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Transport-Driven Polycentric Transformation as a Pathway to Sustainable Urban Development: The Case of Baku Agglomeration

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ABSTRACT:
This study investigates the spatial transformation of Baku urban agglomeration within the context of rapid urbanization, economic restructuring and increasing sustainability challenges. The research develops a multi-layer analytical framework combining morphological analysis perspective to examine the evolution of the agglomeration as an emerging transport-led polycentric system. The analysis is based on spatial-morphological interpretation, corridor-based network evaluation and comparative scenario assessment using key indicators, including centrality, accessibility, functional distribution and environmental constraints. The results reveal a structural mismatch between infrastructural expansion and functional redistribution. While transport corridor development has significantly enhanced territorial connectivity, economic activities and advanced services remain highly concentrated in the metropolitan core. These findings indicate that Baku agglomeration is not yet fully polycentric in a functional sense but is transitioning toward a corridor-driven configuration of polycentricity. Transport infrastructure emerges as a primary structuring mechanism, enabling spatial integration and facilitating the emergence of differentiated urban nodes, although functional decentralization requires further development. From a sustainability perspective, the corridor-based polycentric model contributes to reducing transport congestion, improving accessibility, optimizing land-use distribution and mitigating environmental pressures through the spatial redistribution of functions. The results demonstrate that infrastructure-led spatial restructuring can serve as an effective pathway toward more balanced and resource-efficient metropolitan development. The study contributes to urban theory by proposing that, in contrast to classical models based on economic decentralization, polycentric transformation in post-industrial and resource constrained metropolitan regions may emerge through transport-driven processes. This highlights the need to reconceptualize polycentricity as a context-dependent and infrastructure-mediated phenomenon.

Keywords: Baku agglomeration; polycentric development; transport corridors; urban networks; sustainable urban development; spatial structure; accessibility; metropolitan transformation

1. Introduction

Urban agglomerations represent key forms of spatial organization in contemporary urbanized territories, concentrating population, economic activity and

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infrastructure while playing a critical role in regional development and innovation dynamics (Esposito et al., 2019; Jiang et al., 2025). Under conditions of globalization and accelerated urbanization, these systems increasingly exhibit complex patterns of functional integration and spatial interaction (Boix & Trullén, 2007).

However, agglomeration processes are also associated with structural challenges, including spatial imbalance, transport congestion and environmental pressure resulting from excessive centralization and uneven infrastructure distribution (Yu et al., 2026; Huseynov et al., 2025). These limitations have led to a growing emphasis on polycentric development models and integrated transport systems as key mechanisms for achieving sustainable territorial organization (Chakraborty et al.,2022). As illustrated in Figure 1, the agglomeration is structured through the interaction of global flows, transport corridors and hierarchical urban nodes.

Baku urban agglomeration, the largest metropolitan region in Azerbaijan, provides a critical case for examining these dynamics. Located on the Absheron Peninsula along the Caspian Sea, it has developed as a major industrial and transport hub shaped by oil-based economic specialization and rapid demographic growth. Its spatial structure is characterized by a dominant metropolitan core and a network of secondary settlements, including Sumgait as a major industrial node. Despite a high level of spatial integration driven by transport infrastructure and commuting flows, the agglomeration remains predominantly monocentric. The concentration of advanced services, employment forces institutional functions in Baku reinforces centripetal dynamics, while peripheral areas exhibit limited functional diversification. This imbalance highlights the need to reconsider the mechanisms through which polycentric transformation occurs in post-industrial and resource-dependent metropolitan regions.

Although polycentricity has been widely studied, existing research often treats it primarily because of economic decentralization. Less attention has been given to infrastructure-led pathways of spatial restructuring, particularly in post-Soviet contexts. Moreover, the application of the "buzz-pipeline" framework to urban spatial analysis limited (Filippi, 2024; Wang et al., 2023; Radulescu et al., 2025; Li et al., 2021).

This study aims to analyze the spatial structure of Baku agglomeration and to identify pathways toward a more balanced and integrated metropolitan system. The research focuses on the interaction between transport connectivity, functional organization and settlement structure, emphasizing the role of transport infrastructure, functional differentiation and network-based interactions. In contrast to classical models based mainly on economic decentralization, this study argues that polycentric restructuring in the Baku agglomeration is largely mediated by transport corridors, which create the spatial conditions for functional redistribution but do not automatically produce it. In this context, Baku agglomeration should not be interpreted as a completed polycentric metropolitan system, but rather as a transitional transport-driven spatial structure. Transport corridors have improved accessibility and strengthened connections between the metropolitan core and secondary nodes such as Sumgait, Khirdalan and Alat. However, functional redistribution remains incomplete, because advanced services, employment opportunities and institutional functions are still concentrated in Baku. Therefore, the transformation of the agglomeration is shaped by a structural mismatch between infrastructural integration and functional decentralization. This study argues that

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sustainable metropolitan development in Baku requires not only transport expansion, but also coordinated land-use planning, redistribution of functions and stronger development of secondary urban nodes.

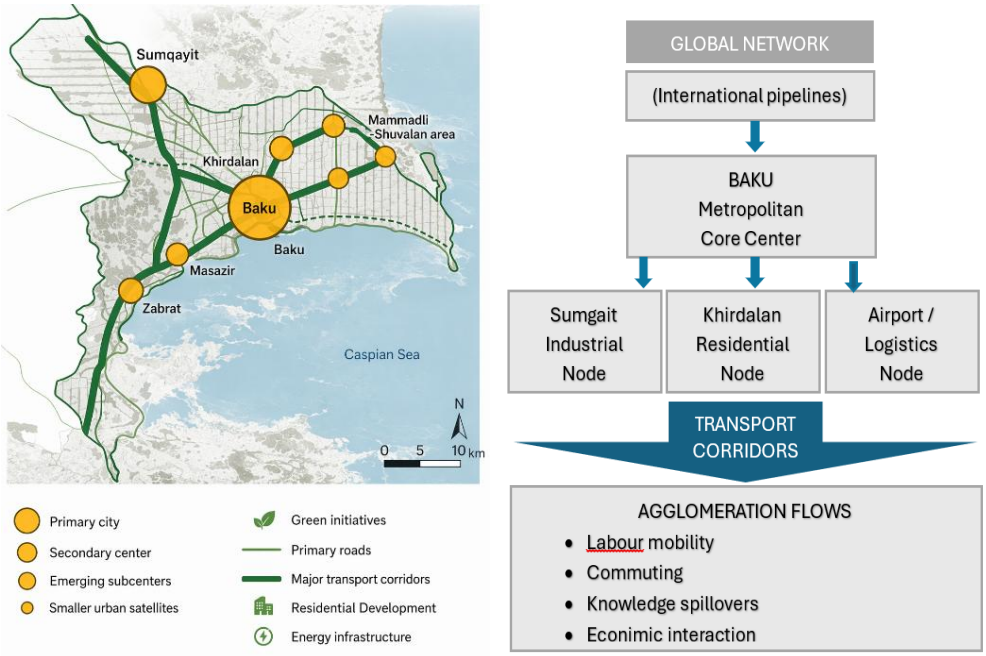

Figure 1: *a. Transport network structure and mobility infrastructure of the Baku agglomeration. b. Conceptual model of transport-led polycentric transformation in Baku agglomeration, illustrating the integration between global networks, metropolitan core, secondary urban nodes, transport corridors and spatial flows*

Furthermore, the study adapts the "buzz-pipeline" framework to a spatial planning context. In this interpretation, "buzz" represents dense intra-agglomeration interactions within the metropolitan core, while "pipelines" correspond to transport and economic linkages connecting the agglomeration to regional and global systems. Their interaction supports the emergence of a network-based polycentric structure characterized by differentiated urban nodes and corridor-mediated connectivity.

