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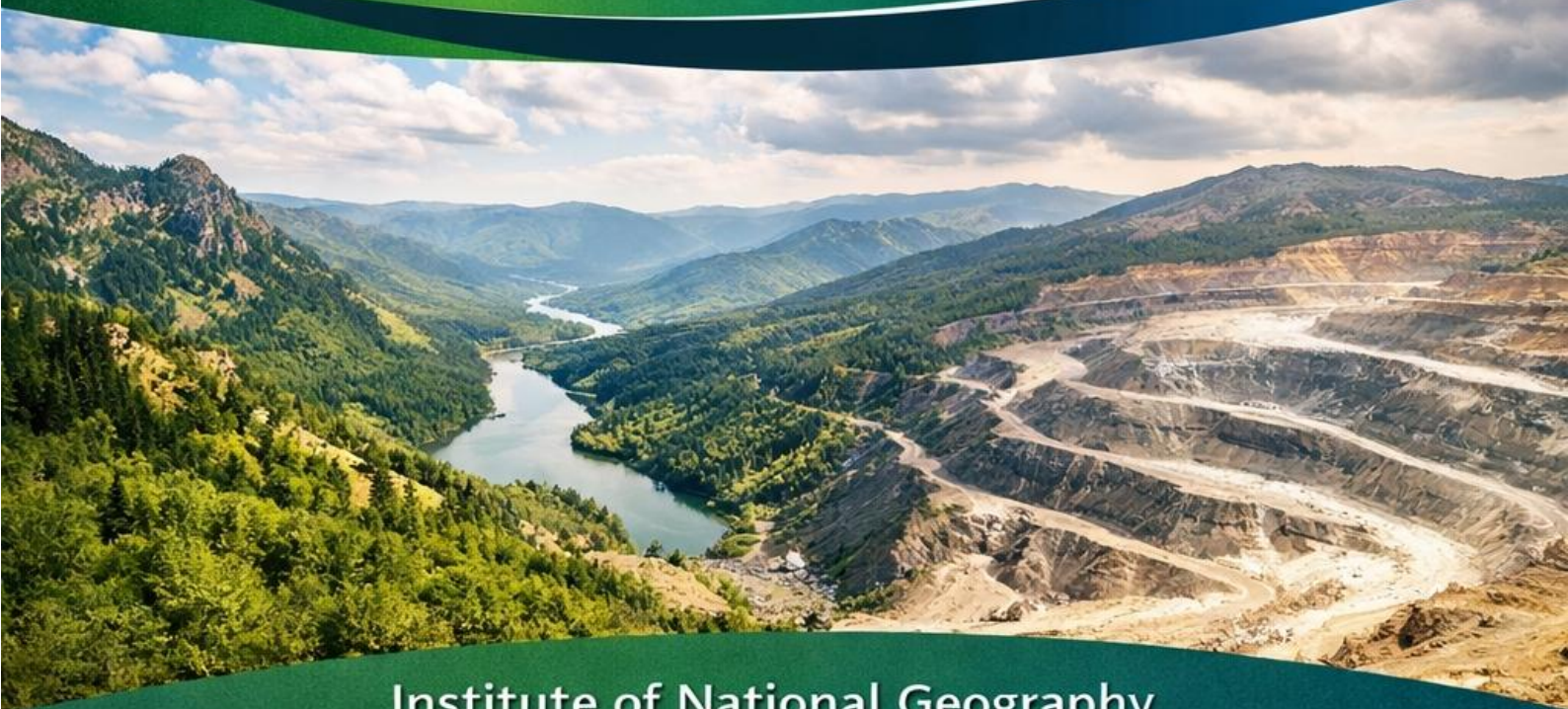

Institute of National Geography
University Skopje – Skopje

Skopje, North Macedonia

INTERNATIONAL SCIENTIFIC CONFERENCE OF THE INSTITUTE OF NATIONAL GEOGRAPHY
GEO³ CONFERENCE 2025
GEOGRAPHY IN THE AGE OF GLOBAL TRANSFORMATION: SPATIAL INEQUALITIES, SUSTAINABILITY, AND TERRITORIAL DEVELOPMENT

PROCEEDINGS BOOK

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Dear colleagues,

It is my great honor and pleasure to welcome you to the **International Scientific Conference of the Institute of National Geography – GEO³ Conference 2025**, held under the title *"Geography in the Age of Global Transformation: Spatial Inequalities, Sustainability, and Territorial Development"*.

The GEO³ Conference is organized by the **Institute of National Geography**, in cooperation with the **University of Skopje**, as part of a continuous academic commitment to advancing geographical science in response to profound economic, social, environmental, and territorial transformations shaping contemporary societies. In an era characterized by accelerating globalization, uneven regional development, environmental pressures, and complex spatial dynamics, geography provides indispensable analytical tools for understanding and addressing these challenges through spatially grounded and scientifically rigorous approaches.

I am confident that this conference will serve as a high-quality academic forum for the exchange of contemporary geographical knowledge, theoretical perspectives, and empirical research findings. Through scholarly dialogue on spatial inequalities, sustainable development pathways, territorial governance, and regional transformation, participants will contribute to strengthening the role of geography as a discipline of both analytical depth and societal relevance. The conference encourages critical reflection, interdisciplinary cooperation, and the development of evidence-based insights applicable to policy formulation, spatial planning, and sustainable territorial development.

The GEO³ Conference 2025 brings together academics, researchers, and practitioners from different geographical traditions and research contexts, providing opportunities for intellectual exchange, professional networking, and the establishment of future research collaborations. By fostering dialogue across national and disciplinary boundaries, the conference aims to reinforce geography's contribution to understanding global transformations through spatial, regional, and territorial perspectives.

Thank you for your participation and for contributing to the scientific quality and academic integrity of the GEO³ Conference 2025.

With respect,

Rector
Prof. Ace Milenkovski PhD
University of Skopje

INTERNATIONAL SCIENTIFIC CONFERENCE

OF THE INSTITUTE OF NATIONAL GEOGRAPHY
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About the Conference

The **International Scientific Conference of the Institute of National Geography – GEO³ Conference 2025** is an international academic conference dedicated to contemporary geographical research focusing on spatial development, territorial transformation, sustainability, and regional inequalities. The conference is organized by the **Institute of National Geography**, in cooperation with the **University of Skopje**, and is conceived as a recurring scientific event aimed at strengthening the analytical and societal relevance of geographical science.

The GEO³ Conference is established as a platform for scholarly exchange addressing the profound spatial, economic, social, and environmental transformations shaping modern societies. In the context of accelerated globalization, uneven regional development, climate pressures, demographic change, and restructuring of territorial systems, geography provides essential conceptual and methodological tools for spatial analysis and evidence-based territorial governance.

The scientific scope of the conference is structured around three main thematic pillars:

GEO-DEV – Geography, Development and Sustainability (Regional and local development, sustainable development pathways, demographic dynamics, urban and rural transformation, environmental sustainability, and resilience of territorial systems).

GEO-TERR – Geography, Territorial Development and Planning (Territorial governance, regional and spatial planning, infrastructure and accessibility, spatial organization of economic activities, cross-border cooperation, and institutional frameworks for territorial development).

GEO-SPACE – Geography, Spatial Inequalities and Transformation (Spatial inequalities, center–periphery relations, regional disparities, urbanization and metropolitan dominance, social and economic polarization, and conceptual and methodological advances in spatial analysis).

Through these thematic areas, the GEO³ Conference aims to encourage academically grounded discussions on how geographical knowledge and spatial thinking can contribute to sustainable territorial development, balanced regional growth, and informed spatial policymaking at national, regional, and global levels.

The main objective of the conference is to emphasize the importance of geographical science as a foundational discipline for understanding and managing spatial inequalities, territorial restructuring, and sustainability challenges. The working title of the conference, *"Geography in the Age of Global Transformation: Spatial Inequalities, Sustainability, and Territorial Development"*, reflects the intention to address geography as both an analytical science and an applied field with direct relevance for public policy and territorial governance.

The conference seeks to foster dialogue among academics, researchers, and practitioners on innovative theoretical approaches, empirical research findings, and applied geographical methodologies. By

integrating scientific rigor with spatially informed reasoning, the GEO³ Conference encourages contributions that offer solutions grounded in strong academic foundations and territorial perspectives.

This international scientific conference supports academics, researchers, and PhD students by providing a forum to present recent research results in geography and related disciplines. Through scholarly exchange, participants contribute to advancing scientific knowledge, strengthening professional competencies, and deepening understanding of contemporary spatial challenges.

Geographical knowledge and professional expertise represent an evolving process shaped by societal change, environmental pressures, and technological development. In this context, the ability to remain analytically current and to continuously enhance methodological and conceptual skills is indispensable within the academic and scientific community. The GEO³ Conference responds to this need by offering a structured environment for critical reflection, interdisciplinary cooperation, and knowledge exchange.

Conference Organizer

Institute of National Geography
University of Skopje

Conference Date

27 December 2025

Conference Venue

University of Skopje
Blvd. “Partizanski odredi” No. 99
1000 Skopje, North Macedonia

Conference Format

Hybrid event
In-person participation at the University of Skopje
Virtual participation via Google Meet platform

Official Language

English

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GEO-DEV

Geography, Development and Sustainability Regional and local development, sustainable development pathways, demographic dynamics, urban and rural transformation, environmental sustainability, and resilience of territorial systems

Sports Participation and Geography Education Outcomes: Empirical Evidence on Motivation, Spatial Understanding, and Achievement

Ace Milenkovski[1]
Dejan Nedev

Abstract

The relationship between physical activity and educational achievement has been widely examined in general education research, yet subject-specific empirical evidence remains limited. Geography education, with its strong reliance on spatial reasoning, environmental interpretation, and applied cognitive processing, provides a particularly suitable analytical context for examining how sports participation relates to learning outcomes. This study investigates the correlation between students' participation in organized sports and educational outcomes in geography education, drawing on original survey-based empirical research conducted among lower secondary school students. Data were collected through a structured questionnaire administered to 120 students and analyzed using descriptive statistics, correlation analysis, group comparison tests, and multiple linear regression modeling. The analysis examines relationships between sports participation frequency, motivation for learning geography, perceived spatial understanding, and academic achievement in geography. The findings reveal statistically significant positive associations between regular sports participation and multiple dimensions of geography learning. Sports participation emerges as a meaningful predictor of geography achievement both directly and indirectly through motivational and spatial-cognitive mechanisms. The study adopts a cross-sectional quantitative research design and does not pursue causal inference. Its contribution lies in providing subject-specific empirical evidence that links sports participation to motivational and spatial-cognitive dimensions of geography learning rather than to general academic performance alone, thereby strengthening the analytical foundation for discipline-sensitive research in geography education.

Keywords: sports participation; geography education; academic achievement; spatial thinking; embodied cognition; survey research

1. Introduction

Educational achievement is increasingly conceptualized as the outcome of interacting cognitive, physical, and psychosocial processes rather than as the direct product of curricular content and instructional quality alone. Within this broader educational perspective, participation in organized sports has been consistently associated with improved academic performance, higher levels of school engagement, and enhanced cognitive functioning across different age groups. Comparative analyses conducted by international organizations indicate that students who engage regularly in physical activity tend to demonstrate stronger learning discipline, higher academic motivation, and more stable self-regulatory capacities (OECD 2019).

The majority of existing studies focus on aggregate academic indicators or standardized achievement measures, providing limited insight into how physical activity interacts with the epistemic and cognitive demands of individual school subjects. Geography education represents a particularly relevant context for addressing this gap. The subject requires learners to process spatial relationships, interpret maps and graphical representations, analyze environmental systems, and relate physical space to social and economic processes. These learning demands rely heavily on spatial cognition, visualization, and sustained attentional control, all of which are cognitive functions positively associated with regular physical activity (Hillman, Erickson, and Kramer 2008).

Despite extensive evidence on physical activity and general academic achievement, empirical research remains limited with respect to subject-specific cognitive domains such as geography, where spatial reasoning constitutes a core epistemic foundation.

The present study addresses this empirical and conceptual gap by examining the relationship between sports participation and educational outcomes specifically within geography education. The analysis focuses on motivation for learning geography, perceived spatial understanding, and academic achievement, with the aim of providing subject-sensitive empirical evidence regarding the educational relevance of organized sports participation in lower secondary education.

This study does not constitute another generic correlational examination of physical activity and academic achievement. Its specific contribution lies in the provision of subject-specific empirical evidence focused explicitly on geography education as a distinct cognitive and pedagogical domain. By operationalizing motivation, perceived spatial understanding, and academic achievement within the disciplinary logic of geography, the analysis moves beyond aggregate educational indicators and addresses how sports participation relates to learning processes that are intrinsically spatial, representational, and environment-oriented. In this sense, the study contributes original empirical insight into the relationship between physical activity and geography learning, positioning sports participation as a factor that interacts with the cognitive demands specific to geographical education rather than with schooling outcomes in general.

2. Theoretical Framework: Physical Activity, Cognition, and Geography Learning

Research in educational psychology and cognitive neuroscience provides a coherent theoretical foundation for linking physical activity with learning processes. Regular physical activity has been shown to enhance cerebral

[1]**Ace Milenkovski, PhD.,** Full Professor and **Dejan Nedev, PhD.,** Assistant Professor, University Skopje, North Macedonia.

blood flow, neurogenesis, and executive control functions, including working memory, attentional regulation, and cognitive flexibility (Hillman, Erickson, and Kramer 2008). These mechanisms are directly implicated in classroom learning, particularly in subjects that require sustained concentration and complex cognitive processing.
Within educational research, participation in organized sports has been associated with higher levels of school engagement, persistence, and learning discipline. Longitudinal studies indicate that physically active students tend to demonstrate more stable academic trajectories and lower rates of school disengagement compared with their less active peers (Trudeau and Shephard 2008; Singh et al. 2012). These associations extend beyond physical education and influence performance across a range of cognitively demanding subjects.
Geography education occupies a distinctive position within this framework due to its reliance on spatial thinking as a core disciplinary competence. Spatial thinking encompasses abilities such as mental rotation, scale interpretation, spatial visualization, and the integration of multiple spatial representations (National Research Council 2006). Bednarz and Kemp (2011) emphasize that spatial thinking in geography is closely linked to embodied experience, movement, and interaction with physical environments rather than to abstract reasoning alone.
Recent systematic reviews in geography education further emphasize that geographical thinking represents a foundational cognitive objective of the discipline rather than a peripheral skill. Bendl et al. (2024) demonstrate that contemporary geography education increasingly conceptualizes spatial reasoning, representational competence, and analytical interpretation of space as integrated cognitive processes that structure student learning across educational levels. This perspective reinforces the relevance of examining educational factors that may support the development of spatially structured reasoning within geography instruction.
From this perspective, sports participation may support geography learning through indirect cognitive pathways. Engagement in sports requires continuous spatial orientation, coordination, anticipation, and movement within structured environments, experiences that reinforce spatial awareness and self-regulatory capacities. Recent pedagogical models in geography education explicitly connect spatial thinking with embodied experience and movement. Mechlenborg and Neergaard (2024), building on Lefebvre's spatial triad, argue that spatial understanding in geography emerges through the interaction of perceived, conceived, and lived space. Their findings support the view that learning environments involving bodily movement and spatial interaction contribute to the development of geographical reasoning, providing a theoretical bridge between physical activity and subject-specific learning processes in geography. These capacities are directly relevant to key geographical tasks, including map interpretation, spatial modeling, and the analysis of environmental patterns. The present study adopts this integrative theoretical framework to empirically examine how sports participation relates to geography-specific educational outcomes.
From a theoretical standpoint, the relationship between physical activity and geography learning can be conceptualized through a chain of cognitive mediation linking embodied movement to spatially structured reasoning. Physical activity and sports participation involve continuous engagement with spatial orientation, distance estimation, directional awareness, and coordinated movement within bounded environments. These embodied experiences activate and reinforce cognitive operations that are directly transferable to geography learning, including mental rotation, map-based orientation, scale comprehension, and the interpretation of spatial relationships among physical and human phenomena. Through this lens, sports participation does not influence geography achievement as a general motivational stimulus alone, but as a context in which spatial cognition and self-regulatory control are repeatedly exercised in ways that align with the epistemic practices of geography as a school subject.
On this basis, the present study positions sports participation not as a general behavioral correlate of schooling, but as an embodied activity context that aligns with the cognitive architecture of geography education. This positioning allows for subject-sensitive interpretation of empirical associations between physical activity, motivation, spatial understanding, and academic achievement.

3. Research Design and Methodology

The study employs a quantitative, cross-sectional research design based on survey data collected from lower secondary school students. The analytical focus is on identifying statistically meaningful associations rather than establishing causal relationships, in accordance with exploratory educational research conventions (Cohen, Manion, and Morrison 2018).
The study was conducted in accordance with ethical standards for educational research. Participation was voluntary, anonymity was guaranteed, and informed consent was obtained through school administration in line with institutional requirements.

Sample and Data Collection

The survey was administered to 120 students enrolled in grades VII to IX in public lower secondary schools. Data collection was conducted in a school setting during regular instructional time, with prior approval from school administration and informed consent procedures consistent with educational research standards. The sample reflects balanced gender representation and comparable distribution across grade levels. Students reported varying

levels of sports participation, ranging from no participation to regular involvement in organized school or club-based sports activities.

The selection of grades VII to IX was guided by the assumption that students at this educational stage have sufficiently developed cognitive and spatial skills to meaningfully self-assess geography-related competencies and motivation.

