on the shortest path between pairs of nodes.	High edge betweenness indicates critical links that bridge different parts of the network. These links are vulnerable points in the network, whose removal can disrupt communication and flow.
Link Multiplexity	Link	Refers to the number of types of relationships shared between two nodes.	Multiplex relationships (multiple types of connections, e.g., professional and personal) indicate stronger and more resilient ties, as well as deeper collaboration between actors.
Structural Equivalence	Node/Link	Measures whether two nodes share similar connections to the same other nodes.	Nodes that are structurally equivalent play similar roles in the network, even if they are not directly connected. This can imply redundancy or complementarity in their roles.
Transitivity	Node/Link	Measures the extent to which the friends of a node are friends with each other.	High transitivity fosters trust and cooperation but may create closed communities that can become insulated from external information or innovation.
Dyadic Constraint	Node/Link	Measures how dependent a node is on a particular relationship.	High dyadic constraint implies reliance on a small number of connections, increasing vulnerability to disruptions. Low constraint allows for flexibility and multiple alternative paths.
Density	Social Network	Proportion of possible connections that are actual connections within the network.	Higher density suggests a more interconnected network with faster communication, but possibly less diversity in thought or slower adaptation to external changes. Low density may indicate fragmentation or specialization.
Network Diameter	Social Network	The longest shortest path between any two nodes in the network.	A large network diameter indicates slower communication between distant nodes, while a smaller diameter suggests faster information exchange and coordination within the network.
Average Path Length	Social Network	Average of the shortest paths between all pairs of nodes.	Shorter average path length implies faster and more efficient communication. A longer path length can suggest more hierarchical or distributed networks, with delayed information flow.
Modularity	Social Network	Measures the strength of division of a network into modules (clusters/communities).	High modularity highlights distinct subgroups within the network, which can represent specialized communities or silos. Low modularity suggests a more integrated, unified network.
Connected Components	Social Network	Identifies distinct subnetworks (components) where all nodes are connected directly or indirectly.	A large number of disconnected components suggests fragmentation or isolation, whereas a single, large component indicates cohesion and inclusivity across the network.
Core-Periphery Structure	Social Network	Differentiates between central (core) and peripheral nodes.	A strong core-periphery structure suggests a clear central leadership or influential group, with peripheral nodes having less influence. This can help identify power structures or vulnerable, less-connected nodes.
Assortativity	Social Network	Tendency of nodes to connect with similar or dissimilar nodes based on their attributes.	High assortativity suggests homophily, where similar nodes connect. Low or negative assortativity can indicate diversity in connections, which can either foster innovation or highlight the separation between different groups.
Network Resilience	Social Network	Measures how well a network can maintain its structure after the removal of nodes or links.	High resilience indicates that the network can withstand the removal of key nodes or links, maintaining connectivity. Low resilience suggests vulnerability to fragmentation if certain actors or connections are removed.

4. SNA potential to asses governance of NBS

Key Outcomes in SNA, their Description, and Examples of Applicability for NBS

In Social Network Analysis (SNA), outcomes refer to the practical results, insights, or changes that occur as a result of analysing the structure and dynamics of a social network. These outcomes can inform decision-making, improve organisational effectiveness, and shape strategies for managing relationships and information flows. Outcomes are distinct from outputs, which are the raw metrics and visualizations produced by the SNA process.