The research is guided by four hypotheses:

(H1) functional linkages generate agglomeration effects;

(H2) transport infrastructure enhances spatial integration;

(H3) polycentric structures reduce territorial disparities;

(H4) Environmentally oriented planning supports sustainable urban development.

By integrating structural, functional and network-based perspectives, the study provides a transferable analytical framework for understanding corridor-driven polycentric transformation in emerging metropolitan regions.

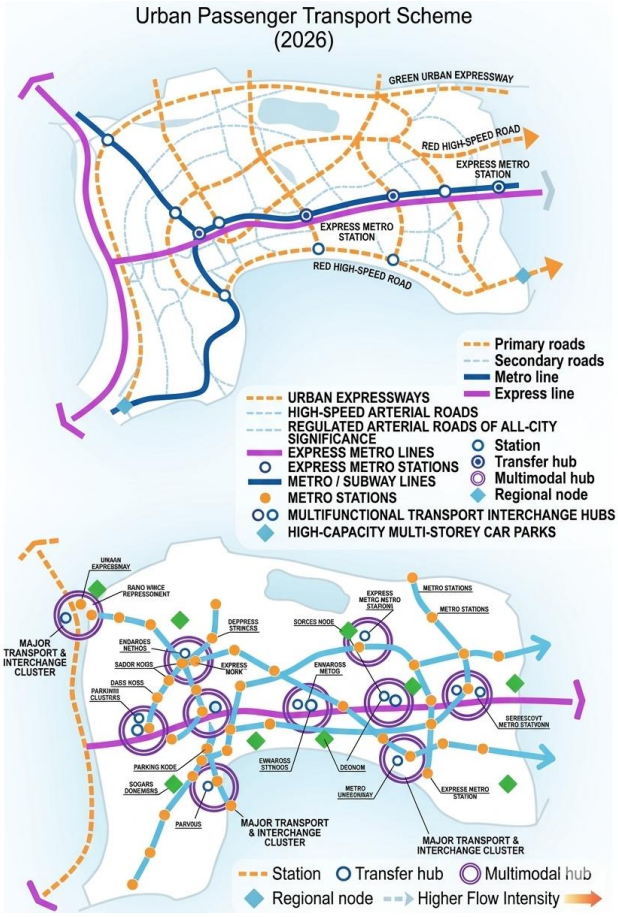

Figure 2: *Spatial structure of the Baku agglomeration illustrates node hierarchy and corridor-based connections (source: developed by the authors)*

2. Theoretical Background

2.1. Urban agglomeration and polycentric restructuring

Urban agglomerations are increasingly conceptualized as complex and dynamic spatial systems shaped by economic concentration, infrastructure development and functional interdependencies between settlements. Rather than static territorial entities, they operate as networks interconnected through flows of people, goods and information (Fang & Yu, 2017; Kii, 2021).

Within this framework, contemporary research emphasizes the role of spatial restructuring processes, particularly the transition from monocentric to polycentric configurations. Polycentric development is traditionally defined as the emergence of multiple urban centers accompanied by the redistribution of economic functions and

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services. However, recent studies extend these interactions and relational integration across urban nodes (Wang et al., 2025; Shang et al., 2025).

This shift reflects a broader transition from morphology-based interpretations toward network-oriented approaches, where spatial organization is increasingly understood through connectivity, interaction intensity and functional specialization. In this context, polycentricity is not solely a structural outcome but a process shaped by multi-scalar interactions within metropolitan systems.

In rapidly urbanizing regions, this transformation is often uneven and path-dependent, influenced by historical industrial development, institutional frameworks and infrastructural pressures (Zhang & Yin, 2025)

2.2. Transport corridors and corridor-based urbanization

Transport infrastructure plays a fundamental role in shaping spatial organizations within urban agglomerations. The development of transport corridors – such as highways, rail systems and multimodal logistics networks – enhances spatial connectivity and facilitates the redistribution of economic activities across regions (Pian et al., 2024).

Recent studies highlight corridor-based urbanization as a key mechanism of spatial transformation, where development is structured along major transport axes rather than distributed uniformly across space. In this context, corridors function as spatial structuring elements that shape land-use patterns, accessibility gradients and the emergence of secondary urban nodes (Duque Ordoñez & Brovelli, 2025; Sogbe et al., 2025).

Beyond physical connectivity, transport networks also contribute to functional integration by reducing travel time, intensifying commuting flows and strengthening economic linkages between core and peripheral areas. However, uneven- infrastructure provision may reinforce spatial inequalities and sustain core-oriented structure, particularly in rapidly developing metropolitan regions (Shi et al., 2025).

2.3. Buzz-pipeline and network-based metropolitan interaction

The "buzz-pipeline" framework, originally introduced in economic geography, conceptualizes the interaction between localized and external networks in shaping spatial development. In this study the framework is reinterpreted within a metropolitan context, providing a novel lens for analyzing agglomeration dynamics. Here, "buzz" is defined as intensive intra-agglomeration interactions, including commuting flows, service exchange, labour-market dependence, knowledge circulation and socio-economic connectivity within the metropolitan system. In contrast, "pipelines" are conceptualized as transport-economic corridors, ports, airport connections and infrastructural linkages that integrate the metropolitan area into regional and global networks. (Henn, 2012).

This reinterpretation provides a framework for understanding how corridor-based connectivity contributes to the transformation of traditionally monocentric urban systems into more polycentric spatial configurations. It highlights that spatial development is shaped by the interaction between internal agglomeration Dynamics and external network integration. While local interactions facilitate knowledge diffusion, trust formation and innovation, external linkages expand Access to markets, resources and broader economic opportunities. Recent studies indicate that a balanced relationship between These dimensions enhances overall system performance, whereas the dominance of one over the

other may result in structural inefficiencies or spatial lock-in. In the Baku agglomeration, local "buzz" can be empirically interpreted through daily commuting flows, concentration of employment, service exchange and institutional interaction within the metropolitan core. Baku remains the main center of administrative, educational, cultural and advanced service functions, which creates intensive internal interaction and labour-market dependence. External "pipelines" are represented by the Baku–Sumgait industrial corridor, the Baku–Alat logistics and port axis, the airport-related mobility corridor and regional transport connections. These corridors link the agglomeration to wider economic networks and support the functional differentiation of secondary nodes. Sumgait is strengthened as an industrial pole, Khirdalan as a residential and service-oriented suburban node, Alat as a logistics hub and the airport zone as a gateway node. Although the present study does not apply detailed quantitative commuting or mobile-data analysis, these relationships are assessed through proxy indicators such as corridor adjacency, accessibility, travel-time distance, node specialization and connectivity level. Therefore, knowledge exchange, labour mobility and institutional cooperation are interpreted as relational processes that support node differentiation, while their uneven distribution also explains the continued dominance of Baku within the agglomeration system.