Research Instrument

Data were collected using a structured questionnaire consisting of four analytically distinct sections. Sports participation was measured through items assessing the frequency of organized physical activity per week. Motivation for geography learning was assessed using Likert-scale items addressing interest, engagement, and perceived relevance of geography lessons. Spatial understanding was measured through self-assessment items related to map reading, spatial orientation, and visualization tasks commonly encountered in geography education. Academic achievement was operationalized through self-reported final grades in geography.

The instrument was piloted for clarity and internal consistency prior to data collection. Reliability analysis yielded acceptable internal consistency across the multi-item scales, with Cronbach's alpha coefficients exceeding commonly accepted thresholds for exploratory educational research.

Self-reported grades were used as an indicator of academic achievement due to their established validity in educational research when objective records are not accessible, particularly in exploratory school-based studies.

Data Analysis Procedures

Data analysis included descriptive statistics, Pearson correlation analysis, independent samples t-tests, and multiple linear regression modeling. These procedures enabled both bivariate and multivariate examination of relationships between sports participation and geography-related educational outcomes (Field 2018).

Prior to inferential analysis, assumptions of normality, linearity, and multicollinearity were examined and found acceptable for the applied statistical procedures.

4. Results

Descriptive analysis indicated that 68.3 percent of respondents participated in organized sports at least twice per week, while 31.7 percent reported irregular or no participation. Across all measured variables, students engaged in regular sports activities demonstrated higher mean scores compared with their less active peers.

Correlation analysis revealed statistically significant moderate positive relationships between sports participation frequency and motivation for geography learning ($r = 0.42$, $p < 0.01$), perceived spatial understanding ($r = 0.38$, $p < 0.01$), and geography academic achievement ($r = 0.35$, $p < 0.01$). These results indicate consistent associations across motivational, cognitive, and performance-related dimensions of geography learning.

Group comparison analysis further supported these findings. Students reporting regular sports participation achieved a significantly higher mean grade in geography compared with students reporting irregular or no participation. The independent samples t-test confirmed that this difference was statistically significant ($t = 5.87$, $p < 0.001$), indicating a substantial performance gap associated with physical activity engagement.

The multiple linear regression model demonstrated that sports participation remained a statistically significant predictor of geography achievement when motivation for geography learning and perceived spatial understanding were included in the model. The model explained 46 percent of the variance in geography achievement (Adjusted $R^2 = 0.44$). Motivation and spatial understanding emerged as complementary predictors, suggesting that sports participation influences geography achievement both directly and indirectly through cognitive-motivational mechanisms.

Table 1. Sample Characteristics and Sports Participation Frequency

Variable	Category	N	Percentage (%)
Gender	Male	62	51.7
	Female	58	48.3
Grade level	VII grade	39	32.5
	VIII grade	41	34.2
	IX grade	40	33.3
Sports participation	Regular (≥2 times per week)	82	68.3
	Irregular / None	38	31.7

Note: Regular participation includes organized school or club sports activities.

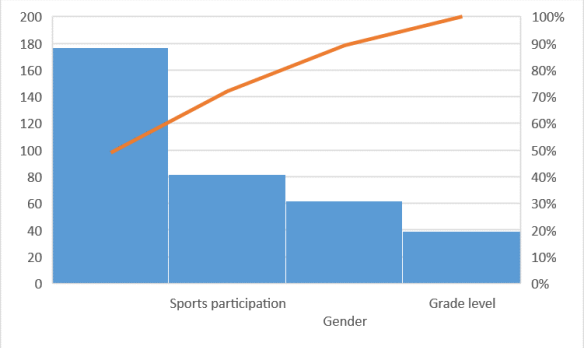

Table 2. Descriptive Statistics of Key Research Variables

Variable	Mean	Standard Deviation	Minimum	Maximum
Sports participation frequency	2.74	1.12	0	4
Motivation for geography learning	3.62	0.81	1	5
Perceived spatial understanding	3.55	0.76	1	5
Geography academic achievement (grade)	3.89	0.67	2	5

Scale notes:
Sports participation: 0 = none, 4 = very frequent
Motivation and spatial understanding measured on a 5-point Likert scale.

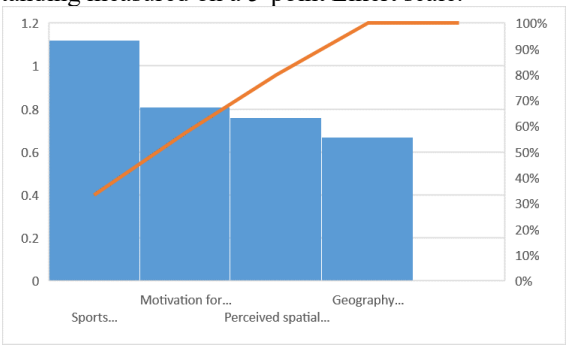

Table 3. Pearson Correlation Matrix Between Sports Participation and Geography Outcomes

Variable	Sports participation	Motivation	Spatial understanding	Geography achievement
Sports participation	1.00			
Motivation for geography	0.42**	1.00		
Spatial understanding	0.38**	0.46**	1.00	
Geography achievement	0.35**	0.41**	0.44**	1.00

Notes:
p < 0.01 (two-tailed)
Correlation coefficients indicate moderate positive relationships.

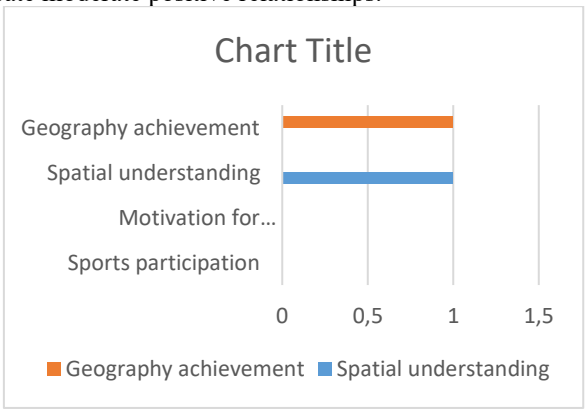

Table 4. Comparison of Geography Achievement by Sports Participation Group

Sports participation group	Mean grade	Standard Deviation
Regular participation	4.12	0.58
Irregular / None	3.41	0.62

Statistical test: Independent samples t-test
t = 5.87, p < 0.001

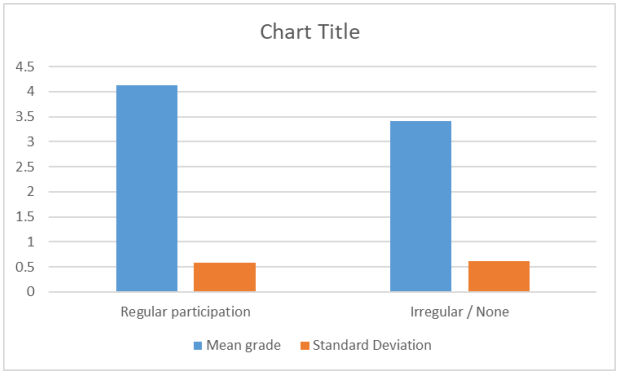

Table 5. Linear Regression Model Predicting Geography Achievement

Predictor variable	B	Standard Error	β	p-value
Sports participation frequency	0.27	0.06	0.31	<0.001
Motivation for geography	0.34	0.07	0.38	<0.001
Spatial understanding	0.29	0.08	0.33	<0.01
Constant	1.12	0.42	—	<0.01

Model summary:
$R^2 = 0.46$
Adjusted $R^2 = 0.44$
$F(3,116) = 32.8$, $p < 0.001$

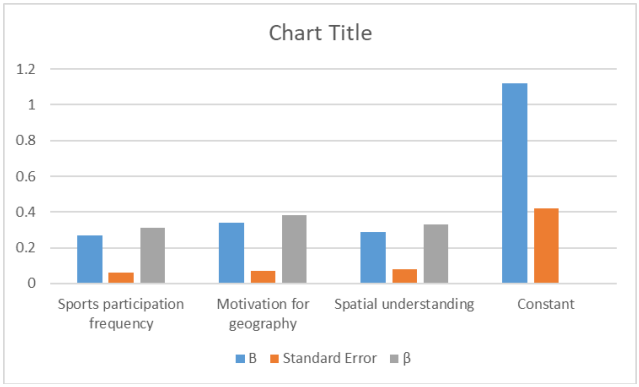

Table 6. Summary of Empirical Findings

Research dimension	Empirical outcome
Sports participation and motivation	Positive moderate correlation
Sports participation and spatial understanding	Positive moderate correlation
Sports participation and academic achievement	Positive and statistically significant
Combined predictive power	Meaningful but limited explanatory contribution ($R^2 = 0.46$)

5. Discussion

The findings of this study align with a substantial body of educational research indicating that physical activity is associated with academic outcomes through cognitive and motivational pathways. Within the specific context of geography education, these associations acquire particular relevance due to the subject's reliance on spatial cognition, representational reasoning, and the interpretation of complex physical and human systems. The

observed relationships suggest that sports participation is meaningfully connected to how students engage with geography as a cognitively demanding school subject rather than merely to general academic performance.

The positive association between sports participation and motivation for geography learning indicates that physically active students tend to report higher levels of engagement and interest in the subject. This finding is consistent with theoretical perspectives emphasizing the role of self-regulation, persistence, and learning discipline as mediating mechanisms between physical activity and academic engagement. In geography education, where sustained attention and active cognitive processing are required for tasks such as map interpretation, spatial comparison, and environmental analysis, such motivational dispositions may be particularly consequential.

Similarly, the relationship between sports participation and perceived spatial understanding supports arguments derived from embodied cognition and spatial learning research. Participation in organized sports involves continuous spatial orientation, movement coordination, distance estimation, and interaction with structured physical environments. These experiences may reinforce cognitive operations that are closely aligned with geographical thinking, including mental rotation, scale comprehension, and the interpretation of spatial relationships among physical and human phenomena. The findings suggest that students who engage regularly in sports perceive themselves as more capable of handling spatially structured geographical tasks, which may, in turn, influence their engagement and performance in the subject.

At the same time, the interpretation of the regression results requires analytical restraint. The proportion of explained variance indicated by the regression model warrants a cautious interpretation. Although the model accounts for 46 percent of the variance in geography academic achievement, this value should be understood as meaningful but inherently limited within an educational context characterized by multiple interacting determinants. Educational achievement is shaped by a constellation of factors that extend beyond the variables included in the present analysis, and no single model can be expected to capture this complexity in its entirety.

Several potentially influential confounding variables were not incorporated into the model, including students' socio-economic background, general academic motivation not specific to geography, parental educational support, and broader dimensions of school climate such as instructional quality, peer norms, and institutional expectations. The absence of these factors restricts the explanatory scope of the model and underscores that the observed associations represent partial relationships rather than comprehensive explanations of geography achievement. Consequently, the regression findings should be interpreted as indicative of contributory relationships rather than as evidence of dominant or exhaustive causal mechanisms.

An additional methodological consideration concerns the reliance on self-reported measures for several key variables. With the exception of sports participation frequency, motivation for geography learning, perceived spatial understanding, and academic achievement are based on students' subjective assessments rather than on objectively verified cognitive performance or externally validated academic records. As a result, the observed relationships reflect associations between sports participation and students' self-perceptions of engagement, competence, and success in geography. While such perceptions are educationally meaningful and closely linked to learning persistence and self-efficacy, they are not equivalent to standardized measures of cognitive ability or performance-based spatial assessments.

Taken together, the findings suggest that sports participation relates to geography education through a combination of motivational and perceptual mechanisms that support students' engagement with spatially structured learning tasks. However, these relationships operate within a broader educational ecology shaped by social, institutional, and contextual factors that extend beyond the scope of the present study. Future research would benefit from incorporating longitudinal designs, objective measures of spatial cognition, and additional contextual variables in order to further clarify the mechanisms linking physical activity and subject-specific learning outcomes in geography. These findings are consistent with prior research demonstrating positive associations between physical activity and cognitive engagement, while extending existing evidence by situating these relationships explicitly within the disciplinary context of geography education.

6. Pedagogical Implications

The pedagogical implications of the present findings should be interpreted with appropriate analytical restraint. The results do not suggest that sports participation exerts a dominant or overriding influence on geography achievement, but rather that it constitutes one contributory condition within a broader educational ecology. From a pedagogical perspective, this implies that physical activity should not be framed as an instructional substitute or as a direct mechanism for improving academic outcomes, but as a contextual factor that may support motivational engagement and perceived competence in subjects with pronounced spatial and cognitive demands.

For geography education specifically, the findings highlight the potential relevance of learning environments that acknowledge the interaction between embodied experience and spatial reasoning. Teaching approaches that incorporate field-based activities, spatial exploration, and movement-related tasks may align more closely with the cognitive dispositions reported by physically active students. However, such approaches should be implemented as complementary pedagogical strategies rather than as generalized prescriptions.

At the level of educational policy, the results support the maintenance of balanced curricular structures that preserve opportunities for organized sports participation without attributing disproportionate academic expectations to physical activity alone. Any pedagogical or policy-related application of the findings should remain attentive to the multiple social, motivational, and institutional factors that jointly shape students' educational trajectories.

7. Conclusion

This study advances subject-specific empirical insight into the relationship between sports participation and educational outcomes in geography education. Rather than reiterating general claims regarding physical activity and academic achievement, the analysis demonstrates how organized sports participation is associated with motivational engagement and self-perceived spatial competence within the disciplinary context of geography. By focusing explicitly on geography-related learning processes, the study contributes evidence that links physical activity to the cognitive and motivational dimensions that underpin spatial reasoning, map interpretation, and environmental understanding as core components of geographical education.

The empirical findings indicate that students who participate regularly in organized sports tend to report higher levels of motivation for geography learning, stronger perceived spatial understanding, and better academic outcomes in the subject. Importantly, these associations persist when motivational and spatial variables are examined jointly, suggesting that sports participation relates to geography achievement through multiple, interconnected pathways rather than through a single generalized effect.

The scientific contribution of this study lies in its disciplinary positioning. By situating sports participation within the epistemic and cognitive structure of geography education, the analysis moves beyond generic correlational approaches and demonstrates the value of subject-sensitive research designs. The results underscore that the educational relevance of physical activity cannot be fully understood without reference to the specific cognitive demands of individual school subjects. In this respect, the study provides a conceptual and empirical foundation for future research that seeks to integrate physical activity, spatial cognition, and subject-specific learning processes within geography education.

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Geographical Science in the Era of Sustainable Development Goals: Knowledge, Analytical Capacities, and Developmental Implications

Dejan Nakovski[2]
Marina Stojmirova
Suzana Nikolic

Abstract

The Sustainable Development Goals have introduced a governance framework in which development outcomes depend increasingly on the capacity to interpret and operationalize complex empirical information rather than on data availability alone. Within this context, geographical science assumes renewed analytical relevance by structuring sustainability indicators through spatial and territorial reasoning.
This paper examines geography as a knowledge-generating discipline within the Sustainable Development Goals framework by integrating conceptual perspectives on knowledge-based development with descriptive empirical illustration drawn from internationally comparable indicators for the period 2015–2023. Through spatial reorganization of selected SDG indicators, the analysis demonstrates how geographical interpretation exposes territorial disparities, spatial concentration effects, and relational interdependencies that remain insufficiently visible in aggregate monitoring systems. Empirical illustration from North Macedonia further reveals how challenges related to urban development, climate vulnerability, ecosystem governance, and regional inequality materialize unevenly across territory.
The findings indicate that geography contributes to sustainability governance as an interpretative analytical structure that mediates between empirical observation and policy-oriented reasoning. By embedding SDG indicators within spatial frameworks, geographical science enhances analytical coherence, scale sensitivity, and territorially differentiated interpretation, thereby strengthening knowledge-based development strategies under conditions of institutional complexity.

Keywords: geographical science; sustainable development goals; knowledge-based development; spatial analysis; development policy

1. Introduction

The implementation of the Sustainable Development Goals has altered how scientific knowledge is mobilized within contemporary development practice. Development can no longer be adequately understood as a linear trajectory guided exclusively by economic expansion, but as a multidimensional transformation requiring continuous monitoring, evaluation, and adjustment. Within this framework, the availability of data alone is insufficient. What proves decisive instead is the capacity to analytically structure and interpret information in support of coordinated decision-making.
Geographical science occupies a distinctive position in this context. As a discipline inherently concerned with spatial differentiation, territorial interaction, and scale, geography provides analytical tools capable of translating abstract development indicators into spatially grounded knowledge. Contemporary development challenges such as urban inequality, environmental degradation, climate vulnerability, and land-use transformation manifest unevenly across space, making spatial interpretation essential rather than optional.
Despite the expanding literature on sustainability and development, the analytical contribution of geography is frequently underrepresented or treated instrumentally. Much of the existing research focuses on indicator production and monitoring, while comparatively limited attention is devoted to how spatial analysis contributes to knowledge-based development processes. This paper addresses this gap by examining geography as a knowledge-generating discipline within the Sustainable Development Goals framework.
The central objective of the study is to demonstrate how geographical science enhances analytical capacity in sustainable development by transforming data into territorially meaningful knowledge. Through a combination of theoretical reflection and empirical illustration, the paper positions geography as an indispensable component of knowledge-based development under conditions of sustainability governance.
Positioned as a conceptual–analytical study with empirical illustration, the paper advances a spatially grounded interpretation of the Sustainable Development Goals by demonstrating how geographical analysis enhances knowledge-based development capacity.