Examples of SNA outcomes useful for Nature-based Solutions (NbS) governance assessment follow in the Annex

THANK YOU

ANNEX

25 stakeholdrs x 8attrib & role

Stakeholder Name	Type of Stakeholder	Primary Interest	Geographical Scope	Resources Provided	Operational Capacity	Stakeholder Influence	Role in NBS Projects	Sector Focus	Role Description
Local Communities	Community	Livelihoods, Ecosystem Services	Local	Local Knowledge, Labour	Implementation, Monitoring	Medium	Project Implementer	Agriculture, Environment Protection	Implement conservation practices and NBS at a local level.
Government Agencies (Ministries of Environment, Water)	Public	Water Supply, Environmental Regulation	National/Regional	Policy, Infrastructure	Regulation, Enforcement	High	Policy-making, Oversight	Water Supply, Environment Protection	Set policies, regulate activities, and oversee NBS implementation.
Water Utilities	Private/ Public	Water Supply, Infrastructure	Regional/Local	Technology, Funding	Infrastructure Operation	High	Service Provider	Water Supply, Sanitation	Provide and manage water infrastructure and services.
Non-Governmental Organizations (NGOs)	Private	Conservation, Advocacy	Global/Regional/Local	Research, Expertise, Awareness	Advocacy, Capacity Building	High	Advocate, Facilitator	Environment Protection, Agriculture	Advocate for and facilitate sustainable practices and NBS projects.
Agricultural Cooperatives	Private/ Public	Sustainable Farming, Resource Use	Local/Regional	Local Knowledge, Labour, Resources	Farming Practices	Medium	Implementer	Agriculture	Support local farmers with sustainable agricultural practices.
Research Institutions (e.g., CGIAR, Universities)	Research Institutions	Agricultural Innovation, Environmental Research	Global/Regional	Research, Data, Expertise	Knowledge Generation	Medium	Researcher, Knowledge Provider	Agriculture, Environment Protection	Conduct research and provide data to support NBS.
Financial Institutions/ Development Banks	Finance/Banking	Funding Green Investments	Global	Loans, Grants, Investment	Large-scale Funding	Very High	Funder, Financial Support	Agriculture, Water Supply, Environment	Fund large-scale NBS projects and infrastructure development.
Indigenous Groups	Grassroots	Cultural Heritage, Land Rights	Local/Regional	Traditional Knowledge	Resource Stewardship	Medium	Stewards of Natural Resources	Environment Protection, Agriculture	Manage natural resources using traditional ecological knowledge.
Bilateral Donors (USAID, DFID)	Public Sector (International Aid)	Development & Climate Resilience	Global/Regional	Funding, Expertise	Funding and Project Management	High	Funder, Policy Advisor	Water Supply, Agriculture, Environment	Fund and advise on development and resilience projects.
Agriculture Corporations (e.g., Bayer, Syngenta)	Private /Public	Agribusiness, Sustainable Sourcing	Global	Investment, Innovation	Technology, Resource Supply	Medium	Innovators, Funders	Agriculture, Environment Protection	Develop agricultural innovations and invest in sustainability.
Water Supply Organisations (e.g., WaterAid)	Private	Clean Water Access, Sanitation	Global/Local	Expertise, Technical Assistance	Water and Sanitation Projects	High	Implementer, Advocate	Water Supply, Sanitation	Implement and advocate for clean water and sanitation solutions.
Irrigation Authorities	Public/Private Sector	Water Management for Agriculture	National/Regional	Infrastructure, Technical Expertise	Water Infrastructure Operation	High	Operator, Service Provider	Water Supply, Agriculture	Manage irrigation systems for agriculture.
Farmers and Agribusiness Networks and organizations	Grassroots	Crop Yield, Soil Health	Local/Regional	Knowledge, Resources	Farming Practices	Medium	Project Implementer	Agriculture	Implement sustainable farming practices at the grassroots level.
Development Banks	Private	Infrastructure Development, Climate Action	Global	Large-scale Funding	Infrastructure Development	Very High	Funder, Technical Advisor	Water Supply, Agriculture, Environment	Provide funding and technical advice for large-scale infrastructure projects.
Technology Firms (e.g., Microsoft, Google)	Private Sector	Data, Innovation	Global	Technology, Data Analytics	Data Management, Innovation	Medium	Innovator, Data Provider	Water Supply, Agriculture, Environment	Provide technological solutions for data collection and monitoring.
Regulatory Agencies	Public Sector	Compliance, Environmental Standards	National/Regional	Regulation, Policy Enforcement	Regulatory Capacity	High	Regulator, Enforcer	Water Supply, Sanitation, Environment	Enforce regulations and ensure compliance.
Municipalities	Public Sector (Local)	Urban Planning, Public Services	Local	Infrastructure, Local Governance	Implementation	Medium	Implementer, Service Provider	Water Supply, Sanitation, Environment	Implement NBS in urban planning and public service delivery.
Wastewater Utilities	Public/Private Sector	Sanitation Services	Regional/Local	Infrastructure, Technology	Infrastructure Operation	High	Service Provider	Sanitation	Wastewater treatment services.
Civil Society Organizations	Non-profit/Community	Social Development, Advocacy	Local/Regional	Advocacy, Mobilization	Capacity Building	Medium	Advocate, Project Implementer	Sanitation, Environment	Advocate for community interests and contribute to local projects.
Professional Associations	Private/Public	Industry Standards, Best Practices	Global/Regional/Local	Expertise, Research	Knowledge Dissemination	Medium	Advisor, Standard Setter	Water Supply, Agriculture, Environment	Set professional standards and provide industry knowledge.