2.4. Research gap in post-Soviet agglomerations

Despite extensive research on urban agglomeration, transport networks and polycentric development, post-Soviet metropolitan systems remain underexplored. These regions exhibit distinct spatial trajectories are shaped by centralized planning legacies, industrial specialization and uneven infrastructural development.

Existing studies largely focus on Western European and Chinese contexts, where polycentric transformation is typically driven by economic decentralization and market-oriented restructuring (Liu et al., 2025). In contrast, post-Soviet agglomerations often follow an alternative pathway in which infrastructural expansion precedes functional diversification. As a result, the role of transport infrastructure as a primary driver of spatial restructuring remains insufficiently addressed. There is a lack of integrated analytical frameworks that simultaneously consider settlement structure, transport networks and functional interactions.

Furthermore, the application of the buzz-pipeline framework at the metropolitan scale remains limited, despite its relevance for explaining network-based spatial dynamics. Addressing this gap, the present study proposes a transport-led, network-based interpretation of polycentric transformation, using Baku agglomeration as a representative case of infrastructure-driven metropolitan development.

3.Research Methodology

3.1. Methodological Approach

This study adopts an integrated methodological framework to analyses the spatial structure and development dynamics of Baku urban agglomeration. The approach combines spatial and morphological analysis, transport connectivity assessment, functional node analysis and comparative evaluation of development models, enabling the

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agglomeration to be interpreted as a complex, network-based spatial system. The analytical workflow is summarized in Figure 3.

To enhance analytical rigor, the study applies a structured evaluation framework based on three core dimensions: centrality, connectivity and functional distribution. In addition, sustainability-related spatial indicators – including accessibility, environmental exposure and transport load – are incorporated to assess spatial development in relation to mobility efficiency, environmental performance and resource distribution.

Centrality is evaluated through the concentration of employment, services and infrastructure within the metropolitan core. Connectivity is assessed through transport network structure, including corridor intensity and radial flows. Functional distribution is analyzed based on the specialization and diversification of urban nodes.

The methodological framework is conceptually illustrated in Figures 3-4. The analysis is conducted in several stages. First, a spatial – morphological analysis of the settlement structure is performed, focusing on key settlements of the Absheron Peninsula (e.g., Nardaran, Mardakan, Buzovna, Bilgah). This stage identifies spatial layout, land – use patterns and functional linkages between the metropolitan core and peripheral areas (Zhou et al., 2025).

Second, a historical – spatial analysis is conducted to examine the territorial development of the agglomeration from 1924 to 2026, based on planning documents and historical maps. This enables the identification of key phases of urban expansion and the role of industrialization and transport infrastructure in shaping spatial transformation.

Third, transport connectivity is analyzed through the identification of major corridors (road, rail and air) and their influence on accessibility, mobility and economic interaction. This stage allows the detection of structural constraints and bottlenecks within the agglomeration system.

Fourth, a functional analysis of urban nodes is conducted, interpreting the agglomeration as a system of interconnected centers with differentiated roles, including the metropolitan core (Baku), industrial nodes (Sumgait), residential areas and logistics hubs.

Fifth, a comparative evaluation of development models (monocentric, polycentric and network-based) is carried out to determine the structural position of the agglomeration and identify transformation pathways (Nowak et al., 2023).

Finally, the results are integrated into a conceptual modeling framework combining polycentric structure, transport corridors and network interactions interpreted through the buzz – pipeline approach. Although the study is primarily conceptual, the integration of sustainability – related spatial indicators provide a semi-quantitative basis for evaluating spatial transformation processes. The applied spatial metrics are used as proxy indicators to approximate structural relationships within the agglomeration in the absence of full-scale quantitative datasets.

3.2. Analytical Design and operational framework

To reduce descriptive bias and enhance analytical transparency, the study operationalizes spatial evaluation through multi-dimensional, environmental constraints and morphological structure. Each dimension is defined through corresponding indicators, enabling a structured interpretation of spatial transformation processes:

Centrality: employment and service concentration (core dominance)

Connectivity: corridor access, radiality and node reachability (transport integration)

Functional distribution: diversity of node specialization (degree of polycentricity)

Environmental constraints: exposure to degraded or restricted areas (planning limitations)

Morphological structure: compactness, dispersion and corridor expansion (settlement form)

These indicators are derived from planning documents, transport network mapping, land-use analysis, environmental data and historical spatial interpretation. This operational framework enables the integration of qualitative spatial analysis with structured comparative evolution, providing a consistent analytical basis for interpreting corridor-driven polycentric transformation.

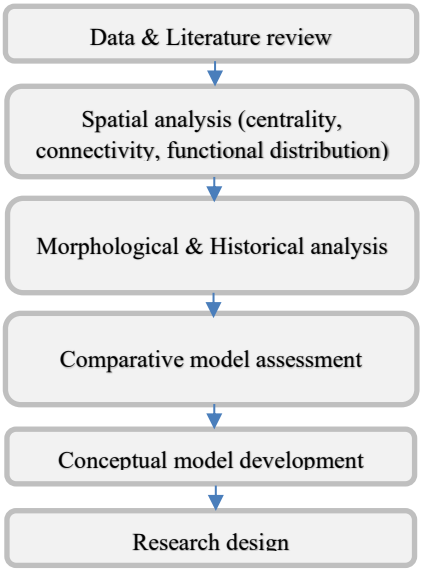

Figure 3: *Methodological framework of the study, illustrating the sequential workflow from data collection and spatial analysis to comparative model assessment and conceptual model development*