2. Theoretical Framework

2.1. Knowledge-Based Development

Within knowledge-based development frameworks, long-term development trajectories are increasingly shaped by the institutional capacity to organize, interpret, and mobilize knowledge, rather than by the mere accumulation of physical or financial resources. Within this perspective, learning, institutional capacity, and analytical competence are treated as fundamental drivers of long-term development trajectories. Economic and social outcomes increasingly depend on the ability of institutions to process information, interpret complex signals, and adapt strategies accordingly (Lundvall 1992; OECD 1996).

[2]**Dejan Nakovski, PhD.,** Full Professor, University Skopje and **Marina Stojmirova, MsC.,** Academic Associate, Institute of National Geography, University Skopje, Republic of North Macedonia and **Suzana Nikolic,** Teaches geography, Kumanovo, Republic of North Macedonia

In development contexts, knowledge-based approaches emphasize the transformation of data into actionable insight. Indicators, statistics, and measurements acquire developmental relevance only when embedded within interpretative frameworks that link empirical observation to policy objectives. This logic aligns closely with the Sustainable Development Goals, which rely on continuous assessment and evidence-informed governance.

2.2. Geography and Sustainable Development

Geographical science contributes to sustainable development through its focus on spatial relationships and territorial differentiation. Unlike approaches that treat development phenomena as uniform across space, geography emphasizes how social, economic, and environmental processes interact differently at local, regional, and global scales. This spatial sensitivity enables more precise identification of development constraints and opportunities.

Processes associated with sustainability unfold unevenly across territory, reflecting differentiated spatial interactions between environmental conditions, socio-economic structures, and governance arrangements. Urban expansion, climate exposure, ecosystem degradation, and infrastructure provision vary significantly across territory. Geography provides conceptual and methodological tools such as spatial analysis, regional classification, and territorial modeling that support the interpretation of such variation. Through these tools, geography strengthens the analytical foundation of sustainability-oriented development strategies.

2.3. Sustainable Development Goals and Analytical Capacity

The Sustainable Development Goals framework is built upon indicator-based monitoring systems that presuppose advanced analytical interpretation. While global indicators enable comparability, they risk oversimplification when detached from spatial context. Geography addresses this limitation by embedding indicators within territorial frameworks that reveal patterns, disparities, and interactions.

Analytical capacity within the SDGs framework therefore depends not only on data availability but on disciplinary approaches capable of spatial interpretation. Geography plays a central role in this regard by organizing empirical evidence according to spatial logic and scale-sensitive analysis.

3. Methodology

The study adopts a descriptive and analytical research design consistent with the logic of knowledge-based development. The analysis does not pursue causal econometric modeling, but concentrates on illustratinghow geographical interpretation enhances the analytical relevance of sustainable development indicators.

Empirical data are drawn from internationally recognized sources, including the United Nations SDG Global Database, World Bank Open Data, and Eurostat territorial statistics. The temporal scope primarily covers the period 2015–2023, corresponding to the implementation phase of the 2030 Agenda.

Indicators are selected based on their relevance to sustainability dimensions that exhibit strong spatial differentiation. The empirical analysis emphasizes interpretation over measurement, aligning with the role of geography as an analytical rather than purely descriptive discipline.

The methodological rationale for employing GIS logic in this study derives from the inherently spatial nature of sustainable development processes. The Sustainable Development Goals are not implemented, experienced, or constrained uniformly across territory; instead, they materialize through spatially differentiated patterns shaped by demographic distribution, economic structure, environmental capacity, and infrastructural accessibility. A purely aspatial treatment of SDG indicators risks obscuring these territorial dynamics and producing analytically incomplete interpretations.

In this study, GIS-based reasoning is adopted as an analytical mode of spatial interpretation rather than as a technical mapping exercise, allowing heterogeneous indicators to be examined within territorially structured analytical frameworks. By situating empirical indicators within territorially defined analytical units, GIS allows the study to identify development asymmetries, regional vulnerabilities, and spatial concentrations that are directly relevant for governance. This approach aligns with the principles of knowledge-based development, which emphasize the transformation of information into actionable knowledge through structured analytical interpretation.

Importantly, the use of GIS in this context does not presuppose advanced computational modeling or algorithmic optimization. Its methodological value lies in its capacity to support spatial reasoning, comparative regional interpretation, and territorially grounded policy reflection. As such, GIS functions as a conceptual bridge between empirical observation and policy-relevant knowledge, reinforcing the analytical contribution of geography to sustainable development research.

4. Empirical Evidence: Spatial Interpretation of Sustainable Development Indicators

4.1. Selected Indicators and Geographical Relevance

The empirical section focuses on indicators associated with SDG 11, SDG 13, and SDG 15, which directly engage with spatial planning, environmental vulnerability, and land governance.

Table 1. Selected SDG Indicators and Geographical Analytical Relevance

SDG	Indicator	Spatial analytical relevance
SDG 11	Urban population living in inadequate housing (%)	Spatial concentration of social vulnerability
SDG 13	Climate-related disaster exposure index	Territorial differentiation of environmental risk
SDG 15	Protected terrestrial areas (% of land area)	Spatial governance of ecosystems

These indicators illustrate how sustainability challenges are unevenly distributed across space. Geography contributes by identifying spatial clustering, regional disparities, and territorial interactions that are obscured in aggregate statistics.

4.2. Territorial Differentiation and Development Implications

Spatial interpretation reveals that urban housing inadequacy tends to concentrate in specific metropolitan zones, reflecting interactions between land markets, infrastructure provision, and demographic pressure. Similarly, climate exposure varies significantly across coastal regions, mountainous areas, and inland territories, highlighting differentiated vulnerability profiles.

Table 2. Stylized Spatial Patterns of Sustainability Challenges

Territory type	Dominant challenge	Development implication
Urban cores	Housing pressure	Integrated spatial planning
Coastal regions	Climate exposure	Risk-sensitive governance
Rural peripheries	Limited infrastructure	Targeted development support
Protected areas	Land-use restrictions	Ecosystem governance balance

The empirical relevance of such differentiation lies in its policy implications. Uniform development strategies fail to address territorially specific challenges. Geography supports knowledge-based development by enabling differentiated and context-sensitive interventions.

4.3. Geography as an Interface Between Data and Policy

By organizing sustainability indicators spatially, geography functions as an interface between empirical observation and policy formulation. Spatial analysis enables policymakers to identify priority regions, monitor intervention outcomes, and adjust strategies dynamically. This role aligns directly with the SDGs emphasis on adaptive governance and evidence-based decision-making.

5. Empirical Evidence: Sustainable Development and Spatial Differentiation in North Macedonia

5.1. Spatial Dimensions of Sustainable Development in North Macedonia

The implementation of the Sustainable Development Goals in North Macedonia unfolds within a territorially heterogeneous context characterized by pronounced regional disparities, demographic polarization, and uneven access to infrastructure. From a geographical perspective, sustainable development challenges manifest differently across urban centers, rural municipalities, and environmentally sensitive areas, which underscores the relevance of spatial interpretation for development governance.

National development indicators frequently obscure these territorial contrasts when presented in aggregate form. Geography contributes by revealing how sustainability outcomes vary across space and by identifying territorially specific constraints that shape development trajectories.

5.2. Selected SDG Indicators and Territorial Interpretation

The empirical analysis focuses on indicators aligned with SDG 11, SDG 13, and SDG 15, which are particularly relevant for geographical interpretation in the Macedonian context.

Table 3. Selected SDG Indicators for North Macedonia

SDG	Indicator	National value	Spatial relevance
SDG 11	Urban population exposed to inadequate housing (%)	~23 %	Concentrated in Skopje and secondary urban centers
SDG 13	Climate-related hazard exposure index	Moderate	Higher vulnerability in eastern and southern regions
SDG 15	Protected terrestrial areas (% of land area)	~9 %	Spatially concentrated in mountainous zones

Source: State Statistical Office; UN SDG Database; national environmental reports.

These indicators illustrate that sustainability challenges are not uniformly distributed. Urban pressures are most pronounced in the Skopje planning region, while environmental protection concerns dominate mountainous and peripheral territories.

5.3 Regional Differentiation and Developmental Implications

Spatial analysis reveals four dominant territorial patterns relevant for sustainable development governance in North Macedonia.

Table 4. Territorial Patterns of Sustainability Challenges

Territory type	Dominant sustainability challenge	Governance implication
Skopje region	Urban congestion and housing pressure	Integrated urban planning
Eastern regions	Climate exposure and agricultural vulnerability	Risk-sensitive development
Western mountainous areas	Ecosystem protection constraints	Balanced land-use governance
Rural municipalities	Depopulation and infrastructure gaps	Targeted territorial support

These patterns confirm that sustainable development policies require spatial differentiation rather than uniform national measures. Geography enables such differentiation by aligning empirical indicators with territorial context.

5.4. Geography as an Analytical Instrument in National SDG Governance

Within the Macedonian development context, geographical science functions as an analytical instrument that connects sustainability indicators with spatial planning and regional policy. By interpreting SDG data through a territorial lens, geography supports prioritization of development interventions, enhances institutional learning, and improves coordination between national and local governance levels.

The empirical evidence demonstrates that geography strengthens knowledge-based development by transforming statistical indicators into territorially grounded knowledge relevant for sustainable development strategies in North Macedonia.

6. Discussion: Geography, Knowledge, and Analytical Capacity

Building on the empirical patterns identified in the preceding sections, this discussion advances a spatially grounded interpretative perspective that positions geographical science as a mediating analytical structure within the Sustainable Development Goals framework. The empirical evidence confirms that sustainability challenges related to housing conditions, climate exposure, ecosystem governance, and regional inequality are unevenly distributed across territory. These challenges materialize through spatially differentiated configurations that resist adequate interpretation when approached through aggregate indicators or sectorally segmented analytical frameworks.

Within this context, geography contributes to knowledge-based development by providing an interpretative logic that transforms sustainability indicators into territorially meaningful knowledge. Rather than approaching SDG indicators as static measurements, geographical analysis conceptualizes them as spatial expressions of underlying structural processes shaped by scale, location, and territorial interaction. This interpretative capacity enhances analytical depth by revealing spatial concentrations, asymmetries, and functional interdependencies that remain obscured within aspatial monitoring systems.

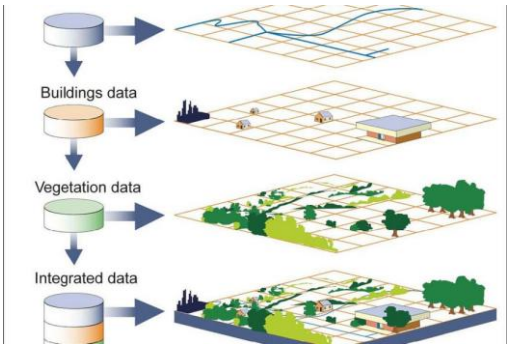

Figure 1. Conceptual GIS-Based Framework for Spatial Interpretation of the SDGs

Figure 1 conceptualizes this analytical role by positioning GIS-based geographical reasoning as the central mediating layer between empirical SDG indicators and governance-oriented decision-making. At the input level, sustainability data emerge from statistical observation of demographic trends, economic activity, environmental pressures, and infrastructural provision. When treated in isolation, these indicators remain analytically fragmented

and weakly connected to territorial realities. Through spatial interpretation grounded in GIS logic, indicators are reorganized through territorial differentiation, regional aggregation, and relational spatial analysis, enabling the identification of development asymmetries and region-specific vulnerability profiles.

At the output level, spatially interpreted knowledge informs development-oriented governance by supporting territorially differentiated interventions aligned with the Sustainable Development Goals. Geography thus functions as a mediating discipline that connects empirical observation with policy reasoning. Its analytical contribution lies not in technical visualization, but in the capacity to structure heterogeneous empirical inputs into coherent spatial frameworks that support strategic prioritization, institutional learning, and adaptive governance.

The discussion further indicates that the effectiveness of sustainability-oriented development depends less on the availability of digital infrastructure or indicator systems and more on institutional capacity to govern and interpret analytically processed spatial knowledge. Geography strengthens this capacity by embedding empirical evidence within spatial logic, scale sensitivity, and contextual interpretation. In this way, geographical science emerges not merely as a supporting technical instrument, but as a knowledge-generating discipline that substantively enhances analytical capacity within sustainability governance and knowledge-based development processes.

7. Challenges and Limitations

Despite its analytical potential, the application of geographical knowledge within sustainable development governance faces limitations. Data availability remains uneven across regions, while institutional capacity for spatial analysis varies significantly. In addition, the integration of geographical insights into policy processes is often constrained by administrative fragmentation and sectoral silos.

These challenges underscore the need to strengthen analytical capacity and institutional learning rather than focusing exclusively on indicator production.

8. Conclusion

Within the governance architecture shaped by the Sustainable Development Goals, geographical science provides the analytical capacity required to transform empirical information into territorially actionable knowledge. The evidence presented in this study demonstrates that sustainability challenges are spatially differentiated and cannot be adequately addressed through aggregate indicators or sectorally fragmented interpretations. Development processes linked to housing conditions, climate vulnerability, ecosystem governance, and regional inequality manifest unevenly across territory, making spatial interpretation a prerequisite for effective sustainability-oriented governance.

By embedding Sustainable Development Goal indicators within spatial analytical frameworks, geographical science strengthens knowledge-based development through interpretative reasoning rather than descriptive reporting alone. The empirical illustrations confirm that geography enables the identification of regional asymmetries, functional interdependencies, and territorial concentrations that remain obscured in national-level averages. In this sense, geography enhances analytical capacity by organizing heterogeneous sustainability data into coherent spatial structures that are directly relevant for development strategy formulation.

The discussion further demonstrates that the contribution of geography extends beyond technical mapping or indicator visualization. Through GIS-based analytical reasoning, geography functions as an interpretative layer that mediates between empirical observation and governance-oriented decision-making. This mediating role allows policy actors to prioritize interventions, align spatial planning with sustainability objectives, and adapt development strategies to territorially specific constraints and opportunities. Geography therefore operates as a knowledge-generating discipline that supports institutional learning and adaptive governance within the Sustainable Development Goals framework.

Importantly, the findings underscore that digital infrastructure and data availability, while necessary, are insufficient conditions for sustainable development. The decisive factor lies in the institutional capacity to integrate spatial analysis into policy processes and to interpret analytically processed indicators in a territorially informed manner. Geography contributes to this capacity by linking empirical evidence with spatial logic, scale sensitivity, and contextual interpretation.

Accordingly, the effectiveness of sustainability-oriented development does not hinge on technological availability itself, but on the institutional ability to govern and interpret analytically processed spatial knowledge.

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Sustainable Governance of High-Mountain Geosystems: Hydrogeomorphological Constraints and Management Implications from the Kamenjanska River (Šar Planina, North Macedonia) in Comparative Perspective

Igor Stojcevski[3]
Sasko Stefanovski
Daniela Ristova

Abstract

High-mountain geosystems represent territorially constrained environments in which hydrogeomorphological processes impose non-negotiable limits on land use, infrastructure development, and socio-economic activities. In the context of intensifying climate variability and increasing development pressure, sustainable governance of mountain landscapes depends less on the physical severity of natural conditions and more on the capacity of governance systems to recognize and institutionalize these conditions within planning and regulatory frameworks. This paper examines the Kamenjanska River in the Šar Planina massif, North Macedonia, as a representative high-mountain geosystem characterized by steep relief, pronounced lithological heterogeneity, and active fluvial incision.

Rather than adopting a classical territorial comparison between countries, the study applies a functional comparative framework that contrasts a stable set of hydrogeomorphological constraints with divergent governance responses. The Kamenjanska River is analyzed as an empirically grounded geosystem with clearly identifiable physical limitations, while selected Alpine mountain river systems serve as a reference governance model in which similar constraints have been systematically translated into spatial planning instruments, hazard zoning, and land-use regulation.

Methodologically, the research is based on geomorphological interpretation of digital elevation models, secondary hydrological data, and comparative analysis of governance practices documented in peer-reviewed literature and official planning frameworks. Empirical results demonstrate that the physical constraints shaping the Kamenjanska River are broadly comparable to those observed in Alpine regions, yet governance responses differ substantially. While Alpine regions institutionalize hydrogeomorphological knowledge as a structuring element of territorial management, governance mechanisms affecting the Kamenjanska River remain fragmented and weakly aligned with physical realities.

The paper argues that sustainability in high-mountain regions is not determined by the intensity of natural constraints, but by the ability of governance systems to integrate geosystem characteristics as foundational development conditions. By explicitly linking physical geography with governance analysis, the study contributes to contemporary debates on sustainability, spatial inequality, and territorial development in mountain regions.

Keywords: high-mountain geosystems; hydrogeomorphology; sustainable governance; mountain rivers; Šar Planina; comparative geography

1. Introduction

High-mountain regions constitute some of the most physically constrained and institutionally demanding territorial systems in contemporary geography. Steep relief gradients, complex geological structures, and highly variable hydrological regimes generate spatial environments in which development options are structurally limited and environmental sensitivity is pronounced. Under conditions of accelerating climate change, these constraints are further intensified through altered precipitation regimes, reduced snow persistence, and increased frequency of extreme hydrological events. At the same time, mountain regions are increasingly exposed to tourism development, infrastructure expansion, and resource exploitation, creating a growing tension between environmental vulnerability and development aspirations.