Transportation Companies	Private Sector	Logistics, Transportation Services	Local/Regional/Global	Logistics, Technology	Transportation Networks	Medium	Service Provider	Environment, Agriculture	Provide logistics and transportation services for NBS projects.
Environmental Protection Agencies	Public Sector (Regulatory)	Conservation, Environmental Protection	National/Regional	Regulation, Technical Expertise	Monitoring and Enforcement	High	Regulator	Environment	Enforce environmental regulations and ensure compliance.
Consumers	Public/Community	Access to Clean Water, Sanitation	Local/Regional	Feedback, Participation	Advocacy	Medium	Advocate, Beneficiary	Water Supply, Sanitation	Provide feedback on NBS projects and advocate for community needs.
Religious Organizations	Community	Social Justice, Community Welfare	Local/Global	Mobilization, Resources	Advocacy, Community Support	Medium	Advocate, Community Mobilizer	Water Supply, Environment	Advocate for social issues and mobilize community resources for NBS initiatives.
Consultancy Firms	Private Sector	Advisory Services, Project Management	Global	Expertise, Technical Support	Project Management	Medium	Advisor, Facilitator	All Sectors	Provide expertise and advisory services for project planning and implementation.

SNA measures and outputs

Table of the Social Network Analysis (SNA) measures for **nodes**, **links**, and the **social network (whole network)** category, along with their descriptions and implications:

SNA Measure	Category	Description	Implications/output
Degree Centrality	**Node**	Number of direct connections a node has.	High degree centrality indicates a node with many direct ties, suggesting influence or control in the network, such as key connectors or information hubs.
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Edge Betweenness	**Link**	Frequency at which a link lies on the shortest path between pairs of nodes.	High edge betweenness indicates critical links that bridge different parts of the network. These links are vulnerable points in the network, whose removal can disrupt communication and flow.
Link Multiplexity	**Link**	Refers to the number of types of relationships shared between two nodes.	Multiplex relationships (multiple types of connections, e.g., professional and personal) indicate stronger and more resilient ties, as well as deeper collaboration between actors.
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Network Resilience	**Social Network**	Measures how well a network can maintain its structure after the removal of nodes or links.	High resilience indicates that the network can withstand the removal of key nodes or links, maintaining connectivity. Low resilience suggests vulnerability to fragmentation if certain actors or connections are removed.

This table provides a comprehensive framework for understanding **node-level**, **link-level**, and **whole network-level** measures in Social Network Analysis (SNA) and their respective implications in analyzing and interpreting the structure and dynamics of social networks.

SNA outcomes and examples

In Social Network Analysis (SNA), outcomes refer to the practical results, insights, or changes that occur as a result of analysing the structure and dynamics of a social network. These outcomes can inform decision-making, improve organizational effectiveness, and shape strategies for managing relationships and information flows. Outcomes are distinct from outputs, which are the raw metrics and visualizations produced by the SNA process.