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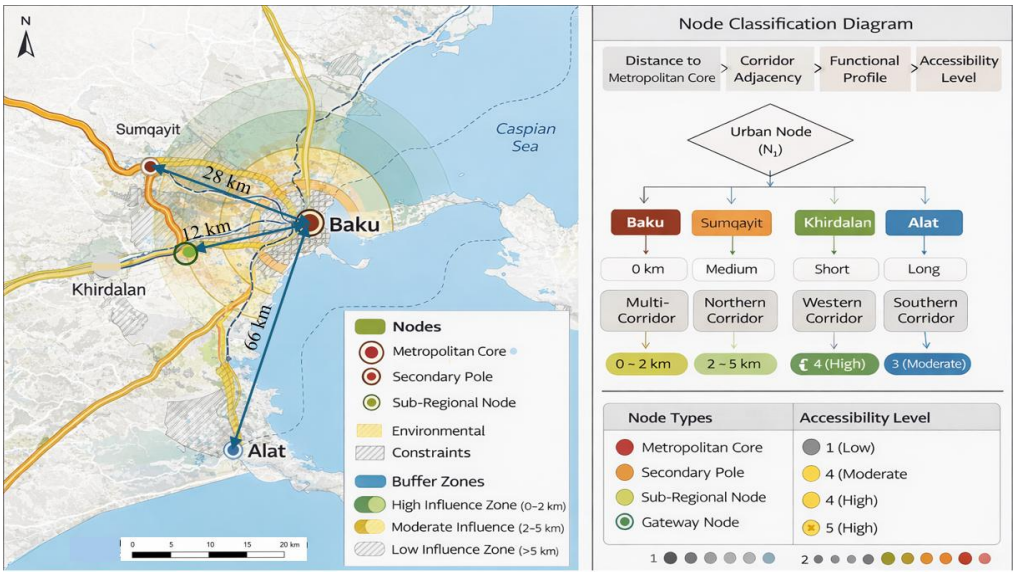

Figure 4: *Spatial configuration and node-based accessibility structure of the Baku agglomeration, illustrating corridor-driven interactions, distance-based influence zones and hierarchical urban nodes*

3.4. Conceptual framework of corridor-driven polycentric transformation

The conceptual framework integrates morphological, functional, transport and environmental dimensions to interpret Baku agglomeration as a network – embedded system. At the structural level, the framework considers node hierarchy, connectivity, functional distribution, accessibility and environmental pressure, complemented by sustainability – related indicators such as accessibility, environmental exposure and transport load. The framework adopts a network perspective, where spatial transformation is driven by interactions between nodes and their position within transport and functional systems. At its core lies the interaction between centrality and connectivity, which produces three key processes:

- corridor -driven restructuring
- functional redistribution,
- and buzz – pipeline complementarity.

In this context, "buzz" represents dense intra – agglomeration interaction within the metropolitan core, while "pipelines" correspond to external corridor – based connections.

3.5. Node evaluation framework

To operate spatial differentiation, a node evaluation framework is applied, linking spatial position. Connectivity and functional specialization. The analysis identifies a hierarchical yet differentiated structure. Baku functions as the metropolitan core,

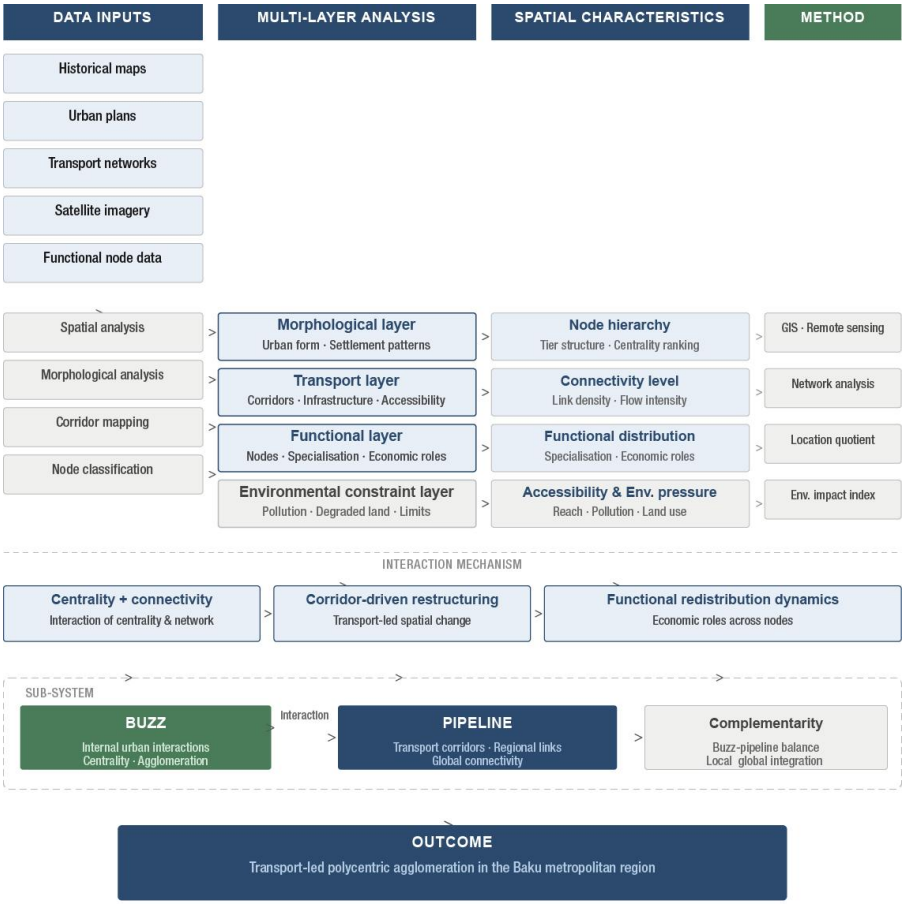

Figure 5: *Conceptual framework of corridor-driven polycentric transformation in Baku agglomeration, illustrating the interaction between multi-layer spatial analysis, centrality – connectivity mechanisms and the buzz-pipeline leading to transport -driven spatial restructuring.*
characterized by maximum accessibility, multi – corridor connectivity and concentration of advanced services.

Sumgait operates as an industrial pole with high accessibility and strong corridor integration, while Khirdalan functions as a residential and service – oriented to the southern corridor, exhibiting moderate accessibility but high external connectivity

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potential. This differentiation supports the interpretation of the agglomeration as a system transitioning toward a corridor – driven polycentric structure. The conceptual framework (Figure 5) synthesizes the interaction between spatial structure, network dynamics and corridor-based connectivity through the buzz-pipeline model.

3.6. Conceptual integration and outcome

The integration of spatial metrics and network processes reveals the emergence of a transport-led polycentric configuration, characterized by strong internal interactions within the metropolitan core ("buzz") and enhanced regional and global connectivity facilitated by transport corridors ("pipelines"). The system demonstrates the gradual formation of interconnected urban nodes and partial functional redistribution, contributing to improved spatial balance. Importantly, the results suggest that polycentric transformation in Baku agglomeration is driven primarily by transport infrastructure rather than endogenous economic decentralization. Transport corridors act as the principal structuring mechanism, enabling both connectivity and functional differentiation.

Accordingly, the agglomeration can be conceptualized as a network-embedded system undergoing corridor-driven restructuring, where infrastructure-led development represents a key pathway of metropolitan evolution.

3.7. Comparative evaluation of spatial development scenarios

To evaluate alternative spatial development models, a comparative assessment is conducted across monocentric, polycentric and corridor-based configurations. The evaluation is structured around four criteria: corridor accessibility, functional diversification, environmental exposure and capacity for spatial load redistribution. Score are assigned through qualitative cross-evaluation of these criteria, reflecting the relative performance of each model in terms of transport integration, functional balance, environmental constraints and redistribution potential.