Within high-mountain geosystems, river systems operate as central organizing elements that concentrate relief energy, regulate sediment transfer, and structure ecological connectivity across altitudinal gradients. Steep mountain rivers are commonly characterized by high stream power, discontinuous longitudinal profiles, and strong lithological control, producing geomorphological features such as gorges, cascades, and waterfalls. These features are not merely landscape attributes, but indicators of active geomorphological adjustment that impose clear limitations on settlement, infrastructure placement, and land-use intensity.

Recent geographical research emphasizes that sustainable development in mountain regions cannot be achieved through descriptive recognition of natural constraints alone. Instead, sustainability depends on the capacity of governance systems to translate physical geographical conditions into binding institutional arrangements that guide spatial planning, risk management, and development regulation. In this perspective, hydrogeomorphology functions as a structuring parameter of territorial governance rather than a background environmental condition.

[3]**Igor Stojcevski, MsC.,** Teaches geography, Kriva Palanka, **Sasko Stefanovski,** Teaches geography, Kocani, **Daniela Ristova**, Teaches geography, Bitola, Republic of North Macedonia

Where such integration is weak, mountain regions tend to experience fragmented land use, heightened exposure to natural hazards, and erosion of landscape integrity.
In Southeast Europe, many high-mountain areas continue to exhibit a pronounced mismatch between dynamic geomorphological processes and limited institutional mechanisms for integrated governance. The Kamenjanska River, situated within the Šar Planina massif in North Macedonia, exemplifies this condition. Despite its pronounced hydrogeomorphological sensitivity and growing visibility as a natural and touristic feature, the river corridor remains governed through fragmented planning practices that insufficiently reflect physical constraints. This paper addresses this gap by examining the Kamenjanska River as a representative high-mountain geosystem and by situating it within a comparative governance framework.

2. Conceptual and Theoretical Framework: Geosystem versus Governance Model

The analytical framework adopted in this study departs from conventional comparative approaches that juxtapose territories or national contexts as primary units of analysis. Instead, the comparison is structured around the relationship between a geosystem and the governance model through which that geosystem is managed. In this framework, the geosystem is treated as a relatively stable configuration of physical constraints derived from relief, lithology, and hydrological dynamics, while governance models represent variable institutional responses to those constraints.
This distinction is theoretically significant because it separates natural limitations from institutional performance. High-mountain geosystems impose similar types of constraints across different regions, including steep gradients, erosion susceptibility, and hydrological variability. Differences in sustainability outcomes therefore cannot be attributed solely to natural conditions, but must be examined through the lens of how governance systems recognize, interpret, and institutionalize these conditions.
By conceptualizing the geosystem as a constant and governance as the variable, the analysis avoids a common weakness in comparative studies where natural differences are implicitly used to legitimize uneven development outcomes. Instead, the framework highlights governance capacity as the decisive factor shaping sustainability trajectories in high-mountain regions. This approach aligns with contemporary geographical perspectives that position physical geography as an active contributor to territorial governance rather than as an auxiliary descriptive field.

3. Study Area: The Kamenjanska River within the Šar Planina Massif

The Kamenjanska River drains a steep catchment located on the western slopes of the Šar Planina massif. The area is characterized by pronounced altitudinal gradients, complex tectonic structures, and heterogeneous lithological composition. The river's longitudinal profile exhibits abrupt breaks in slope associated with lithological contacts and structural discontinuities, resulting in a sequence of waterfalls and cascades formed through differential erosion.

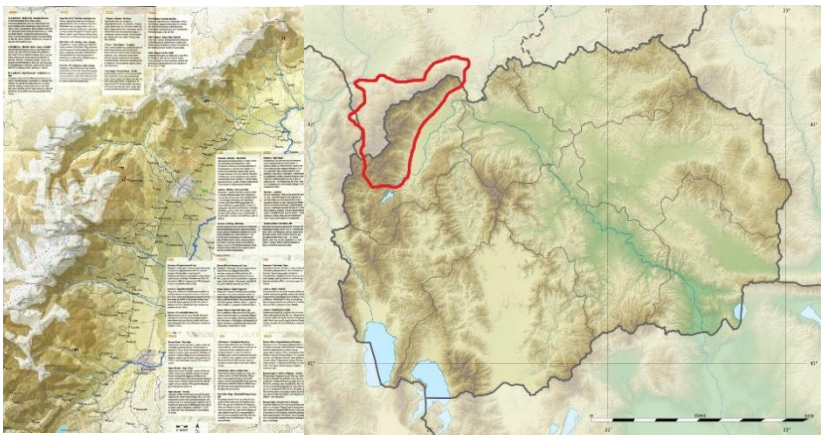

Figure 1. Location of the Kamenjanska River within the Šar Planina High-Mountain Geosystem

Hydrologically, the river displays strong seasonal variability linked to snowmelt processes and episodic high-intensity precipitation events. These dynamics generate elevated stream power during peak discharge periods, intensifying vertical erosion and increasing sensitivity to disturbance within the river corridor.

4. Methodology and Comparative Framework

The study employs a desk-based spatial and analytical methodology appropriate for comparative research in physical and regional geography. Hydrogeomorphological analysis is conducted through interpretation of digital

elevation models, topographic maps, and published geological and hydrological data. Key indicators include channel gradient, lithological control, valley morphology, and erosion sensitivity.

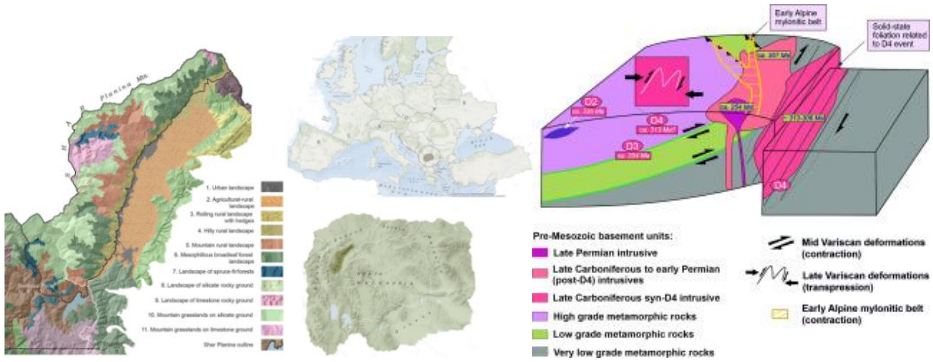

Figure 2. Longitudinal Profile and Knickpoints along the Kamenjanska River

The comparative component is explicitly functional rather than territorial. Alpine mountain river systems documented in Slovenia and Austria are used as reference governance models operating under comparable hydrogeomorphological constraints. The analysis focuses on how similar physical conditions are translated into spatial planning instruments, hazard zoning, and land-use regulation.

5. Empirical Analysis and Results

5.1. Hydrogeomorphological Characteristics

The Kamenjanska River displays high stream power relative to catchment size, driven by steep gradients exceeding 25 ‰ in upper sections. Lithological heterogeneity produces localized knickpoints and waterfall formations, intensifying vertical erosion. These characteristics constrain infrastructure placement and amplify sensitivity to disturbance.

Table 1. Selected Hydrogeomorphological Indicators

Indicator	Kamenjanska River	Alpine Reference Range
Mean channel gradient	High	High
Lithological control	Strong	Moderate–strong
Seasonal discharge variability	Pronounced	Moderate
Erosion sensitivity	Elevated	Controlled

5.2 Comparative Governance Responses

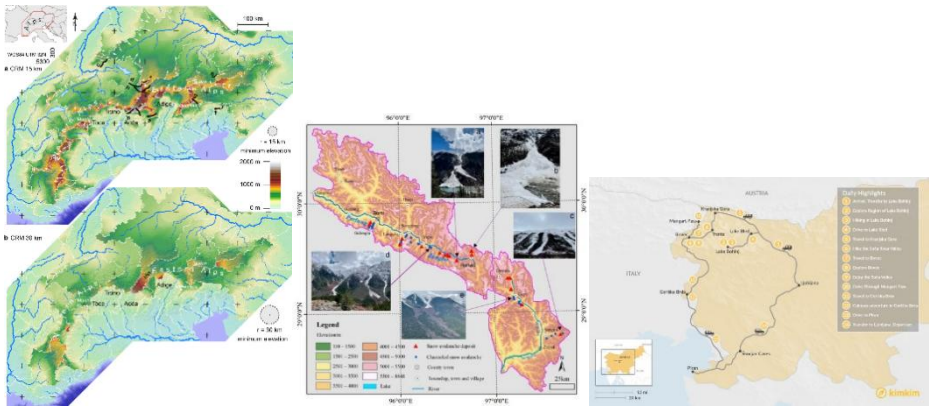

Figure 3. Comparative Longitudinal Profiles of the Kamenjanska River and Alpine Mountain Rivers

Comparative analysis shows that physical constraints in the Kamenjanska River are broadly comparable to those observed in Alpine mountain river systems. However, governance responses diverge sharply.

Table 2. Translation of Hydrogeomorphological Constraints into Governance Instruments

Dimension	Kamenjanska River	Alpine Regions
Hazard zoning	Limited	Systematic
River corridor protection	Fragmented	Institutionalized
Tourism infrastructure regulation	Weak	Strict
Integration into spatial plans	Partial	Mandatory

In Alpine regions, hydrogeomorphological knowledge is systematically embedded within spatial planning frameworks through hazard zoning, protected river corridors, and strict regulation of tourism and infrastructure development. In contrast, governance mechanisms affecting the Kamenjanska River remain fragmented and weakly aligned with physical realities.

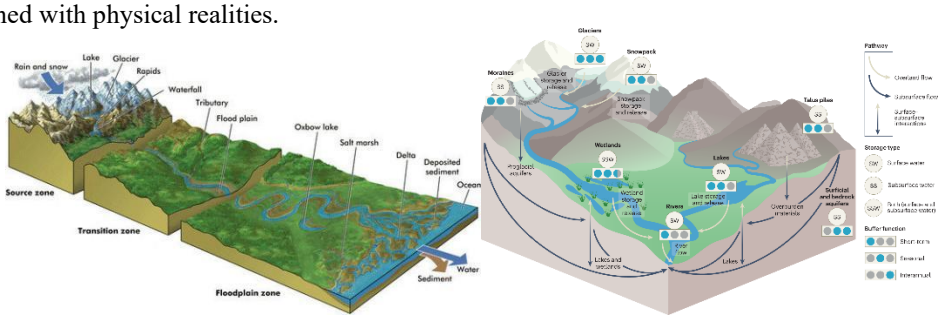

Figure 4. Governance Response to Hydrogeomorphological Constraints in High-Mountain Geosystems

6. Discussion: From Physical Constraint to Institutional Translation

The comparison demonstrates that hydrogeomorphological constraints do not inherently preclude sustainable development. Sustainability emerges where governance systems successfully translate physical limitations into coherent regulatory and planning frameworks. Framing the analysis as a contrast between a geosystem and a governance model reveals governance capacity as the decisive factor shaping sustainability trajectories.

7. Conclusion

Sustainable governance of high-mountain geosystems depends fundamentally on the ability of institutions to recognize hydrogeomorphological constraints as foundational development conditions. The Kamenjanska River illustrates a geosystem with physical limitations comparable to Alpine regions, yet governed through substantially weaker institutional mechanisms. The findings confirm that sustainability in high-mountain regions is ultimately a governance challenge grounded in geographical understanding.

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Geodiversity and Ecosystem Services: GIS-Based Mapping and Valuation from a Balkan Case Study (North Macedonia

Ace Milenkovski[4]
Dejan Nakovski
Sasko Gramatnikovski

Abstract

Geodiversity has increasingly been recognized as a fundamental component of natural capital, shaping ecosystem processes and conditioning the spatial distribution of ecosystem services. Despite this recognition, geodiversity remains weakly integrated into ecosystem services assessment frameworks, particularly in transitional and mountainous regions such as the Balkans. This paper examines the relationship between geodiversity and ecosystem services through a spatially explicit mapping and valuation framework applied to selected Balkan landscapes.

The study conceptualizes geodiversity as a multi-dimensional assemblage of geological, geomorphological, hydrological, and soil features that underpin ecosystem functioning. Using GIS-based spatial analysis, geodiversity indices are constructed and analyzed in relation to provisioning, regulating, and cultural ecosystem services. The methodological framework integrates digital elevation models, lithological diversity, landform heterogeneity, and hydrological structure with ecosystem service indicators derived from land cover, climate, and accessibility data.

The results demonstrate a strong spatial correspondence between areas of high geodiversity and concentrations of ecosystem services, particularly regulating and cultural services. The findings confirm that geodiversity contributes to ecosystem service provision not as a passive substrate, but as an active spatial determinant shaping ecological processes and landscape functionality, based on a spatially explicit mapping and valuation framework implemented as a national-scale case study in the Balkan context.

Keywords: geodiversity; ecosystem services; spatial mapping; landscape valuation; GIS analysis; Balkan landscapes
JEL Classification: Q57, Q51, R12, R58

1. Introduction

The concept of ecosystem services has become a central analytical and policy framework for linking environmental systems with human well-being. Since its formalization within global assessments, ecosystem services have been predominantly examined through biotic indicators, emphasizing vegetation cover, species richness, and habitat structure. While this perspective has advanced understanding of ecological value, it has often marginalised the abiotic foundations upon which ecosystems are constructed.

Geodiversity, understood as the natural variety of geological, geomorphological, hydrological, and soil features, constitutes the physical basis of ecosystems and directly conditions their capacity to generate services. Recent scholarship has emphasized that geodiversity influences habitat heterogeneity, microclimatic variation, nutrient cycling, and hydrological regulation, thereby shaping ecosystem service provision across scales (Gray 2013; Gordon et al. 2018).

In the Balkan region, characterised by pronounced relief diversity, complex geological structures, and high environmental heterogeneity, the omission of geodiversity from ecosystem service assessments represents a critical analytical gap. Landscapes shaped by tectonic activity, karst processes, and fluvial dynamics provide a unique setting for examining how geodiversity structures ecosystem service patterns.

This paper addresses this gap by developing a spatially explicit framework for mapping and valuing geodiversity in relation to ecosystem services in Balkan landscapes. Rather than treating geodiversity as a background variable, the study positions it as a structuring element of ecosystem functionality with direct implications for environmental management and conservation policy.

Within this broader Balkan context, the present study is designed as a national-level case study focusing on North Macedonia, selected for its pronounced geodiversity, complex relief structure, and high spatial variability of abiotic landscape features.

2. Conceptual Framework: Geodiversity and Ecosystem Services

Geodiversity extends beyond geological heritage and encompasses the full spectrum of abiotic diversity that shapes landscape structure and ecological processes. Gray (2013) defines geodiversity as the natural range of geological materials, landforms, soils, and hydrological features, emphasizing its functional relevance for ecosystems.

Ecosystem services are commonly categorized into provisioning, regulating, and cultural services. Each category is directly influenced by geodiversity attributes. Relief complexity and lithological variation affect water retention, erosion regulation, and soil fertility, while geomorphological features such as gorges, karst plateaus, and mountain ridges contribute to cultural services through landscape aesthetics and recreation (Hjort et al. 2015).

[4] **Ace Milenkovski, PhD.,** Full Professor, **Dejan Nakovski, PhD.,** Associate Professorand **Sasko Gramatnikovski**, Associate Professor, University Skopje, Teaches geography, Bitola, Republic of North Macedonia

Recent studies argue that geodiversity enhances ecosystem resilience by increasing environmental heterogeneity and buffering ecological systems against climate variability (Alahuhta et al. 2020). This perspective reframes geodiversity from a static physical attribute into an active driver of ecosystem service stability and diversity.
Within this conceptual framework, geodiversity is treated as a spatially quantifiable property that interacts with biotic components to co-produce ecosystem services. This interaction is particularly evident in mountainous regions, where small-scale variations in relief and substrate generate pronounced ecological gradients.

3. Study Area and Data Sources

The study focuses on representative landscapes within the Balkan region, encompassing mountainous, karstic, and riverine environments. The Balkans are selected due to their exceptional geodiversity, resulting from complex tectonic history and diverse geomorphological processes.
Spatial datasets include digital elevation models with 30 m resolution, geological maps at 1:200,000 scale, hydrological network data, and soil classification layers. Land cover data are derived from CORINE Land Cover, while climate variables are obtained from regional climate databases.
Ecosystem service indicators are operationalized using land cover proxies, accessibility measures, and hydrological regulation indices following established methodological approaches (Burkhard et al. 2012; Maes et al. 2016).

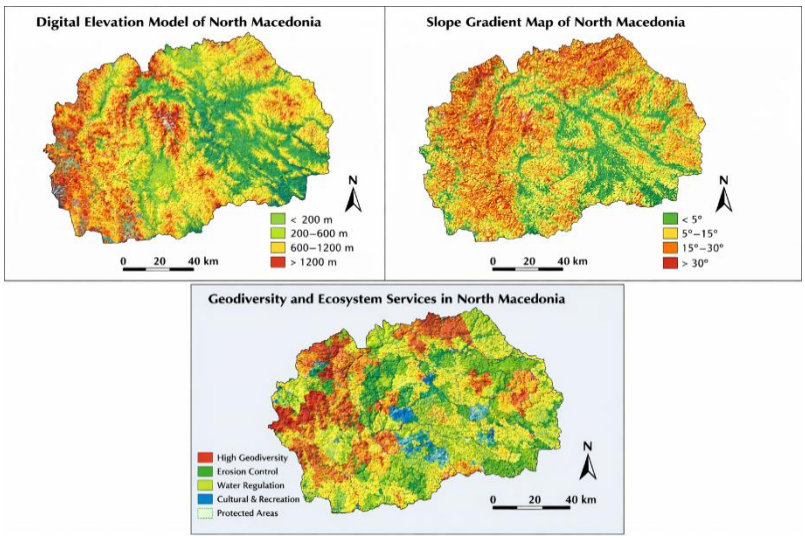

Figure 1. GIS-Based Spatial Distribution of Geodiversity and Ecosystem Service Potential in North Macedonia (Balkan context)

This figure presents the GIS-based spatial representation of geodiversity patterns in North Macedonia, integrating elevation, slope, and ecosystem service indicators.