Key Outcomes in SNA, their Description, and Examples of Applicability for Nature-Based Solutions (NBS):

Outcome	Description	Useful Examples for Nature-Based Solutions (NBS)			Measures that imply the outcomes	Methodological approaches	Actors / stakeholders	Data and information collection	SNA, data and information processing tools
		Title and context of the literary work	**Outcome Example**	**Bibliography**					
Enhanced Communication and Collaboration	Strengthening relationships and improving information flow between stakeholders involved in NBS.	"The role of network structure in Integrated Water Management (IWM): a case study of collaboration and influence for adopting NBS." Context: Case study in Houston, Texas, USA, where decision-making stakeholders from various sectors and levels of governance engaged in a participatory modelling workshop to improve adoption of NBS through IWM. Stakeholder communication was analysed using fuzzy cognitive mapping (FCM) converted to SNA.	In this study, the authors describe how ongoing partnership with the stakeholders result in an opportunity for adaptive learning, where the NBS planning paradigm began to shift toward trans-scale collaboration aimed at high-leverage management opportunities. The case study network was characterized by a limited degree of internal coordination (low density index), high democratic potential (low hierarchy index), and high-efficiency management opportunities (high centrality index), which transcended across socio-institutional scales.	Castro CV, Carney C and de Brito MM (2023) The role of network structure in integrated water management: a case study of collaboration and influence for adopting nature-based solutions. Front. Water 5:1011952. doi: 10.3389/frwa.2023.101195	1 Network density 2 Network centralisation 3 Hierarchy index	The stakeholders used fuzzy cognitive mapping (FCM) to define an IWM model comprising multifaceted elements and their interrelationships, which influenced the adoption of NBS in Houston	1 Regulatory Agencies 2 Consumers 3 Municipalities 4 Water and Wastewater Utilities 5 Civil Society Organizations 6 Environmental Protection Agencies 7 Health Organizations 8 Firefighting Entities Consultancy Firms	Stakeholder workshop	FCM software named Mental Modeler
Identification of gaps in information sharing, data and resources access	Efficiently identify organizational fragmentation and gaps in the allocation of resources based on network analysis, identifying key players for NBS implementation.	"Socio-technical challenges towards data-driven and integrated urban water management: A socio-technical network approach" Context: Potential challenges, such as organisational fragmentation, data access, information gaps, and diverging perceptions in urban water management in three urban water systems (three case studies) in Switzerland.	The study analyses management inputs such as: (i) information exchange between social actors, (ii) technical connections between technical elements, (iii) operation from social actors to technical elements, and (iv) data transfer from technical elements to social actors. SNA allowed to study relations between social actors and technical elements and illustrated the heterogeneity in actor-infrastructure relations for three different Urban Water Systems in the context of data-driven and integrated Urban Water management; The study highlighted (a) the gaps in the exchange of information among certain actors of Institution A with B and vice-versa, and the need to overcome organisational fragmentation and information exchange gaps;	Manny, L. (2023). Socio-technical challenges towards data-driven and integrated urban water management: A socio-technical network approach. ELSEVIER Journal, Sustainable Cities and Society, 90.	1. Degree Centrality 2. Betweenness Centrality 3. Closeness Centrality 4. Eigenvector Centrality 5. Density 6. Network Diameter 7. Modularity 8. Model coefficient	The author used a multilevel SNA approach to represent and analyse practice-oriented and scientific gaps in the socio-technical networks.	1 Regulatory Agencies 2 Consumers 3 Municipalities 4 Water Utilities 5 Civil Society Organizations 6 Environmental Protection Agencies 7 Data Scientists/Engineers 8 Software Developers 9 Research Institutions/Academia	(1) semi-structured context interviews, (2) document analysis, and (3) case-specific online surveys.	Exponential Random Graph Model (ERGM); SCADA2 systems; R studio
Risk Management	Identifying vulnerable points in the network and creating strategies to mitigate risks for NBS success.		The author identified the risk that information gaps pose to various purposes, such as continuous supervision, real-time control, or monitoring of environmental impacts in the case of Urban Water Systems;						