The results demonstrate that the corridor-based model performs more effectively than the monocentric configuration, particularly in improving accessibility, reducing pressure on the metropolitan core and enhancing functional balance across the agglomeration. Compared to conventional polycentric models, the corridor-based approach provides a more context-sensitive pathway for spatial transformation under existing infrastructural and institutional conditions. These findings indicate that transport infrastructure functions as the primary structuring mechanism in the transition toward polycentric development. Corridor-based connectivity emerges as a decisive factor in shaping metropolitan spatial organization and enabling more balanced and integrated urban systems.

4.Results and discussion.

4.1. Spatial structure and functional organization

The empirical comparison of centrality, connectivity and functional distribution reveals a structural mismatch within Baku agglomeration. As illustrated in Figure 4, the spatial configuration reflects a hierarchical structure shaped by corridor-based accessibility and node interactions. While transport corridor expansion has significantly enhanced

territorial connectivity, the spatial concentration of advanced services and institutional functions remains highly centralized in Baku. This indicates that the agglomeration is not yet functionally polycentric but is transitioning toward a corridor-driven configuration of polycentricity.

This imbalance is reflected in the dominance of the metropolitan core, where economic activities, governance functions and advanced services are concentrated, while peripheral areas remain functionally limited. Despite improvements in transport infrastructure, functional redistribution across secondary nodes remains insufficient, reinforcing the centrality of Baku within the agglomeration system.

Historically, the agglomeration evolved around Baku as a dominant economic and administrative core, corresponding to a classical monocentric model characterized by high concentration of resources and infrastructure. At present, the settlement system across the Absheron Peninsula continues to exhibit strong centripetal tendencies, with economic activity and infrastructure concentrated in the metropolitan core. At the same time, intensive commuting flows and transport interactions indicate a high level of spatial integration. Polycentric spatial structure of Baku agglomeration, Baku functions as the metropolitan core, while Sumgait, Khirdalan and other settlements operate as secondary nodes with industrial, residential and logistics specialization (Figure 4). However, their functional capacity remains limited, indicating that infrastructural connectivity has not yet been matched by functional decentralization. This confirms that polycentricity in Baku agglomeration is emerging as a transport-induced rather than function-induced process.

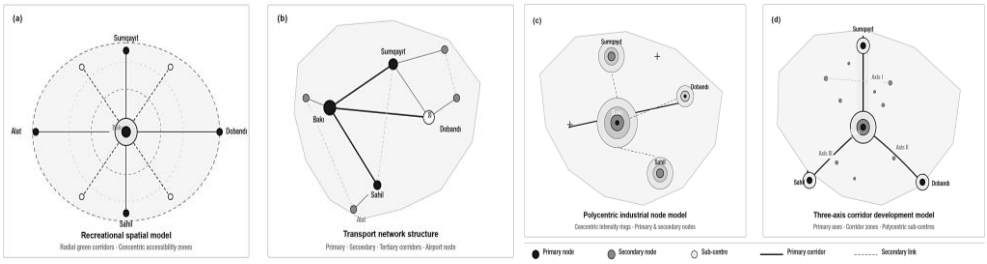

Figure 6: *Evaluation of spatial transformation models of the Baku agglomeration (a) radial-recreational structure, (b) transport network configuration, (c) industrial polycentric model, (d) three-axis corridor development. Source: Authors' elaboration based on historical planning documents*

The historical evaluation of the agglomeration demonstrates the integration of structural and functional components with the historical dynamics of urban development. It reflects the transition from industrial to smart urban systems and highlights how the interaction between economic activities, service systems, transport infrastructure, residential areas and recreational functions contributes to a more adaptive metropolitan structure, emphasizing the role of industrial growth and transport infrastructure - driven transformation. Despite increased connectivity, spatial development remains uneven. The concentration of employment, education and specialized services in Baku reinforces centripetal dynamics and limits the development of secondary urban centers (Akola et al., 2023). Territorial expansion further intensifies this imbalance, while geographical

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constraints of the Absheron Peninsula limit uncontrolled growth and underscore the need for more efficient land-use strategies.

Transport networks play a dual role by enhancing spatial integration while simultaneously contributing to socio-economic disparities. At the same time, contemporary development trends align with global shifts toward sustainable mobility and polycentric organization.

Environmental constraints further influence spatial transformation, as urban expansion and industrial activity intensify ecological pressure, necessitating the integration of environmental considerations into planning processes (Akola & Charlotte, 2025).

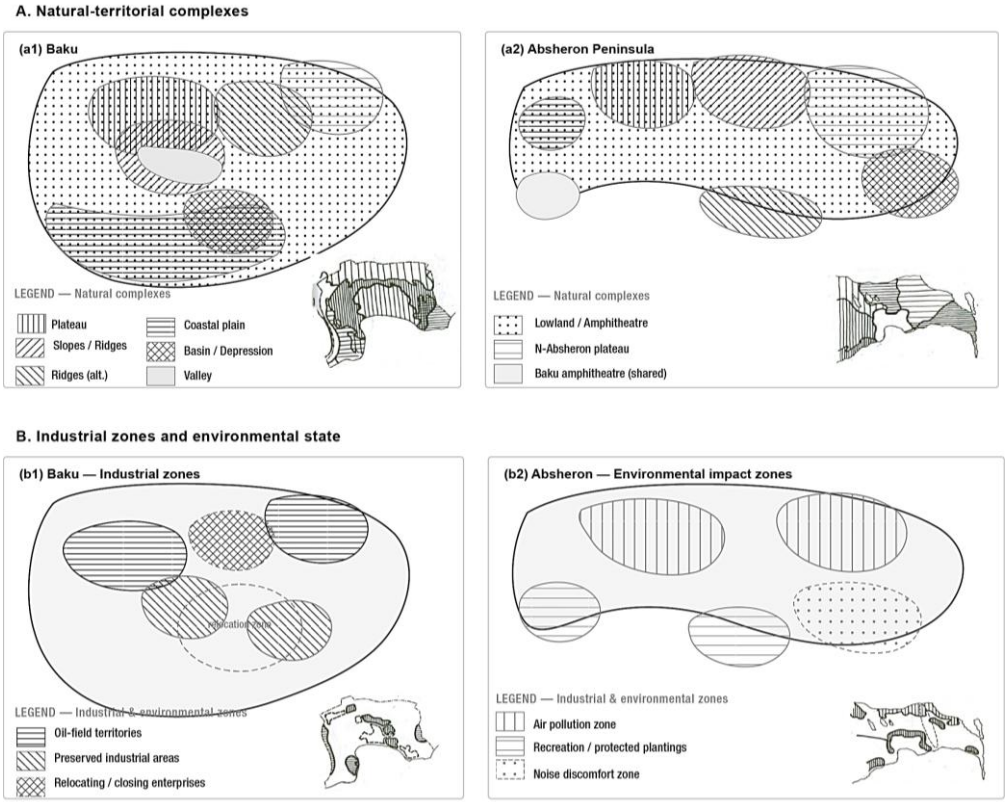

Figure 7: *Regional preconditions of the Baku agglomeration (a1-a2) natural-territorial complexes (b1-b2) industrial and environmental zones. Source: Authors' elaboration based on archival planning documents (1970-2026)*

Quantitative interpretation based on spatial metrics reinforces these findings. The centrality index of Baku significantly exceeds that of secondary nodes, while improvements in connectivity have not been accompanied by proportional functional diversification. Accessibility values are highest in Baku due to its multi-corridor integration, whereas

secondary nodes such as Sumgait lower accessibility but higher strategic connectivity as a logistics gateway (Figure 6).