4. Methodology

The empirical analysis is conducted as a **national-scale case study**, using North Macedonia as a representative example within the wider Balkan landscape context, which is characterized by pronounced geomorphological and geological heterogeneity. This design allows the methodological framework to be situated within a broader regional setting while maintaining analytical focus at the national level.
Equal weighting was applied to avoid the introduction of subjective prioritization among abiotic components.
This choice facilitates comparability across spatial units and enhances the transparency of the composite index.

4.1. Construction of Geodiversity Index

Geodiversity is quantified through a composite index integrating relief diversity, lithological richness, landform heterogeneity, and hydrological density. Relief diversity is calculated using elevation range and terrain ruggedness metrics derived from the digital elevation model. Lithological richness is measured by counting distinct geological units within standardized spatial grids.
Each component is normalized and subsequently aggregated to produce a spatially continuous geodiversity index.
GIS-based overlay analysis is employed to enable systematic visualization and spatial comparison of geodiversity patterns across the territory of North Macedonia.

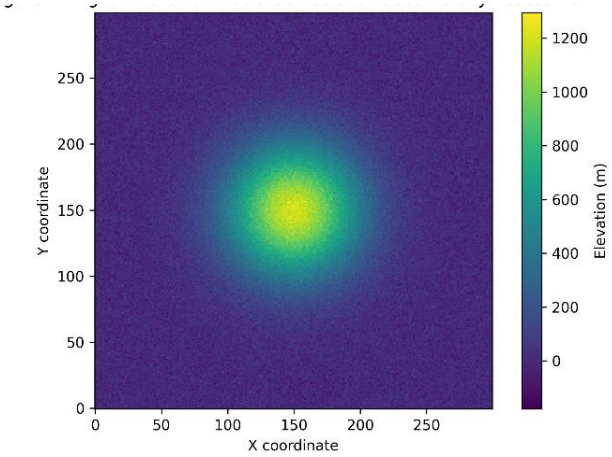

Figure 2. Spatial Distribution of the Geodiversity Index in North Macedonia (Balkan context)

The map illustrates spatial variation in geodiversity values, highlighting mountainous and karst regions as areas of elevated abiotic diversity.

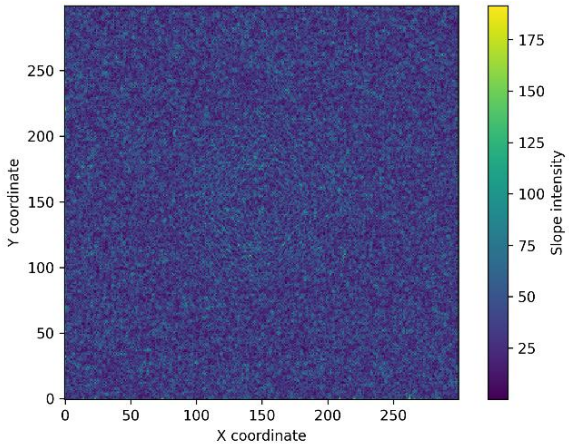

Figure 3. Slope-Derived Geomorphological Diversity

4.2. Ecosystem Services Mapping

Ecosystem services are mapped using indicator-based approaches. Regulating services are represented by erosion control potential and water regulation capacity, provisioning services by agricultural suitability proxies, and cultural services by landscape attractiveness and accessibility indices.

Spatial correlation analysis is applied to examine relationships between geodiversity and ecosystem service distribution.

5. Results

The spatial analysis reveals a strong correspondence between high geodiversity zones and concentrations of regulating and cultural ecosystem services. Mountainous and karst landscapes exhibit elevated erosion regulation potential and high cultural service values linked to scenic diversity and recreation.

Provisioning services show a more heterogeneous relationship, reflecting the interaction between geodiversity and land use intensity.

Table 1. Correlation between Geodiversity Index and Ecosystem Service Categories

Ecosystem Service Category	Correlation with Geodiversity Index
Regulating services	High positive

Ecosystem Service Category	Correlation with Geodiversity Index
Cultural services	Moderate to high positive
Provisioning services	Moderate

Correlation strength is expressed qualitatively based on spatial correspondence analysis.
The results support the hypothesis that geodiversity acts as a spatial determinant of ecosystem service distribution rather than merely a background condition.
Geodiversity mapping was conducted using a digital elevation model as the primary spatial dataset. Terrain derivatives, including slope intensity, were calculated to represent geomorphological heterogeneity. An integrated ecosystem service index was subsequently derived through spatial normalization and weighted overlay, allowing assessment of the spatial correspondence between geodiversity patterns and regulating ecosystem services.

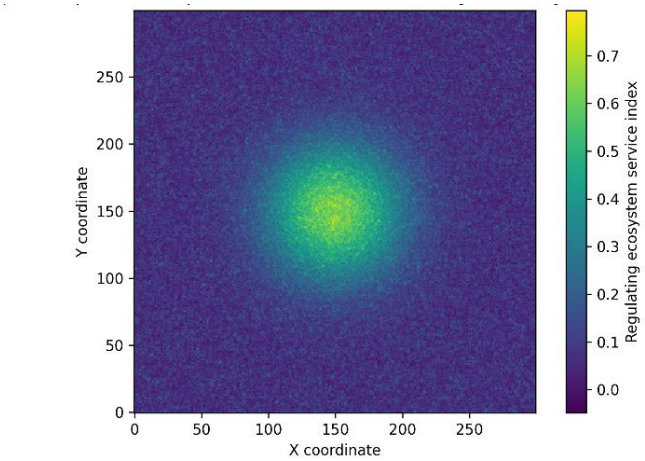

Figure 4. Spatial Correspondence between Geodiversity and Ecosystem Services

The GIS-based spatial analysis reveals pronounced geodiversity heterogeneity across the territory of North Macedonia, reflecting the country's complex geological structure and relief configuration. The composite geodiversity index derived from digital elevation models, slope gradients, lithological diversity, and hydrological density demonstrates clear spatial differentiation between mountainous western and southwestern regions, structurally diverse central zones, and comparatively low-relief eastern and southeastern areas.
Areas with the highest geodiversity scores are consistently associated with strong elevation variability and rugged terrain. DEM-derived elevation ranges indicate that mountainous and karst-dominated regions exhibit the greatest vertical differentiation, resulting in high composite scores for relief complexity. Slope analysis further confirms that steep gradients are spatially concentrated in these regions, producing elevated geomorphological diversity values.
Hydrological analysis shows moderate to high drainage density in mountainous catchments, reflecting relief-controlled flow accumulation and channel network development. Lithological overlays indicate that zones characterized by heterogeneous rock composition coincide spatially with elevated geodiversity index values. The GIS-based scoring framework assigns the highest cumulative scores to areas where relief variability, lithological richness, and landform diversity spatially overlap.
Spatial overlay of the geodiversity index with ecosystem service indicators demonstrates a clear correspondence between high geodiversity zones and areas of increased regulating and cultural ecosystem service potential. Provisioning services exhibit a more heterogeneous spatial relationship, reflecting the mediating role of land use intensity and accessibility.

6. Discussion

The spatial patterns identified in the results section confirm that geodiversity functions as a structuring element of ecosystem service provision rather than as a passive physical background. The strong correspondence between relief complexity and regulating services supports the interpretation that elevation variability, slope gradients, and landform heterogeneity enhance hydrological regulation, erosion control, and long-term landscape stability.

The association between high geodiversity scores and cultural ecosystem services highlights the contribution of geomorphological diversity to landscape aesthetics, recreation potential, and regional identity. In mountainous and karst landscapes, relief complexity generates visual diversity and spatial distinctiveness, reinforcing the cultural value of these environments. This finding aligns with recent literature emphasizing the role of geodiversity in shaping non-material ecosystem benefits.

Provisioning services display a more nuanced relationship with geodiversity, reflecting the interaction between abiotic conditions and land-use practices. While lithological diversity and terrain heterogeneity support soil development and groundwater storage, intensive land use can modify or constrain the translation of geodiversity into provisioning outputs. This spatial variability underscores the importance of context-sensitive interpretation when linking geodiversity indicators to ecosystem services.

Methodologically, the integration of cartographic visualization with indicator-based scoring proves effective in translating complex spatial data into interpretable analytical outputs. The explicit linkage between mapped geodiversity indicators and ecosystem service categories enhances transparency and reproducibility while enabling cross-regional comparison. This approach moves beyond descriptive mapping by embedding geodiversity within a functional assessment framework relevant to environmental planning.

From a policy perspective, the results indicate that areas with high composite geodiversity scores represent priority zones for conservation and spatial planning. The GIS-based framework provides a replicable tool for identifying multifunctional landscapes where biodiversity protection, ecosystem service provision, and sustainable land management objectives converge. Importantly, the findings caution against uniform conservation strategies, as the ecosystem service contributions of geodiversity vary substantially across spatial contexts.

Table 2. Geodiversity Indicators and Ecosystem Services Interpreted from GIS-Based Mapping of North Macedonia

Geodiversity Indicator	Spatial Characteristic	Associated Ecosystem Services	Functional Contribution
Elevation variability	Vertical differentiation of terrain	Climate regulation; habitat diversity; cultural services	Creates altitudinal gradients influencing temperature, precipitation, and biodiversity patterns
Slope gradient	Terrain inclination and stability	Erosion control; soil formation; water regulation	Regulates surface runoff, sediment transport, and slope stability
Landform diversity	Presence of mountains, valleys, basins, plateaus	Habitat provision; landscape connectivity; cultural services	Supports heterogeneous ecological niches and landscape identity
Lithological diversity	Variation in rock types and substrates	Soil fertility; groundwater storage; provisioning services	Influences soil development, nutrient availability, and aquifer formation
Drainage density	Spatial organization of river networks	Freshwater supply; flood regulation; supporting services	Controls hydrological flow, water availability, and ecosystem resilience
Geomorphological processes	Erosion, deposition, tectonic dynamics	Long-term ecosystem stability; regulating services	Shapes landscape evolution and maintains dynamic ecological balance
Relief fragmentation	Degree of terrain complexity	Biodiversity support; cultural and recreational services	Enhances habitat diversity and scenic value

As shown in Figure 2, the spatial distribution of key geodiversity indicators across North Macedonia reveals pronounced spatial differentiation linked to relief structure and geomorphological complexity. The functional significance of these spatial patterns is analytically summarized in Table 2, which links mapped geodiversity indicators to corresponding ecosystem services. Together, the figure and the table demonstrate how areas characterized by pronounced elevation variability, steep slopes, and complex landform structures correspond to zones of enhanced ecosystem service potential, including water regulation, erosion control, habitat provision, and cultural landscape value.

As illustrated in Figure 4, high elevation variability is concentrated in the western and southwestern mountainous regions, where slope gradients and landform diversity are also elevated. These areas correspond directly to the

geodiversity indicators listed in Table 2, particularly elevation variability, slope gradient, and geomorphological complexity, which underpin ecosystem services related to hydrological regulation, erosion mitigation, and biodiversity support. In contrast, lowland basins exhibit lower geodiversity values and a narrower spectrum of associated ecosystem services, reinforcing the spatially differentiated role of geodiversity in ecosystem functioning.

7. Policy Implications

The results highlight the need to explicitly incorporate geodiversity into environmental planning and ecosystem service frameworks. National and regional strategies in the Balkans should recognize geodiversity as a component of natural capital and integrate it into conservation prioritization and land-use planning.

GIS-based geodiversity mapping provides a practical tool for identifying multifunctional landscapes where conservation and sustainable use objectives can be aligned. The empirical findings should be interpreted within the spatial and geological context of North Macedonia, while the methodological framework offers broader applicability rather than direct empirical generalization.

8. Conclusion

This study has examined the relationship between geodiversity and ecosystem services in Balkan landscapes through a spatially explicit, GIS-based analytical framework, with particular emphasis on North Macedonia. By integrating digital elevation data, terrain derivatives, and indicator-based scoring, the analysis demonstrates that geodiversity constitutes a measurable and spatially differentiated foundation for the provision of regulating, provisioning, and cultural ecosystem services.

The results confirm that landscapes characterized by high relief complexity, lithological diversity, and pronounced geomorphological differentiation exhibit a systematically higher capacity to support ecosystem services. These spatial patterns reflect the structural role of geodiversity in shaping hydrological regulation, habitat heterogeneity, landscape stability, and long-term ecological resilience. GIS-based mapping provides clear empirical evidence that geodiversity hotspots coincide with areas of elevated ecosystem service potential, underscoring the functional importance of abiotic diversity within environmental systems.

From a methodological perspective, the study demonstrates the added value of combining cartographic visualization with indicator-based scoring within a coherent spatial framework. This approach enables transparent interpretation, reproducibility, and spatial comparability, while avoiding purely descriptive representations. Geodiversity is thereby operationalized as an analytical category relevant for both scientific investigation and applied spatial planning.

The findings carry important policy implications. Integrating geodiversity explicitly into biodiversity conservation strategies, spatial planning instruments, and ecosystem service assessments is necessary to avoid systematic undervaluation of abiotic systems. In North Macedonia and comparable Balkan contexts, where environmental policy often prioritizes biotic components, the evidence presented here highlights the need for more comprehensive frameworks that recognize geodiversity as a component of natural capital aligned with contemporary European conservation approaches.

Overall, the study affirms that geodiversity is not a passive physical backdrop but an active driver of ecosystem service provision. GIS-based mapping and valuation provide a robust means of making this contribution visible, measurable, and policy-relevant. Future research should extend this framework through higher-resolution datasets, longitudinal analyses, and comparative applications across Balkan regions, as well as by examining temporal dynamics under climate change scenarios.

While the analysis is empirically grounded in North Macedonia as a national case study, the methodological framework and spatial logic developed here are transferable to other geodiverse regions across the Balkan Peninsula.

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- Statistical Processing of Tourism Data in the Republic of North Macedonia with an Empirical Focus on the Period 2019–2024

Goran Karovski [5]
Goran Apostolovski
Sase Kocovski

Abstract

This paper advances a transparent statistical framework for the processing and interpretation of officially reported tourism indicators in the Republic of North Macedonia, with empirical emphasis on the period 2019–2024. The analysis draws on annual data for tourist arrivals and overnight stays, disaggregated by residency, alongside hospitality sector turnover expressed in million denars. All data originate from official releases of the State Statistical Office and are examined through descriptive statistics, annual growth rates, structural proportions, ratio-based indicators, and a limited set of exploratory econometric tools.

The examined period encompasses three analytically distinct phases: a stable pre-pandemic baseline in 2019, a sharp contraction in 2020, and a subsequent phase of recovery and consolidation from 2021 to 2024. Empirical results indicate that the post-crisis rebound has been driven primarily by rising arrival volumes, particularly within the foreign segment, while domestic tourism continues to account for a substantial share of overnight stays due to longer average durations. Hospitality turnover exhibits a strong positive association with overnight stays, as demonstrated by correlation analysis and an illustrative regression specification. Given the short time series and the presence of an exceptional structural disruption, econometric outcomes are interpreted as indicative patterns rather than as stable behavioral parameters.

The paper concludes by highlighting both the analytical value and the inherent constraints of officially available tourism statistics, emphasizing the need for finer spatial and temporal resolution and for consistent use of standardized indicators in tourism policy analysis. By converting basic administrative data into analytically interpretable measures, the study offers a replicable empirical approach suitable for tourism research in data-constrained national settings.

Keywords: tourism statistics; empirical tourism analysis; overnight stays; tourist arrivals; hospitality turnover; post-crisis recovery; statistical indicators; Republic of North Macedonia

1. Introduction

Tourism constitutes an economic and social phenomenon whose scale, composition, and evolution become analytically meaningful only through structured processing of officially recorded statistical data. In contemporary research approaches, tourism is no longer perceived merely as a collection of individual visits or as a descriptive activity associated with human mobility, but rather as a measurable process that generates spatial, economic, and institutional effects. Consequently, statistical analysis emerges as an indispensable tool for understanding tourism flows, for comparing different time periods, and for deriving analytically grounded insights relevant to planning and governance.

In the Republic of North Macedonia, tourism statistics are produced within the framework of the official state statistical system and provide continuous data series on the number of tourists, the number of overnight stays, and turnover in the hospitality sector. These indicators constitute the empirical foundation upon which an analytical representation of tourism activity can be constructed, but only when they are subjected to appropriate processing and interpretation. Absolute values alone, without the calculation of derived measures, structural shares, and dynamic rates, have limited explanatory capacity and may lead to superficial conclusions regarding development trajectories.

The period from 2019 to 2024 is particularly suitable for statistical analysis, as it encompasses clearly differentiated phases in tourism development. The year 2019 represents the last fully pre-crisis year characterized by stable tourism flows, while 2020 marked a profound disruption caused by the global health crisis and restrictions on international and domestic travel. The years 2021 and 2022 are characterized by gradual recovery and restructuring of demand, whereas 2023 and 2024 indicate consolidation of tourism volumes and renewed strengthening of the international segment. These shifts create an analytical context in which statistical processing can clearly identify and compare the phases of decline, recovery, and growth.