Improve Stakeholder Integration in Planning	Promoting the exchange of new ideas and solutions by connecting diverse groups within the NBS network.	"Stakeholder analysis combined with social network analysis provides fine-grained insights into water infrastructure planning processes." Context: Examination of infrastructure planning in the Swiss water and sanitation sector, aiming to investigate fragmentation in water infrastructure planning, to understand how actors from different decision levels and sectors are represented, and which interests they follow.	The authors examined infrastructure planning in the Swiss water and sanitation sector, the network analysis confirmed the strong fragmentation shown by little collaboration between the water supply and wastewater sector. They also found few ties between local, cantonal, and national actors confirming vertical fragmentation and identified an opportunity for enhancing knowledge transfer, resource mobilization and consensus building in planning.	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, 25 (2013) 134e148.	1 Betweenness centrality 2 Degree centrality-The structural importance of an actor	Combining stakeholder with social network analysis	1 Governmental authorities 2 Regulator 3 Municipalities (local government) 4 Water utilities 5 Consultants and experts 6 Civil society organizations	(1)Literature review (2) Information request	R statistics and graphics software
Identification of Key Influencers	Identifying central actors who can drive NBS adoption and implementation.	"Stakeholders' involvement in the planning of nature-based solutions: A network analysis approach" Context: Identification of the key stakeholders within the environmental planning processes through analysis of seven Local Environmental Action Plans from Romania.	The authors applied SNA to understand NBS governance structures aiming to identify the **key stakeholders within the environmental planning processes** to be considered in NBS promotion, as well as to understand their actual position in a conceptual collaboration network. For that purpose, a sample of seven Local Environmental Action Plans from Romania was used. The study allowed the identification and classification of the key stakeholders engaged in integrating NBS into environmental planning processes.	Mitincu, C.-G., Niţă, M.-R., Hossu, C.-A., Iojă, I.-C., & Nita, A. (2023). Stakeholders' involvement in the planning of nature-based solutions: A network analysis approach; Environmental Science and Policy, 141 .	1 Degree centrality; 2 Eigenvector centrality; 3 Betweenness centrality	Social network analysis (SNA)	1Local governments and municipalities: 2 Environmental agencies and NGOs 3 Research or educational institutions 4 Local communities and citizens	(1)Literature review (2) Information request (survey)	UCINET software; NetDraw (version 2.176)
Strategic Decision-Making	Guiding policy and operational decisions based on network insights to improve NBS strategies.	"Social network analysis of stakeholder governance landscapes in infrastructure megaprojects: a case of the Delhi–Mumbai Industrial corridor project" Context: The author analysed various aspects of the interaction between stakeholders namely: connectedness and power structure, and assessed the actor-level attributes such as (i) authority, (ii) coordination ability, (iii) power and (iii) information accessibility of various key stakeholders.	The study concluded that eigenvector centrality is a better representative of a focal organization's coordination effectiveness. This conclusion have the potential of improving coordination among stakeholders by improving power allocation.	Halder, A. (2024). Social network analysis of stakeholder governance landscapes in infrastructure megaprojects: a case of the Delhi–Mumbai Industrial corridor project. Springer Nature - Innovative Infrastructure Solutions, 9:209 pags 1 to 27.	1 Degree centrality 2 Network density 3 Closeness centrality	Interpretive policy analysis; systematic grey-literature based case-study and social network analysis	1 Government authorities 2 Infrastructure development agencies 3 Private sector companies: (Firms involved in construction, logistics, and other services). 4 Local communities and landowners 5 Consultants and technical experts.	(1) Research on publicly available data (2)Literature review (3) Information request	UCINet 6 software
Faster Decision-Making	Streamlining the decision-making process by improving connectivity between key NBS actors.		The study has contributed by offering a novel analytical framework of coupling innovative interpretive policy analysis grounded on publicly available secondary data, grey literature, and social network analysis.		1 Degree centrality 2 Network density 3 Closeness centrality				
Leadership and Influence Optimization	Positioning key influencers in the network to lead NBS projects and mobilize support.		The study assessed actor-level attributes like authority, coordination ability, power and information accessibility of various key stakeholders and identified a state with lower information asymmetry in stakeholder governance due to the high focal organization centralities and high overall network density, this state can serve as examples to promote change in the other states.		1 Firm centrality 2 Overall network cohesion 3 Network density				