Similarly, connectivity measures confirm that Baku operates as the primary network hub, while secondary nodes display corridor-specific integration patterns. The composite node index indicates a hierarchical yet differentiated structure, where centrality remains dominant, but improving accessibility and connectivity in peripheral nodes signal an emerging transition toward polycentricity. This mismatch should also be interpreted through broader socio-spatial and institutional conditions. Housing affordability, demographic mobility, socio-economic inequality and access to public services influence the ability of secondary nodes to attract residents, services and employment opportunities. In addition, informal economic activity in peripheral settlements and fragmented governance responsibilities between metropolitan and local authorities may limit the capacity of secondary nodes to develop as independent functional centers. If peripheral settlements remain dependent on the metropolitan core for higher-order services, jobs and administrative functions, improved accessibility may increase commuting intensity rather than produce balanced decentralization. Therefore, the evaluation of polycentric transformation requires not only spatial and infrastructural indicators, but also attention to social, demographic and governance-related factors that shape everyday metropolitan interaction and functional redistribution.

Overall, the results demonstrate that Baku agglomeration represents a transitional spatial system in which infrastructural expansion has outpaced functional redistribution. This produces a hybrid configuration where network connectivity coexists with persistent monocentric dominance. From a theoretical perspective, these findings suggest that polycentric transformation in resource-constrained metropolitan regions may follow an alternative pathway, in which transport infrastructure acts as the primary catalyst of spatial restructuring. This supports a reconceptualization of polycentric urban theory toward infrastructure-led development trajectories.

4.2. Network interaction and Buzz – Pipeline dynamics

The spatial organization of Baku agglomeration reflects a differentiated interaction structure shaped by the interplay between internal intensity and external connectivity. The conceptual interaction between internal and external networks is illustrated in Figure 8. Within this system, the metropolitan core functions as a dominant "buzz" zone, concentrating economic activity, labour mobility and social interaction, while secondary nodes such as Sumgait, Khirdalan and Alat exhibit more specialized functional roles. Table 1 provides a qualitative assessment of node specialization and connectivity levels within the agglomeration.

Transport corridors operate as "pipelines", linking intra-agglomeration interactions with regional and global systems and enabling flows of labour, goods and knowledge, thereby reinforcing the agglomeration as a network-embedded system.

Despite improved connectivity, advanced services and institutional functions remain concentrated in Baku, resulting in uneven interaction intensity across the agglomeration. Network analysis indicates that a dominant share of flows remains oriented toward the metropolitan core, reinforcing its structural centrality. The qualitative network assessment presented in Table 1 supports the interpretation of uneven functional

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distribution and confirms the dominant role of the metropolitan core. This pattern can be observed in the differentiated roles of the main nodes. The Baku–Sumgait corridor concentrates industrial and labour-related interaction, the Baku–Khirdalan direction reflects suburban commuting and residential dependence, while the Baku–Alat corridor supports logistics, port functions and external economic connectivity. These examples show that "buzz" and "pipeline" dynamics do not operate separately; rather, they interact through corridor-based mobility and functional specialization. However, because higher-order services and institutional decision-making remain concentrated in Baku, these interactions still reinforce core dominance more than balanced functional decentralization.

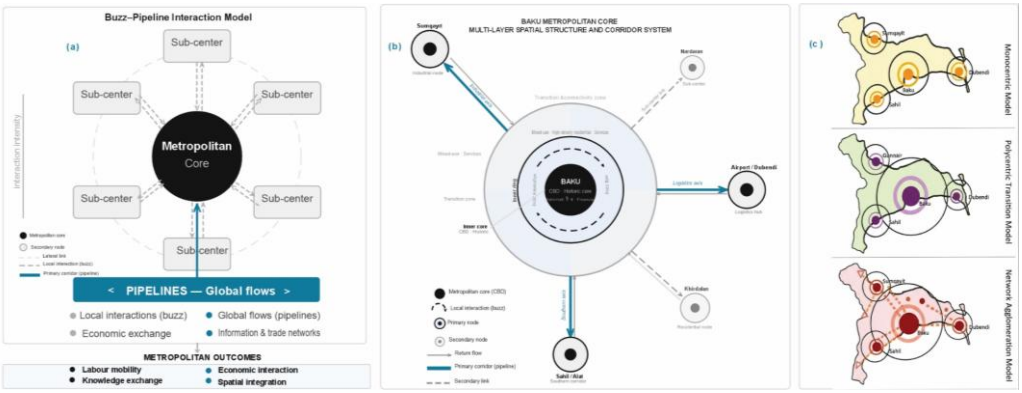

Figure 8: *Conceptual model of buzz–pipeline interaction and polycentric spatial transformation in the Baku agglomeration. (a) Spatial evolution model illustrating the transport-led polycentric urban structure. (b) Multi-layer metropolitan core model highlighting the interaction between central urban functions, transition zones and primary transport corridors. (c) Interaction between transport corridors, functional urban nodes and spatial flows in the transition toward a network-based metropolitan system (source: authors' elaboration)*

As illustrated in Figure 7, the spatial configuration reflects the interaction of natural conditions, industrial structures, environmental constraints and transport corridors, highlighting the multi-layered nature of spatial transformation.

From a network perspective, the agglomeration is evolving toward a corridor-mediated form of polycentricity; however, this transition remains insufficiently realized. Transport infrastructure has advanced more rapidly than functional redistribution, meaning that connectivity expansion does not immediately translate into balanced spatial development.

These findings suggest that transport alone is insufficient to generate polycentricity. Corridors act as enabling frameworks that shape interaction potential but do not guarantee functional decentralization.

Accordingly, the buzz - pipeline framework can be interpreted as a spatial mechanism structuring internal and external interactions. In this study, "buzz" corresponds to dense intra-agglomeration interactions within the metropolitan core, whereas "pipelines" represent strategic transport–economic linkages connecting the agglomeration to external systems (Bathelt et al., 2004; Bathelt, 2007).