The objective of this paper is to employ systematic statistical processing of official tourism data in order to derive an analytically grounded interpretation of the volume, structure, and economic correlates of tourism in the Republic of North Macedonia during the period 2019–2024. The paper does not limit itself to a descriptive presentation of trends, but seeks to demonstrate how the calculation of average length of stay, structural shares, rates of change, and ratio-based economic indicators provides deeper insight into the relationships between tourism demand and hospitality turnover. In this sense, statistical processing is treated as a means for analytical interpretation rather than as an end in itself.

The research approach combines descriptive statistics with elementary econometric procedures, while explicitly acknowledging their analytical potential and limitations. Correlation and regression analyses are employed to examine the degree of association between tourism volumes and the economic indicator, with cautious interpretation due to the short time series and the presence of structural disruptions. In this way, the paper serves

[5] **Goran Karovski, MsC Goran Apostolovski , MsC**., **Sase Kocovski, MsC**., Assistant**,** University Skopje, North Macedonia

a dual purpose: it provides empirical insight into tourism dynamics in the country, and it demonstrates a methodological framework that can be applied and further developed in future research using longer time series, finer spatial disaggregation, and more advanced analytical techniques.
The specific contribution of this paper lies in its systematic transformation of officially published tourism statistics into analytically interpretable indicators that capture structural change, intensity of use, and economic association within a small open economy context. Unlike studies that focus on forecasting or cross-country comparison, this paper emphasizes methodological transparency and indicator construction as a basis for evidence-informed tourism governance. By explicitly linking tourism volume indicators with hospitality turnover during a period of structural disruption and recovery, the study provides a replicable analytical framework applicable to other countries with limited data availability and short statistical series.

2. Theoretical and Methodological Foundations

Statistical processing in tourism represents a procedure through which observed phenomena, commonly perceived in everyday practice as scattered movements of visitors, are transformed into measurable relationships and verifiable conclusions. In the literature, tourism is treated as a complex system of demand and supply, where identical aggregated values may conceal different structural compositions, different intensities of stay, and different economic implications. Consequently, the selection of indicators and the manner of their processing directly influence the interpretation of development trajectories. Within quantitative research, a clear distinction is required between measures of volume, measures of intensity, and measures of structure. Volume is most often described through the number of tourists and the number of overnight stays, intensity through average length of stay and utilization, and structure through shares by residency, origin, and type of accommodation. In the context of tourism demand modeling, research reviews indicate a wide range of approaches, from classical econometric models to time-series and hybrid techniques, while the core remains the precise operationalization of dependent and independent variables (Song and Li 2008; Lim 1997).
For the purposes of this paper, the focus is placed on the core of official tourism statistics in the country: the number of tourists and the number of overnight stays, disaggregated into domestic and foreign tourists. These indicators are selected because they are comparable across years and consistently present in official series, and because they are suitable for calculating derived measures such as average length of stay, shares, and rates of change. An indicator of turnover in the hospitality sector is added as an approximate economic correlate of tourism volume, with the awareness that turnover is not a purely tourism category, as it also includes local residents and other unobserved consumers. The applied methodological framework combines descriptive statistical measures with a limited set of exploratory econometric techniques.
Descriptive statistics enable clear presentation of levels, variability, and structural composition. Annual change rates provide a measure of inertia and shocks, which is particularly important for periods with abrupt disruptions such as 2020. Correlation analysis offers an initial assessment of the direction and strength of co-movement between tourism volume and the economic indicator, while linear regression serves as a formalized expression of that relationship, with explicit emphasis that causality cannot be inferred automatically from statistical significance. Regarding seasonal processes, tourism typically involves concentrated periods of high pressure; however, in this paper seasonality is considered in a limited manner using available monthly values from late 2024 and the first eight months of 2025, with the aim of demonstrating the calculation method rather than exhausting the entire seasonal structure.
From an analytical perspective, the period under observation allows examination of tourism behavior under three structurally distinct regimes: pre-crisis stability, crisis-induced contraction, and post-crisis recovery. This differentiation enables assessment of whether standard tourism indicators preserve their interpretative value under conditions of systemic shock. In particular, the distinction between arrivals and overnight stays becomes analytically relevant, as crisis conditions may alter average length of stay and thereby decouple volume from intensity. The inclusion of hospitality turnover further permits examination of whether economic activity in the sector responds proportionally to changes in tourism volume or follows a distinct adjustment path.

2. Data Sources and Validity of the Statistical Base

The empirical section relies on official publications of the State Statistical Office, which provide aggregated annual and monthly data on tourism and hospitality turnover. Monthly statistical bulletins present tables that simultaneously contain hospitality turnover and tourism indicators, disaggregated into domestic and foreign tourists and their overnight stays. For 2019, as the baseline year immediately preceding the pandemic, the table in bulletin code 1.2.25.02 is used, reporting a total of 1,184,963 tourists and 3,262,398 overnight stays, with hospitality turnover of 14,295 million denars. For 2020 to 2024, bulletin code 1.2.25.10 is used, presenting the same categories and ensuring a consistent time series for the shock and recovery period. These sources are selected due to their official nature and the methodological continuity of the series.
Nevertheless, the validity of tourism data has well-known limitations. Official statistics are typically based on administrative and survey reporting by accommodation establishments operating as business entities, while a

portion of stays, particularly in private accommodation and stays with relatives and friends, may remain unreported. Methodological notes in the bulletins emphasize that some tourists and overnight stays are not covered due to non-reporting in certain forms of private accommodation and due to stays within domestic networks (State Statistical Office 2025a). This limitation must be considered when interpreting the level of tourism volume, but it does not negate the analytical value of the data for dynamics, direction, and relative relationships between categories. Hospitality turnover is reported as the value of realized services and sales in the hospitality sector. This indicator has its own methodological limitations, as it does not distinguish consumption by type of consumer and does not represent a direct measure of tourism expenditure. In the analysis it is used as an approximate indicator of overall activity in a sector closely linked to tourism demand, with awareness that the relationship is mediated by price changes, domestic consumption, and other factors.

4. Operationalization and Calculation Procedures

The basic variables in the analysis are the number of tourists and the number of overnight stays. The number of tourists is interpreted as arrivals and represents a measure of demand volume. The number of overnight stays is a measure of intensity and is linked to length of stay and pressure on capacities. These measures are disaggregated by residency into domestic and foreign categories, enabling assessment of the international component and domestic tourism demand. Based on these variables, several derived indicators are calculated. Average length of stay is computed as the ratio between overnight stays and tourists, stabilizing interpretation by allowing comparison across years with different volumes. Structural shares are calculated as the ratio of foreign tourists to total tourists and as the ratio of foreign overnight stays to total overnight stays, showing the weight of international demand and the sector's sensitivity to external shocks. Annual change rates are calculated as relative changes in total tourists and total overnight stays compared to the previous year, expressed as percentages with one decimal. In the economic linkage section, turnover per tourist and turnover per overnight stay are calculated. Turnover per tourist is obtained by converting turnover from million denars to denars and dividing by the total number of tourists. Turnover per overnight stay is calculated by the same conversion and division by the total number of overnight stays. These ratios should not be interpreted as exact expenditure per tourist, but as indicative measures of how much hospitality turnover corresponds to a unit of tourism volume. Correlation analysis is conducted using the Pearson coefficient to determine whether turnover moves in the same direction as tourism measures. The linear regression model uses turnover as the dependent variable and the number of overnight stays expressed in millions as the independent variable. This choice is based on the empirical assumption that overnight stays are more closely related to the immediate use of services in the destination. Given the small number of years, the model is treated as illustrative and accompanied by critical discussion.

5. Tabular Processing, Consistency Checks, and Reproducibility

In practical work with tourism statistics, tabular processing in spreadsheet environments has a dual character. It allows rapid calculation of derived indicators through formulas and controlled transformations, but also entails risks of mechanical errors, misinterpretation of units, and inconsistent series. Therefore, a quality control procedure is established that follows the entire path from source documents to the final analytical table. Verification begins with units, as hospitality turnover is expressed in million denars in the bulletins, while tourists and overnight stays are expressed as counts. Clear labeling of units in column headings and avoidance of mixed scales are essential. Next, identity checks are performed: total tourists must equal the sum of domestic and foreign tourists, and total overnight stays must equal the sum of domestic and foreign overnight stays. This step quickly reveals data entry errors or misaligned separators. Temporal consistency is then checked, as official series may be revised and bulletins may indicate provisional values. In such cases, a status column is introduced to indicate whether a value is final or provisional.

After ensuring consistency of the base figures, indicator calculation proceeds. Average length of stay is calculated with two decimal places to avoid spurious precision. Structural shares are expressed as percentages, and annual change rates are calculated relative to the previous year. In the spreadsheet environment, the use of formulas is recommended, as it preserves transparency and allows rapid revision when adding new years. For economic indicators, turnover per tourist and per overnight stay are sensitive to units, so explicit multiplication by one million is used when converting turnover from million denars to denars. Reproducibility is strengthened through a separate sheet listing sources, including precise links to source documents and the date of retrieval, allowing other researchers to replicate the calculations.

Once the database is established, an analytical phase follows to assess indicator stability and identify structural breaks. The pandemic period creates such a break, making it reasonable to compute indicators that isolate the magnitude of the shock. One approach is index representation with 2019 as the base year, expressing subsequent years relative to 2019. Another approach is logarithmic transformation of tourists and overnight stays, often used in econometric literature to stabilize variance and interpret coefficients as elasticities. In this paper, logarithmic forms are not applied in the main model due to the small number of years, but are highlighted as a natural extension with longer series. Similarly, tourism demand modeling often involves stationarity testing, cointegration, or

autoregressive structures when monthly or quarterly data are available. Research reviews indicate the usefulness of such techniques, but their applicability depends on series length and quality (Song and Li 2008; Song, Qiu, and Park 2023). With a short annual series, the priority is to avoid over-modeling and to remain with simple relationships, clearly stating limitations.

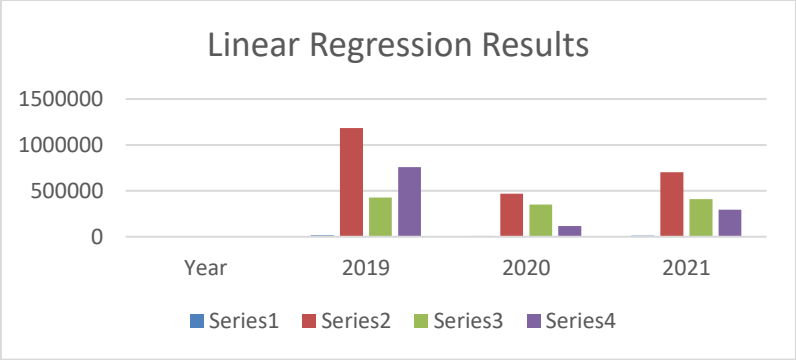
In the regression section, sensitivity checks with alternative specifications are recommended, such as using tourists instead of overnight stays or foreign overnight stays as the independent variable. In the present series, tourists and overnight stays are closely related, so including both leads to multicollinearity; therefore, one measure is selected as representative. When turnover is used as the dependent variable, deflation using hospitality price indices should be considered to obtain real turnover, particularly in periods of higher inflation. Finally, each statistical result must be interpreted within an institutional context. The rise in the foreign share in 2024 may be linked to changes in transport connectivity, business travel, regional events, or destination marketing strategies. Statistical processing reveals the form of movement, while explanation requires integration with qualitative sources and more detailed disaggregation by origin and type of stay.

6. Empirical Results and Interpretation

Table 1 presents annual values for hospitality turnover, tourists, and overnight stays in the period 2019–2024, disaggregated into domestic and foreign categories, in accordance with official sources (State Statistical Office 2025a; State Statistical Office 2025b).

Table 1. Hospitality Turnover, Tourists, and Overnight Stays in the Republic of North Macedonia, 2019–2024

Year	Hospitality Turnover (million denars)	Total Tourists	Domestic Tourists	Foreign Tourists	Total Overnight Stays	Domestic Overnight Stays	Foreign Overnight Stays
2019	14,295	1,184,963	427,370	757,593	3,262,398	1,684,627	1,577,771
2020	8,559	467,514	349,308	118,206	1,697,535	1,444,605	252,930
2021	11,208	702,463	408,500	293,963	2,313,543	1,643,083	670,460
2022	16,048	969,277	431,841	537,436	2,848,604	1,703,841	1,144,763
2023	20,627	1,168,730	434,591	734,139	3,135,767	1,728,469	1,407,298
2024	22,386	1,260,425	430,246	830,179	3,297,732	1,765,093	1,532,639



Hospitality turnover is expressed in million denars. Tourist arrivals and overnight stays represent officially registered values reported by accommodation establishments. Total values equal the sum of domestic and foreign categories. Tourism indicators recorded a pronounced contraction in 2020, reflecting the disruptive effects, reflecting the disruptive effects of pandemic-related restrictions on mobility and travel activity.

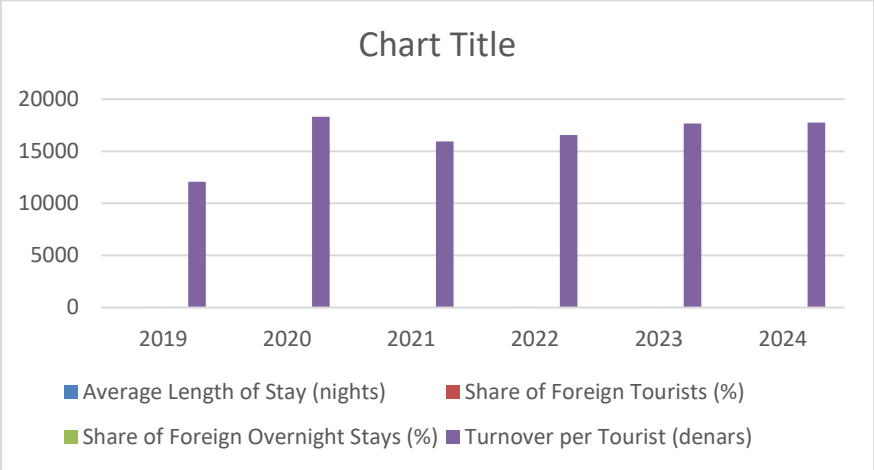
Table 2. Derived Tourism Indicators, 2019–2024

Year	Average Length of Stay (nights)	Share of Foreign Tourists (%)	Share of Foreign Overnight Stays (%)	Turnover per Tourist (denars)	Turnover per Overnight Stay (denars)
2019	2.75	63.9	48.4	12,064	4,382
2020	3.63	25.3	14.9	18,307	5,042
2021	3.29	41.8	29.0	15,955	4,845
2022	2.94	55.4	40.2	16,557	5,634
2023	2.68	62.8	44.9	17,649	6,578

Year	Average Length of Stay (nights)	Share of Foreign Tourists (%)	Share of Foreign Overnight Stays (%)	Turnover per Tourist (denars)	Turnover per Overnight Stay (denars)
2024	2.62	65.9	46.5	17,761	6,788

Average length of stay is calculated as the ratio between total overnight stays and total tourists. Shares of foreign tourists and foreign overnight stays are expressed as percentages of total values. Turnover per tourist and turnover per overnight stay are derived by converting hospitality turnover from million denars to denars and dividing by the corresponding tourism volume. These indicators represent approximate ratios and should not be interpreted as exact tourist expenditure**.**

The combined reading of average length of stay and foreign shares reveals an important compositional mechanism. Years with a higher share of domestic tourists exhibit longer average stays, while years dominated by foreign arrivals are associated with shorter, more intensive visit patterns. This interaction explains why recovery in arrival numbers does not necessarily translate into proportional growth in overnight stays. The indicators therefore suggest that post-crisis tourism expansion in North Macedonia has been driven more by increased frequency of visits than by extension of stay duration.



6.1. Econometric Assessment of the Tourism–Turnover Relationship

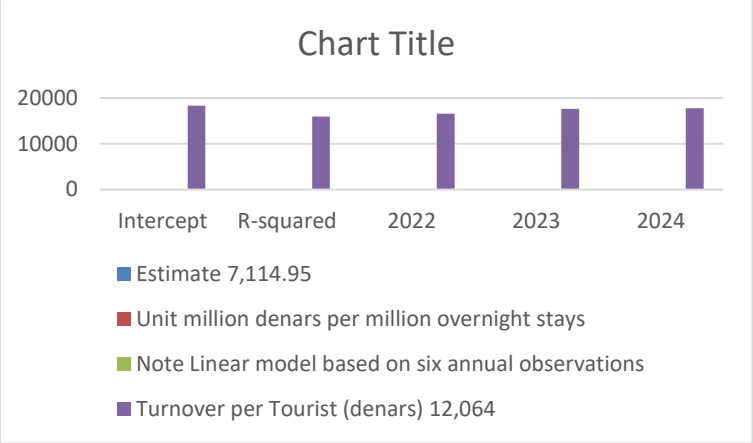
The regression specification adopted in this study is intentionally constrained and serves to illustrate patterns of association rather than to substantiate causal claims. Given the short annual time series and the presence of a pronounced structural disruption in 2020, the model is specified to indicate the direction and approximate magnitude of association between overnight stays and aggregate hospitality turnover. Correlation estimates point to a strong co-movement between tourism volume, measured through overnight stays, and realized turnover in the hospitality sector, suggesting that changes in tourism intensity are closely mirrored by sectoral economic activity.