This table provides a clear framework for how **SNA outcomes** can be applied to enhance the design, implementation, and success of **Nature-Based Solutions (NBS)** projects.

stakeholder attrib. categories								
Stakeholder Name	**Type of Stakeholder**	**Primary Interest**	**Geographical Scope**	**Resources Provided**	**Operational Capacity**	**Stakeholder Influence**	**Role in NBS Projects**	**Sector Focus**
Attribute definition	The classification of the stakeholder based on their role	The main goal or motivation of the stakeholder in relation to the NBS project.	The geographical area where the stakeholder operates or has influence	The types of resources that the stakeholder contributes to the NBS project	The ability of the stakeholder to execute tasks related to the project.	The degree to which the stakeholder can affect the decision-making process, outcomes, or direction of the NBS project.	The specific function or involvement of the stakeholder in the NBS project	The main sector in which the stakeholder operates
Attribute categories	1 Public Sector	1 Water Supply Services	1 National	1 Policy making	1 Regulation (ability to influence or control processes, behaviours, or activities through rules, standards, and policies)	1 High (High capacity to affect the decision-making process, outcomes, or direction of the NBS project)	1 Project Implementer	1 Water Supply
	2 Private Sector	2 Environmental protection	2 Regional- Infra Nacional	2 Technology	2 Utility Operation	2 Very High	2 Service Provider	2 Sanitation
	3 Intergovernmental	3 Nature Conservation	3 Local	3 Knowledge (Understanding, awareness gained through learning)	3 Capacity Building	3 Medium	3 Advocate	3 Environment
	4 Community	4 Sanitation services	4 Global	4 Infrastructure	4 Enforcement	4 Low	4 Funder	4 Agriculture
		5 Sustainability	5 Regional International	5 Labour	5 Farming	5 Very Low	5 Oversight	5 Water Resources
		6 Agriculture sustainability		6 Research (investigation and study in order to establish facts and conclusions)	6 Knowledge Generation/ Dissemination		6 Knowledge Provider	6 Energy
		7 Funding (Investments)		7 Loans, Grants, Capital, Financial Resources, Funding	7 Funding		7 Capacity Builder	7 Public Works
		8 Culture		8 Technical Assistance	8 Monitoring and Evaluation		8 Community Mobilizer	8 Housing
		9 Legal/Justice,		9 Policy Enforcement	9 Technical Assistance		9 Data Provider	9 Urban planning
		10 Climate Resilience		10 Regulation	10 Project Management		10 Project Beneficiary	10 Logistics
		11 Water resources sustainability		11 Advocacy	11 Project Design		11 Enforcer/ Supervisor / Auditor	11 Finance
		12 Innovation		12 Logistics	12 Infrastructure construction		12 Regulator	13 Legal/Justice
		13 Infrastructure Development		13 Land	13 Compliance Enforcement		13 Advisor	
		14 Logistics, Transportation Services		14 Equipment	14 Data Collection and Management		14 Standard Setter/ legislator/Policy maker	
		15 Community Welfare			15 Innovation			
					16 Work force			
					17 Logistic			
					18 Advocacy			