Overall, the results indicate that Baku agglomeration represents a transitional system in which network expansion coexists with persistent core dominance, while corridor-based connectivity precedes functional redistribution. This reinforces the interpretation of Baku agglomeration as a corridor-mediated transitional system. In comparative terms, the Baku case differs from many Western European polycentric models, where secondary urban centers often emerge through long-term economic decentralization, regional governance mechanisms and the redistribution of services and employment. In such contexts, polycentricity is usually associated with a relatively mature functional division between metropolitan centers and secondary nodes. By contrast, Baku demonstrates a more infrastructure-led and transitional pathway, in which transport corridors have advanced faster than functional decentralization. The Baku case also differs from several Chinese urban agglomeration models, where polycentric transformation is frequently supported by large-scale state-led urban expansion, industrial relocation, new-town development and high-speed transport investment. Although Baku shares with Chinese cases the strong role of infrastructure in shaping metropolitan restructuring, its secondary nodes remain more functionally limited and more dependent on the metropolitan core. Therefore, Baku occupies an intermediate position between European functional polycentricity and Chinese state-led corridor urbanization. This comparison highlights the broader theoretical implication of the study: in post-Soviet metropolitan regions, polycentric transformation may emerge not primarily through mature economic decentralization or large-scale new-town development, but through corridor-mediated restructuring shaped by inherited monocentric patterns, infrastructure priorities and uneven functional redistribution.

4.3 Morphological Transformation and Spatial Reconfiguration

The morphological analysis reveals a transition from inherited compact settlement forms to a network-driven spatial configuration. Traditional settlements of the Absheron Peninsula exhibit climate-responsive, compact morphologies shaped by local environmental conditions, while contemporary urban expansion is increasingly structured along transport corridors, producing a linear–nodal spatial pattern.

This shift reflects a broader transformation in which accessibility and connectivity replace geographical and historical determinants as primary drivers of urban form. As transport corridors intensify their structuring role, spatial development becomes increasingly aligned with network logic.

These dynamics correspond to wider urbanization trends observed in rapidly developing metropolitan regions, where infrastructural expansion generates new forms of spatial differentiation. In Baku agglomeration, this process is reinforced by socio-economic restructuring, including service sector growth and increasing spatial polarization.

At the same time, development is characterized by structural imbalances. Rapid territorial expansion has outpaced functional diversification and infrastructure provision, leading to uneven spatial patterns and increasing environmental pressure. Geographical constraints of the Absheron Peninsula further limit expansion and highlight the importance of efficient land-use strategies.

The settlement system is also characterized by fragmentation, with numerous small settlements exhibiting limited development potential. This necessitates a selective

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planning approach focused on strengthening strategically located nodes capable of supporting polycentric development (Marchigiani & Bonfantini, 2022).

Morphological analysis indicates a growing hybrid spatial structure combining traditional compact forms with corridor-based expansion. Importantly, spatial imbalance is not solely the result of urban growth, but of the mismatch between infrastructural expansion and functional redistribution.

Consequently, effective spatial planning should integrate inherited morphological logic with emerging network-based structures rather than replace it. Overall, the transformation of Baku agglomeration reflects a shift toward a corridor-driven spatial configuration shaped by mobility and connectivity systems.

5. Planning Implications for Baku Agglomeration

The findings indicate that the future development of Baku agglomeration requires a transition toward an integrated and system-oriented planning model addressing spatial efficiency, transport connectivity, environmental constraints and functional redistribution.

Table 1: Functional specialization and connectivity assessment of key urban nodes in the Baku agglomeration

Urban Node	Functional Role	Connectivity Level	Accessibility (Approx. Travel Time to Baku Core)	Spatial Significance
Baku (Core)	Metropolitan core (administrative, economic, service center)	High	0 min – 0 min	Dominant core with high service concentration
Sumqayit	Industrial node	Medium–High	30–40 min	Secondary growth pole linked via northern transport corridor
Khirdalan	Residential node	Medium	15–25 min	Suburban integration zone; dependent on core for services
Alat	Logistics and port hub	Low-Medium	60–70 min	Strategic southern corridor node with future development potential
Airport (Heydar Aliyev International Airport)	Logistics and mobility hub	High	20–30 min	Key gateway connecting the agglomeration to global networks

A key implication concerns the redistribution of functions across agglomeration. The concentration of economic activity and services in Baku reinforces spatial imbalance, highlighting the need to strengthen secondary nodes such as Sumgait, Khirdalan and Alat, which already exhibit differentiated functional roles.

The functional differentiation and connectivity of key urban nodes are summarized in Table 1, which provides a qualitative assessment of their roles within the agglomeration structure.

Transport infrastructure emerges as the primary structuring mechanism in this transformation. The existing radial system should evolve into a more networked configuration incorporating corridor-based and ring connections. Multimodal transport integration is essential for improving accessibility, reducing congestion and enhancing inter-node connectivity (Šišak & Lukić, 2025).

Morphological analysis further suggests that traditional settlement patterns such as those illustrated in Figure 8a - should be integrated into contemporary planning strategies due to their environmental adaptability. At the same time, environmental constraints (Figure 8b) require the incorporation of ecological corridors, green infrastructure and rehabilitation strategies into spatial planning processes.

Infrastructure modernization, including water, energy and waste systems, should be approached as an integrated and hierarchical network, supporting sustainable resource management (Akiyama et al., 2025).

At a broader scale, the agglomeration is transitioning toward a linear–nodal, corridor-oriented spatial structure, where transport-economic corridors act as key organizing elements. Coastal zones and transit-oriented territories are expected to play an increasing role in future development. Table 1 complements the conceptual model presented in Figure 8 by providing a qualitative assessment of functional specializations and connectivity levels of key urban nodes.

Overall, the results indicate that Baku agglomeration is evolving toward a multi-axis, corridor-driven polycentric system. This transformation depends on the coordinated integration of transport infrastructure, functional specialization and environmental regulation within a unified planning framework.

The analysis of node differentiation further confirms a hierarchical yet evolving structure: Baku remains the dominant core, while secondary nodes exhibit increasing specialization in industrial, residential and logistics functions. However, this transition is still in progress, as infrastructural integration has advanced more rapidly than functional redistribution.

5.1 Prospects for the Development of Baku Settlement System

Baku case suggests that polycentric transformation in post-industrial and resource-dependent metropolitan regions may emerge not through classical economic decentralization alone, but through corridor-mediated restructuring, in which transport infrastructure precedes and conditions functional redistribution.

Accordingly, the future development of Baku settlement system requires a systemic and analytically grounded planning approach integrating territorial organization, economic restructuring, socio-cultural dynamics and sustainability principles. In this context, spatial planning should be understood as a dynamic process coordinating interactions between infrastructure systems, functional specialization and environmental constraints. As illustrated in Figure 7, the spatial evolution of the agglomeration reflects a transition from a monocentric configuration toward a corridor-driven network structure, shaped by the interaction of transport network, functional nodes and spatial flows.

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5.2. Corridor System as a Structuring Mechanism

The analysis demonstrates that transport–economic corridors increasingly function as primary structuring elements of spatial organization. The northern axis (Baku–Sumgait) reinforces industrial specialization, the western direction (toward Khirdalan) supports residential expansion and commuting, while the southern corridor (Baku–Alat) operates as a strategic logistics gateway integrating the agglomeration into international networks. Coastal and peripheral corridors further contribute to energy production, recreation and environmental functions.