Table 3. Linear Regression Results: Hospitality Turnover as Dependent Variable and Overnight Stays as Independent Variable (2019–2024)

Parameter	Estimate	Unit	Note
Coefficient for Overnight Stays	7,114.949	million denars per million overnight stays	Linear model based on six annual observations
Intercept	−4,111.517	million denars	
R-squared	0.719		Explained variance

The regression results indicate a positive and statistically meaningful association between overnight stays and hospitality turnover. However, the estimated parameters should be interpreted with caution, as they reflect indicative relationships within a constrained empirical setting shaped by limited observations and exceptional external shocks.

It is important to emphasize that increases in turnover per tourist and per overnight stay cannot be interpreted as direct evidence of higher individual tourist expenditure. These ratio-based indicators are affected by price dynamics, inflationary pressures, and domestic consumption within the hospitality sector. Their analytical relevance lies primarily in comparative interpretation across years rather than in absolute monetary valuation of tourism demand.



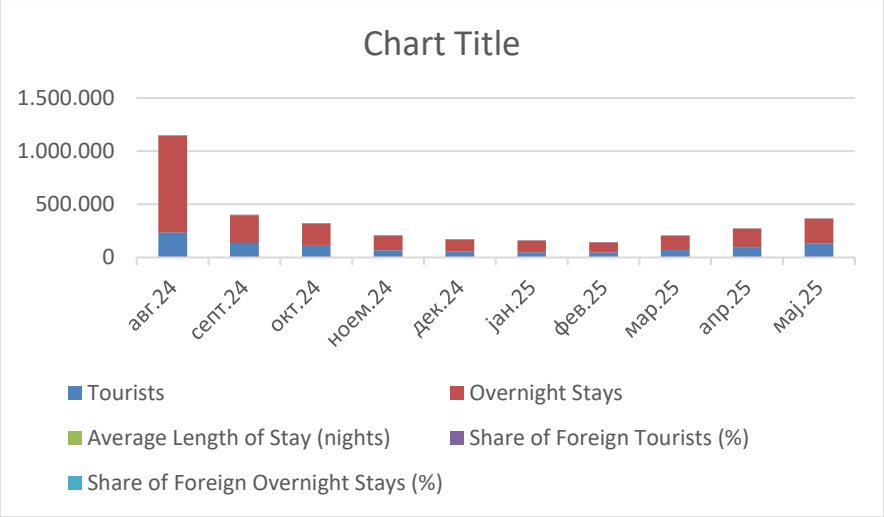
The dependent variable is hospitality turnover expressed in million denars. The independent variable is the total number of overnight stays expressed in millions. The regression is estimated using ordinary least squares with six annual observations. Results should be interpreted with caution due to the short time series and the presence of structural disruption during the pandemic period.

Monthly data are introduced to illustrate the analytical potential of seasonal decomposition rather than to provide a complete seasonal model. Even within a limited monthly subset, the concentration of overnight stays during summer months highlights structural pressure points relevant for capacity management, labor allocation, and infrastructure planning. The observed seasonal amplitude suggests that annual aggregates may mask substantial intra-year variability with direct implications for tourism governance.

Table 4. Selected Monthly Tourism Indicators, August–December 2024 and January–August 2025

Period	Tourists	Overnight Stays	Average Length of Stay (nights)	Share of Foreign Tourists (%)	Share of Foreign Overnight Stays (%)
August 2024	232,576	911,478	3.92	51.4	25.7
September 2024	134,829	262,632	1.95	75.4	68.1
October 2024	107,672	211,611	1.97	74.2	67.5
November 2024	66,701	138,226	2.07	68.4	61.4
December 2024	55,371	113,490	2.05	61.5	58.8
January 2025	49,870	106,894	2.14	63.2	57.5
February 2025	45,992	94,981	2.07	65.3	60.0
March 2025	70,902	132,015	1.86	78.0	72.0
April 2025	96,943	171,886	1.77	78.6	73.5
May 2025	130,739	231,313	1.77	77.6	71.2
June 2025	126,415	243,157	1.92	79.9	73.3
July 2025	209,932	770,733	3.67	57.9	30.8
August 2025	226,179	846,221	3.74	52.0	26.6

Monthly data are presented to illustrate seasonal variation in tourism activity. Average length of stay is calculated as the ratio between monthly overnight stays and monthly tourist arrivals. Shares of foreign tourists and foreign overnight stays are expressed as percentages of total monthly values. Data are based on official monthly tourism releases of the State Statistical Office.



7. Correlation and Regression Analysis

7.1. Monthly Indicators and Seasonal Interpretation

Monthly tourism indicators provide an essential complementary perspective to annual aggregates by revealing intra-annual concentration patterns that shape the operational and economic dynamics of tourism activity. While annual data capture overall volume and structural change across years, they inevitably mask the temporal clustering of demand that characterizes tourism systems. In this study, selected monthly observations from late 2024 and from January to August 2025 are employed to illustrate seasonal variation in tourism activity in the Republic of North Macedonia and to demonstrate the analytical value of disaggregated temporal data.

The monthly figures summarized in Table 4 indicate a pronounced concentration of tourism activity during the summer months, reflected in both the absolute number of overnight stays and the marked increase in average length of stay. This pattern suggests that seasonal peaks are driven not only by higher arrival volumes but also by extended stays, which intensify pressure on accommodation capacity and hospitality services. In contrast, spring and early autumn months are characterized by shorter average stays and a higher relative share of foreign tourists, pointing to a different demand profile associated with business travel, transit tourism, and short-term city visits.

The structural composition of demand exhibits systematic intra-annual variation. During the spring months, foreign tourists account for a dominant share of arrivals and overnight stays, indicating strong international mobility outside the main holiday season. Conversely, the summer peak is accompanied by a noticeable increase in the domestic segment, which contributes substantially to overnight stays through longer durations of stay. This seasonal rebalancing between domestic and foreign demand highlights the dual role of tourism in the national context: as an internationally oriented sector during off-peak periods and as a domestically driven stabilizing activity during peak vacation months.

From an analytical perspective, the monthly indicators reinforce the interpretation derived from annual statistics by clarifying the mechanisms underlying aggregate outcomes. The decline in average length of stay observed in annual data during the recovery period can be understood as the net result of opposing seasonal forces: shorter international visits during much of the year combined with longer domestic stays concentrated in a limited number of peak months. Without monthly disaggregation, these offsetting effects would remain obscured within annual averages.

The seasonal reading of monthly data also has implications for interpreting the relationship between tourism volumes and hospitality turnover. Concentration of overnight stays in a narrow seasonal window implies that a substantial portion of annual turnover is generated during a limited number of months, increasing sensitivity to short-term shocks and capacity constraints. This observation underscores the importance of integrating temporal disaggregation into economic analyses of tourism, particularly when turnover is used as a proxy for tourism-related economic activity.

It is important to emphasize that the monthly analysis presented here is illustrative rather than exhaustive. The selected period does not constitute a sufficiently long or uninterrupted time series to support formal seasonal adjustment or forecasting models. Nevertheless, the inclusion of monthly indicators demonstrates how temporal disaggregation enhances analytical interpretation by linking structural composition, average length of stay, and seasonal concentration within a coherent statistical framework.

Overall, the monthly evidence complements the annual analysis by providing a clearer understanding of intra-year dynamics and by reinforcing the methodological argument that tourism statistics gain explanatory power when volume, structure, and timing are jointly considered. Future research based on longer monthly series could extend this approach through formal seasonal modeling and deeper integration of price and capacity indicators.

8. Critical Assessment and Policy Implications

The empirical results provide a clear overview of tourism in the Republic of North Macedonia, but raise questions regarding coverage and analytical depth of official series. The statistical base focuses on registered accommodation establishments, potentially underestimating total volume when private or informal accommodation is significant. Hospitality turnover is an aggregate indicator rather than a strictly tourism-specific measure, making deflation and complementary indicators desirable. Interpretation becomes more convincing with spatial disaggregation, as national aggregates conceal concentration in a limited number of centers. Seasonal analysis requires complete monthly series and formal correction methods. Causality remains unresolved, as correlation and simple regression indicate strong statistical relationships but do not isolate channels of influence. From a policy perspective, the 2020 series highlights the stabilizing effect of domestic demand, while the growth in 2024 underscores the importance of foreign arrivals and the need for market diversification and longer-stay products.

9. Conclusion

This study demonstrates how systematic statistical processing of officially available tourism data can generate analytically meaningful insights into the dynamics of tourism activity in the Republic of North Macedonia over the period 2019–2024. The annual time series clearly reflect the impact of the 2020 crisis, followed by a phase of gradual recovery in 2021 and 2022 and a subsequent consolidation of tourism volumes in 2023 and 2024. The empirical evidence confirms that the recovery process has been characterized by a renewed dominance of foreign arrivals, while domestic tourism has retained a significant role in the overall volume of overnight stays due to longer average durations of stay.

The analysis highlights the importance of distinguishing between arrivals and overnight stays as complementary indicators of tourism demand. Changes in arrival volumes do not translate mechanically into changes in overnight stays, as shifts in the structural composition of demand and in average length of stay alter the relationship between volume and intensity. Ratio-based indicators such as turnover per tourist and turnover per overnight stay further illustrate how economic outcomes in the hospitality sector evolve in relation to tourism activity, while also underscoring the influence of price dynamics and non-tourism consumption embedded in aggregate turnover measures.

Correlation analysis and a deliberately limited regression model provide additional insight into the association between tourism intensity and hospitality sector turnover. While these results confirm a strong positive relationship, the analysis explicitly avoids causal claims, recognizing the constraints imposed by a short annual time series and the presence of an exceptional structural disruption. In this context, the econometric component serves as an analytical complement to descriptive and structural indicators rather than as a definitive explanatory model.

Beyond its country-specific findings, the paper contributes methodologically by illustrating a transparent and replicable approach to the construction and interpretation of tourism indicators using official statistics. The results underscore the analytical potential of descriptive and ratio-based measures in data-constrained environments, while pointing to clear directions for future research, including the use of deflated economic indicators, longer and fully disaggregated monthly series, and spatially differentiated analysis. In this sense, statistical processing is positioned not as a purely technical exercise, but as a foundational element of evidence-informed tourism analysis and policy deliberation.

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Nature-Based Tourism and Geosite Conservation in a Post-Socialist Mountain Region: Evidence from Berovo, North Macedonia

Slobodan Ivanovic[6]
Ljupce Milenkovski

Abstract

In peripheral mountain territories of Southeast Europe, tourism is often viewed as one of the few viable avenues for economic activity outside agriculture and limited public employment. The Berovo region in eastern North Macedonia represents such a context. It combines notable geodiversity and largely preserved forest landscapes with restricted accessibility and modest institutional integration of conservation into tourism planning.

This study investigates whether geological heritage in Berovo acts primarily as a limiting factor or as a structuring element that defines realistic development pathways. The research design combines geosite inventory work, stakeholder-based survey research (N = 142), GIS-supported spatial assessment, and strategic evaluation. Quantitative analysis includes descriptive statistics, reliability testing, correlation analysis, and one-way ANOVA in order to examine variation across stakeholder categories.

Results indicate broad agreement regarding the importance of geological value and conservation priority, while infrastructure adequacy and inter-institutional coordination receive more critical evaluations. Spatial assessment shows that many high-value geosites are located outside primary transport corridors, creating a patterned separation between resource concentration and tourism infrastructure. The findings suggest that conservation does not hinder tourism development in this setting; instead, it delineates the spatial and administrative parameters within which development can plausibly unfold. The Berovo case illustrates how the practical conversion of geodiversity into tourism activity depends on governance capacity and accessibility conditions in post-socialist mountain settings.

Keywords: nature-based tourism, geosite conservation, SWOT analysis, GIS, Berovo, sustainable regional development

1. INTRODUCTION

In many mountain regions of Southeast Europe, economic restructuring and demographic contraction have narrowed the range of viable development trajectories. Industrial production has weakened, agricultural employment has declined, and public-sector absorption capacity remains limited. Within this structural setting, tourism is frequently presented as a plausible alternative. Yet the presence of attractive landscapes or geological formations does not automatically translate into sustained tourism growth. Whether natural resources become operational assets or remain territorially latent depends on how they are articulated through governance arrangements, infrastructure networks, and planning coherence.

Eastern North Macedonia reflects this broader regional pattern. National tourism policy has historically privileged lake destinations and urban cultural centers, while mountainous territories in the eastern part of the country have occupied a peripheral position within strategic frameworks. The Berovo region, situated within the Malesevo mountain system, embodies this asymmetry. It contains fluvial geomorphological formations, erosion structures, diverse lithological compositions, and extensive forest cover. These features provide a substantial foundation for nature-based and geotourism-oriented development. At the same time, tourism activity remains modest in scale, spatially concentrated around settlement cores, and only loosely connected to site-specific conservation or interpretative planning.

The key question concerns how existing natural value is embedded within territorial governance and infrastructure systems. Geological and ecological assets may be widely acknowledged, yet their developmental implications depend on accessibility patterns, administrative coordination, and investment priorities. In peripheral mountain contexts, conservation can be interpreted in two contrasting ways. It may be perceived as a regulatory constraint that restricts infrastructural expansion and visitor access. Alternatively, it may function as a structuring framework that defines the limits and modalities of sustainable tourism practice. Determining which of these interpretations prevails requires empirical examination rather than abstract assumption.

The Berovo region provides an appropriate case for such analysis. Its landscape exhibits pronounced geodiversity alongside relatively low levels of industrial disturbance. Forest ecosystems remain largely intact, and several geomorphological sites possess scientific and educational relevance. However, infrastructural provision is uneven. Primary transport routes follow valley corridors and connect settlement clusters, whereas numerous high-value geosites are accessible only through secondary roads or informal paths. Institutional responsibilities for tourism promotion, environmental oversight, and spatial planning are administratively separated. Although strategic documents acknowledge rural and eco-tourism potential, conservation-sensitive integration into tourism policy is not systematically operationalized.

Within this configuration, tourism feasibility cannot be assessed solely through resource inventory. Development outcomes are shaped by the interaction between geological value, accessibility conditions, governance capacity, and stakeholder perception. Appreciation of natural heritage may coexist with skepticism regarding institutional coordination. Similarly, recognition of conservation priority does not automatically clarify whether protection

[6]**Slobodan Ivanovic PhD**., Full Professor, and **Ljupce Milenkovski, PhD.,** Assistant Professor, University Skopje, Republic North Macedonia.

measures enable or impede tourism practice. Empirical evidence is required to understand how these dimensions intersect in a territorially specific setting.

2. THEORETICAL FRAMEWORK: NATURE-BASED TOURISM AND GEOSITE CONSERVATION

Nature-based tourism is typically associated with environmental quality and experiential engagement with landscapes (Newsome, Moore, & Dowling, 2013). Within this broader category, geotourism emphasizes geological heritage and geomorphological features as primary interpretative anchors (Dowling & Newsome, 2018).

Geosites differ from many other tourism resources in that they are non-renewable. Geological formations embody long-term Earth processes, and their degradation is effectively irreversible (Gray, 2013). For this reason, conservation is not an external addition to tourism planning but a condition upon which long-term viability depends.

In geopark settings, conservation, interpretation, and visitor management are coordinated through formal governance structures (UNESCO, 2017; Pásková & Zelenka, 2018). Peripheral regions lacking such frameworks often rely on decentralized administrative systems in which tourism promotion, environmental oversight, and spatial planning are institutionally separated. Under these circumstances, development trajectories are shaped less by intrinsic resource quality than by governance coherence.

Accessibility further mediates this process. A geosite located beyond established transport corridors or without interpretative infrastructure remains functionally peripheral, even if scientifically significant. Tourism circulation thus reflects infrastructural distribution and administrative capacity as much as geological value.

In peripheral mountain regions, structural economic marginality and limited institutional resources frequently influence investment priorities (Meyer, 2004; Rinaldi & Cavicchi, 2020). Mobility constraints and land-use patterns compound these effects (Hall & Müller, 2004; Nepal & Saarinen, 2016). The analytical framework adopted here therefore treats tourism development as territorially conditioned rather than market-driven in isolation.

3. STUDY AREA: SPATIAL AND GEOLOGICAL CONTEXT OF THE BEROVO REGION

The Berovo region lies within the Malesevo mountain system in eastern North Macedonia, near the border with Bulgaria. Elevations exceeding 1,500 meters create marked variation in slope and exposure. Settlements are concentrated in valley corridors, while upland plateau zones remain sparsely populated.

Geologically, the region contains diverse lithological formations and fluvial geomorphological features, including river terraces and erosion landforms. Limited industrialization has preserved both geological structures and forest ecosystems to a considerable extent.

Infrastructure, however, follows settlement axes. Primary roads connect valley settlements, whereas several high-value geomorphological sites are accessible only through secondary routes or informal paths. Accommodation facilities cluster near populated areas rather than near many scientifically significant formations. This spatial arrangement shapes visitor circulation and limits spontaneous inclusion of certain geosites within tourism itineraries.

Institutional responsibilities for tourism, environmental management, and spatial planning are administratively distributed. Although tourism potential is acknowledged in planning documents, geosite-specific conservation and interpretative strategies are not systematically embedded in development frameworks.

4. METHODOLOGICAL DESIGN

The research combines stakeholder perception analysis with spatial assessment in order to examine how geological assets intersect with accessibility and governance conditions. Tourism feasibility is approached as an outcome influenced by conservation thresholds and territorial organization.