These corridors act not only as infrastructure but as spatial organizers shaping land use, mobility and economic activity across the agglomeration.

5.3. Scenario-Based Spatial Evaluation

Comparative analysis indicates that the corridor-based model provides the most balanced spatial outcome when evaluated in terms of accessibility, functional distribution, environmental exposure and transport load.

While the monocentric model is characterized by high congestion and functional concentration and classical polycentric models rely on gradual redistribution, the corridor-based configuration enables a more immediate transformation by simultaneously improving connectivity, supporting node specialization and redistributing spatial pressures.

This confirms that transport infrastructure, combined with functional differentiation, acts as a decisive mechanism for accelerating polycentric transformation.

5.4. Functional Redistribution and Node Differentiation

The transformation of the settlement system is closely linked to functional redistribution across urban nodes. Baku remains the dominant metropolitan core, while secondary nodes exhibit increasing specialization aligned with corridor dynamics.

Sumgait functions as the principal industrial pole, Khirdalan as a residential and service-oriented node within commuting systems and Alat as a strategic logistics hub connecting the agglomeration to global networks. Peripheral settlements contribute to recreation, energy infrastructure and spatial expansion.

This pattern reflects a shift toward functional complementarity, where secondary nodes act as structural counterbalances to the metropolitan core, supporting a more balanced spatial configuration.

5.5. Environmental Constraints and Spatial Regulation

Environmental conditions constitute a key structuring factor. As illustrated in Figure 7, contaminated soils, pollution zones and noise exposure areas impose significant constraints on spatial development. At the same time, environmental improvements in former industrial areas create new opportunities for redevelopment.

These dynamics require the integration of ecological corridors, green infrastructure and environmentally sensitive zoning into spatial planning frameworks, ensuring both spatial efficiency and sustainability.

5.6. Emerging Spatial Model and Theoretical Implications

The prospective spatial structure of Baku agglomeration can be defined as a multi-axis, corridor-driven polycentric system characterized by corridor-based connectivity, differentiated node specialization and integration into regional and global networks.

This transformation reflects a shift from territorially bounded urban forms toward network-based spatial organization, where accessibility and connectivity become primary structuring principles.

From a theoretical perspective, Baku case highlights an alternative pathway of metropolitan transformation. Unlike classical European models driven by economic decentralization, polycentric development in this context emerges through infrastructure-led processes, where infrastructure systems preceded and condition uneven functional distribution.

This finding supports a reconceptualization of polycentric urban theory as a context-dependent and multi-dimensional process shaped by the interaction of transport systems, environmental constraints and functional specialization.

6. Conclusion

This study provides a comprehensive analysis of the spatial structure and transformation dynamics of Baku urban agglomeration under conditions of rapid urbanization and economic restructuring. The findings demonstrate that the agglomeration is transitioning from a historically monocentric configuration toward a network-oriented metropolitan system; however, this transformation is unfinished.

The results reveal a persistent structural imbalance characterized by the concentration of advanced services, employment and institutional functions in the metropolitan core, alongside uneven infrastructure distribution, transport congestion and increasing environmental pressures. These findings highlight the limitations of monocentric development models in addressing contemporary metropolitan challenges.

A key contribution of the study is the identification of a structural mismatch between connectivity and functional distribution. While transport corridor expansion has significantly improved accessibility, functional redistribution across secondary nodes remains limited. This confirms that infrastructural development alone is insufficient to generate functional polycentricity without parallel processes of specialization and decentralization.

The findings further demonstrate that polycentric transformation in Baku agglomeration is predominantly transport driven. Transport–economic corridors enhance spatial integration and create the conditions for the emergence of secondary nodes, functioning not only as infrastructure but as primary structuring mechanisms shaping spatial organization and mobility patterns.

The application of the buzz–pipeline framework reinforces this interpretation. Baku operates as a dominant "buzz" zone, concentrating intra-agglomeration interactions, while transport corridors function as "pipelines" connecting local dynamics to regional and global networks. This interaction explains the coexistence of spatial concentration in the core with increasing spatial connectivity and supports the interpretation of the agglomeration as a corridor-driven transitional system.

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From a theoretical perspective, the study contributes to polycentric urban theory by demonstrating that, in contrast to classical models based on economic decentralization, polycentric transformation in post-industrial and resource-constrained regions may emerge through infrastructure-led processes. This finding supports a reconceptualization of polycentricity as a context-dependent and multi-dimensional phenomenon shaped by transport systems, functional differentiation and environmental constraints.

The proposed conceptual model defines Baku agglomeration as a linear–nodal polycentric system, where transport corridors, hierarchical nodes and network-based interactions jointly determine spatial development. This model provides a transferable analytical framework for understanding metropolitan restructuring in emerging regions and highlights the role of corridor-based development in improving accessibility, reducing congestion and supporting more balanced and sustainable spatial organization.

Limitations and Future Research

Despite its contributions, the study has several limitations. The analysis relies primarily on qualitative and conceptual approaches, with limited application of advanced quantitative methods. Although GIS-based spatial metrics are incorporated, these function as proxy indicators, the empirical validation remains semi-quantitative due to the absence of high-resolution mobility and socio-economic datasets.

In addition, the study focuses on a single case - Baku agglomeration -which may limit the direct generalizability of the findings. However, this case is selected as a representative example of a post-industrial, resource-dependent metropolitan region undergoing transport-led spatial transformation, providing a relevant context for theory-building.

Future research should strengthen empirical validation through the integration of high-resolution spatial and mobility data, including commuting flows and transport interaction datasets. Future research should strengthen the empirical validation of the proposed framework through comparative metropolitan case studies, particularly across post-Soviet, European and Asian urban agglomerations. Such comparison would help to test whether corridor-driven polycentric transformation is specific to the Baku case or represents a broader pathway of infrastructure-led metropolitan restructuring. Further research should also integrate commuting datasets, public transport ridership data, spatial interaction modelling and high-resolution mobility analysis. These data would make it possible to evaluate how daily mobility, labour-market flows and inter-node interactions influence the functional differentiation of secondary urban nodes. In addition, advanced quantitative techniques, including GIS-based accessibility modelling and network indicators such as betweenness centrality, closeness centrality and eigenvector centrality, could provide stronger evidence regarding the long-term sustainability and functional effectiveness of transport-led metropolitan restructuring. Such extensions would allow future studies to assess whether improved transport connectivity contributes to balanced functional redistribution or, conversely, reinforces commuting dependence on the metropolitan core. The application of advanced network-based metrics (e.g., betweenness and closeness centrality), GIS-based accessibility modeling and spatial interaction models would enable a more robust quantitative assessment of corridor-driven polycentric transformation. Comparative studies across multiple metropolitan regions would further enhance the generalizability of the proposed framework.

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