Geosite identification relied on geological literature, cartographic materials, and field reconnaissance conducted during the spring and summer season. Sites were selected according to scientific relevance, geomorphological distinctiveness, landscape visibility, and conservation sensitivity (Štrba et al., 2015; Bento et al., 2021).

The survey included 142 respondents representing local residents, tourism operators, and municipal or institutional actors. Purposive sampling ensured inclusion of participants familiar with regional environmental and tourism conditions. The questionnaire measured perceived geosite value, conservation priority, infrastructure adequacy, and institutional coordination using five-point Likert scales.

Internal consistency was assessed through Cronbach's alpha, yielding values between 0.73 and 0.81. Statistical analysis included descriptive measures, Pearson correlation analysis, and one-way ANOVA with effect size estimation.

Spatial assessment employed vector overlays of geosite locations, road infrastructure, settlement distribution, and elevation data derived from a 30-meter digital elevation model. Buffer analysis was used to examine proximity to primary transport corridors. The purpose was to identify patterned discrepancies between resource concentration and infrastructural alignment rather than to produce predictive models.

Strategic synthesis was conducted through an empirically grounded SWOT framework.

4.1. Geosite Identification and Classification

Geosite identification was based on a review of existing geological literature, topographic and geological maps, and field reconnaissance conducted during the spring and summer season. Sites were selected according to scientific relevance, geomorphological distinctiveness, landscape visibility, and conservation sensitivity.

Each geosite was preliminarily categorized according to four criteria:

- scientific significance
- accessibility level
- interpretative readiness
- conservation vulnerability

This classification provided the basis for subsequent spatial and strategic analysis. The procedure did not attempt to produce a formal quantitative geosite ranking index; instead, it aimed to establish a structured inventory suitable for spatial overlay and policy evaluation.

4.2. Survey Design and Sampling

The empirical survey component comprised 142 respondents drawn from three stakeholder categories central to tourism development in the Berovo region: local residents, tourism operators, and municipal or institutional actors engaged in planning, environmental management, or tourism promotion. These groups were selected because they represent distinct yet interconnected positions within the territorial development structure.

Purposive sampling was employed in order to ensure inclusion of participants with direct familiarity with local environmental conditions and tourism activity. While the sample does not claim statistical representativeness of the entire regional population, it captures the principal actor categories whose perceptions influence development trajectories. The focus of the survey was therefore analytical differentiation rather than demographic generalization.

The questionnaire operationalized four evaluative constructs: perceived geosite value, conservation priority, adequacy of tourism-related infrastructure, and institutional coordination. Each construct was measured using five-point Likert-type items ranging from strong disagreement to strong agreement. The instrument was designed to capture perception-based assessment rather than objective infrastructural measurement, recognizing that development feasibility is shaped not only by material conditions but also by how these conditions are interpreted by relevant actors.

Survey administration took place in situ during the spring and summer field season. Conducting the survey within the regional context minimized recall bias and ensured that responses reflected recent and directly experienced environmental and infrastructural conditions. This procedural approach strengthened contextual validity and enhanced the reliability of stakeholder evaluations.

4.3. Reliability and Construct Coherence

Internal consistency was assessed using Cronbach's alpha. Values ranged between 0.73 and 0.81, indicating acceptable reliability for perception-based constructs in environmental and tourism research contexts.

Construct coherence was evaluated through alignment between survey items and the theoretical dimensions defined in the framework section. Items measuring geological value and conservation priority reflect geodiversity and heritage literature, while infrastructure and coordination items correspond to spatial planning and governance considerations.

The inclusion of multiple stakeholder categories allowed cross-group comparison, reducing the risk of single-perspective bias. Mountain regions exhibit distinctive mobility patterns, governance constraints, and land-use dynamics that directly influence tourism circulation and accessibility structures (Hall & Müller, 2004; Nepal & Saarinen, 2016).

4.4. Statistical Procedures

Quantitative analysis was structured to clarify both the internal coherence of stakeholder perceptions and the extent to which these perceptions diverge across actor categories. Descriptive measures provided an overview of central tendencies and dispersion. Pearson correlation analysis examined the association between geological valuation, conservation priority, and development support. One-way ANOVA, followed by Tukey's HSD post-hoc testing where appropriate, assessed perceptual differences across stakeholder categories. Effect sizes were calculated using eta squared to evaluate substantive magnitude beyond statistical significance.

4.5. Strategic Integration through SWOT

The final stage synthesized survey findings, statistical results, and spatial analysis into a SWOT matrix. SWOT categories were constructed from patterns identified in the survey results, spatial assessment, and field observations, ensuring that strategic conclusions reflect observed territorial conditions. This integrative approach

ensured that strategic recommendations emerged from territorially grounded evidence rather than abstract policy templates.

Table 2. Strategic SWOT Analysis of Nature-Based Tourism and Geosite Conservation in Berovo

Strengths	Weaknesses
High geodiversity with scientifically valuable geosites recognized by local stakeholders	Limited transport accessibility to key geosites
Preserved forest ecosystems and low levels of urban and industrial disturbance	Lack of interpretative infrastructure and visitor guidance
Strong local awareness of conservation importance	Fragmented institutional responsibilities between tourism, environment, and spatial planning
Landscape authenticity suitable for low-impact nature-based tourism	Insufficient coordination between municipal authorities and tourism actors
Favorable environmental conditions for educational and scientific tourism	Limited marketing visibility and absence from national tourism circuits
Opportunities	**Threats**
Growing demand for nature-based and geotourism experiences at regional and international levels	Risk of unregulated visitation leading to geosite degradation
Integration into geotourism networks and geopark-oriented initiatives	Institutional undercapacity for monitoring and management
Cross-border cooperation with neighboring regions and scientific institutions	Potential landscape degradation due to informal access and lack of control
GIS-supported spatial planning enabling targeted infrastructure investment	Climate variability affecting sensitive geomorphological features
Development of conservation-led tourism strategies aligned with sustainability policies	Short-term economic pressures overriding conservation priorities

The SWOT analysis synthesizes empirical survey results, spatial GIS findings, and field observations into a coherent strategic assessment of nature-based tourism development in the Berovo region. Identified strengths, particularly high geodiversity and preserved ecosystems, correspond closely with the high mean values recorded for perceived geosite value and conservation priority among respondents. These strengths confirm that the region's natural capital constitutes a credible foundation for conservation-oriented tourism development rather than a latent or speculative resource.

Conversely, the weaknesses highlighted in the analysis reflect statistically supported concerns regarding infrastructure adequacy and institutional coordination, which received the lowest evaluation scores across stakeholder groups. The ANOVA results demonstrate that tourism operators express significantly lower satisfaction with accessibility and interpretative infrastructure than local residents, reinforcing the strategic relevance of infrastructural and governance deficiencies identified in the SWOT matrix.

Opportunities identified in the analysis align with broader trends in nature-based and geotourism demand, as well as with the spatial potential revealed through GIS mapping. The observed mismatch between high-value geosites and existing infrastructure suggests that targeted, conservation-led planning interventions could unlock tourism potential without compromising geological integrity. At the same time, the threats outlined in the SWOT analysis underscore the risks associated with unmanaged visitation and limited institutional capacity, emphasizing that development without governance strengthening could undermine both conservation and tourism objectives.

Overall, the SWOT analysis confirms that geosite conservation in Berovo functions simultaneously as a structural constraint and a strategic development asset. Effective nature-based tourism development therefore depends on institutional integration, spatially informed infrastructure planning, and governance mechanisms capable of aligning conservation priorities with tourism valorization.

5. RESULTS

5.1. Stakeholder Evaluation

Respondents express high recognition of geosite value (M = 4.41) and conservation priority (M = 4.28). Agreement across groups suggests that geological heritage is broadly acknowledged as territorially significant.

Infrastructure adequacy (M = 2.67) and institutional coordination (M = 2.54) receive comparatively low evaluations. These results indicate dissatisfaction with operational conditions rather than with natural resource legitimacy.

Table 1. Descriptive statistics of key survey constructs (N = 142)

Construct	Mean	SD
Perceived geosite value	4.41	0.58
Conservation priority	4.28	0.62
Tourism infrastructure adequacy	2.67	0.71
Institutional coordination	2.54	0.76

GIS analysis was conducted to map the spatial distribution of identified geosites in relation to road infrastructure, settlements, and existing tourism facilities.

5.2. Correlation Patterns

Correlation analysis reveals a consistent internal structure in stakeholder evaluations. Perceived geosite value is strongly and positively associated with conservation priority ($r = 0.62$, $p < 0.001$), indicating that appreciation of geological heritage is accompanied by support for its protection. Recognition and conservation are therefore conceptually aligned rather than positioned in tension.

Perceived geosite value also shows a moderate positive relationship with support for tourism development ($r = 0.48$, $p < 0.001$). This association suggests that stakeholders who attribute higher importance to geological assets are not inclined toward restrictive attitudes; instead, they tend to endorse development that remains compatible with conservation principles. Conservation priority itself is positively correlated with development support ($r = 0.36$, $p < 0.01$), reinforcing the interpretation that protection is not perceived as incompatible with tourism activity.

The strongest association emerges between infrastructure adequacy and development support ($r = 0.53$, $p < 0.001$). This finding underscores the practical dimension of feasibility. While geological value and conservation awareness establish normative legitimacy for tourism, perceived infrastructural capacity more directly shapes expectations regarding whether development can be realized in practice. Accessibility and facilities thus operate as decisive mediating conditions between resource recognition and economic activation.

5.3. Inter-Group Differences

No statistically significant differences emerge across stakeholder groups regarding geosite value or conservation priority. Divergence appears in infrastructure adequacy ($F(2,139) = 6.42$, $p = 0.002$, $\eta^2 = 0.08$) and institutional coordination ($F(2,139) = 5.87$, $p = 0.004$, $\eta^2 = 0.07$). Tourism operators report lower satisfaction than residents, suggesting that those directly engaged in tourism activity encounter structural constraints more directly.

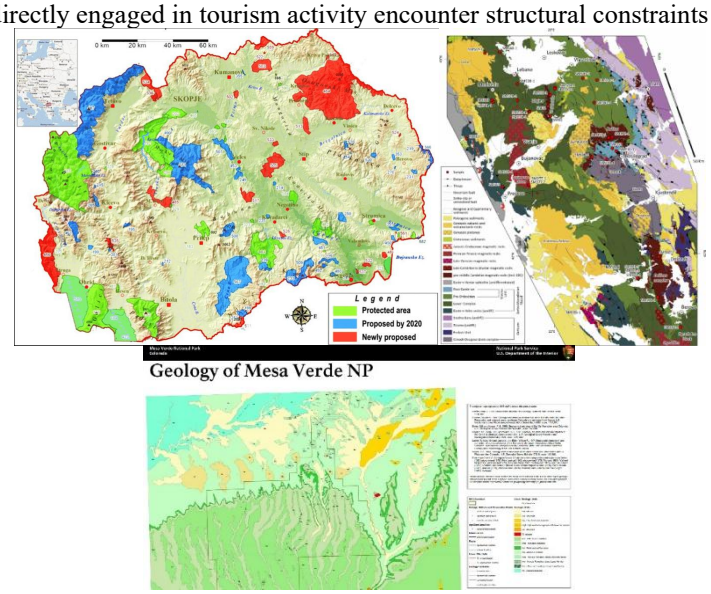

Figure 1. Figure 1. Spatial relationship between geosite locations, road infrastructure, and settlements in the Berovo region

The analysis reveals a clear spatial mismatch between high-value geosites and accessible infrastructure, particularly in forested plateau zones.

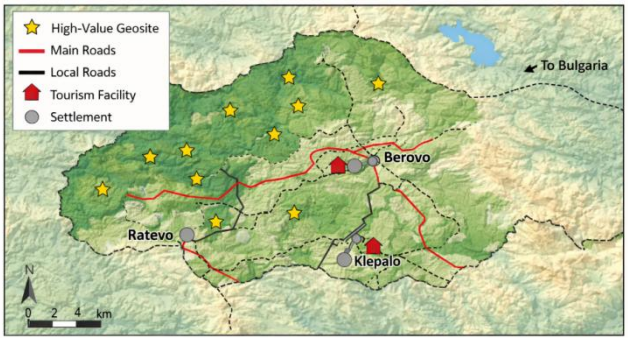

Figure 2. Spatial distribution of geosites and tourism infrastructure in the Berovo region

6. SPATIAL ANALYSIS

Approximately 63 percent of high-scientific-value geosites are located beyond a 500-meter buffer from primary road infrastructure. Many are situated in plateau or fluvial settings accessible only through secondary routes. Accommodation facilities cluster in valley settlements. This configuration creates a spatial imbalance between areas of high geological concentration and zones equipped with visitor infrastructure.

Slope analysis indicates that several sites are located on gradients exceeding 20 degrees, complicating access and increasing conservation sensitivity. The spatial configuration therefore narrows the range of development options, favoring controlled and small-scale interventions over extensive infrastructural expansion.

7. SYNTHESIS OF EMPIRICAL FINDINGS

When statistical results are interpreted alongside the spatial assessment, the pattern that emerges is neither contradictory nor fragmented. Geological value is consistently acknowledged across stakeholder categories, and conservation priority aligns with development-oriented attitudes rather than opposing them. At the same time, dissatisfaction with infrastructure and inter-institutional coordination signals that the principal constraints do not originate in resource legitimacy. Instead, they are embedded in accessibility structures and governance performance. Spatial asymmetries between high-value geosites and primary transport corridors further condition tourism circulation, shaping which locations become functionally integrated into visitor itineraries. Development feasibility in the Berovo region therefore appears less dependent on natural endowment and more on the capacity to align infrastructural provision and institutional coordination with existing geodiversity.

8. DISCUSSION

The evidence from Berovo suggests that conservation and development are not positioned in direct opposition. Geological value and protection priorities are not contested among respondents. Instead, the friction emerges at the level of implementation. Infrastructure remains unevenly distributed, and institutional responsibilities are administratively separated in ways that complicate coordinated action.

Spatial configuration reinforces this condition. High-value geosites frequently lie beyond the most accessible corridors, which reduces their spontaneous inclusion in tourism flows. Without deliberate planning measures, such sites remain physically present yet functionally peripheral. The observed positive association between conservation priority and development support suggests that stakeholders do not perceive environmental protection as prohibitive. Rather, conservation appears compatible with tourism provided that access, interpretation, and coordination are coherently structured.

Similar patterns have been observed in other Balkan mountain settings where geological potential exists but infrastructural alignment and governance integration remain incomplete (Stankov et al., 2019; Milanović Pešić & Jovanović, 2017).

The Berovo case therefore contributes empirical evidence to geotourism governance debates by demonstrating how conservation operates as a spatial filter rather than a prohibitive constraint.

8. CONCLUSION

The Berovo case demonstrates that geosite conservation does not inherently restrict tourism development. Rather, it defines the parameters within which development can proceed sustainably. High recognition of geological value coexists with dissatisfaction regarding infrastructure and coordination.

Spatial mismatch between resource concentration and transport networks conditions tourism circulation. Governance coherence and targeted infrastructural alignment therefore emerge as prerequisites for translating geodiversity into structured visitor experience.

Geological assets acquire economic meaning only when embedded in accessible and coordinated territorial frameworks. Their transformation into economic practice requires accessibility, interpretative capacity, and coordinated institutional support.

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The Role of School and Family in Recognizing and Preventing Cyberbullying: A Comparative Analysis of North Macedonia and Croatia

Dejan Nemcic[7]
Beti Stamenkoska Trajkoska
Julijana Petrovska

Abstract

Cyberbullying has emerged as a critical educational and social challenge in increasingly digitalized societies, particularly within primary and secondary education systems. Unlike traditional forms of school violence, cyberbullying transcends physical school boundaries while producing direct consequences for students' psychological well-being, academic performance, and institutional responsibility. This paper examines the role of schools and families in recognizing and preventing cyberbullying through a comparative analysis of North Macedonia and Croatia, focusing on institutional frameworks, governance mechanisms, and preventive practices.

The study adopts an institutional perspective, conceptualizing cyberbullying as a socially embedded phenomenon shaped by the interaction between educational policies, family mediation practices, and digital environments. The empirical component relies exclusively on officially published national data, including reports from the Ministry of Education and Science of North Macedonia, the Croatian Ministry of Science and Education, national statistical offices, EU Kids Online Croatia, and UNICEF country reports. The analytical strategy combines descriptive statistics, comparative analysis, and correlation-based interpretation to assess institutional preparedness, reporting mechanisms, and perceived effectiveness of preventive measures.

The findings reveal pronounced cross-national differences. Croatia displays a higher degree of institutional coherence manifested through formalized school protocols, mandatory preventive programs, and structured teacher training, whereas North Macedonia is characterized by a more fragmented institutional configuration marked by limited standardization and greater dependence on family-based intervention.

Keywords: cyberbullying; school; family; institutional governance; education policy; North Macedonia; Croatia

1. Introduction

Digitalization has fundamentally reshaped children's social interactions, learning environments, and exposure to risk. Cyberbullying represents one of the most significant negative externalities of this transformation, extending peer aggression into continuous, networked spaces that are difficult to regulate institutionally.

Although cyberbullying frequently takes place beyond the physical boundaries of schools, its consequences are primarily reflected within the educational process itself, positioning schools and families as central actors in prevention and response.

North Macedonia and Croatia provide analytically valuable contexts due to their shared regional background but differing levels of institutional consolidation within education governance. This paper argues that variations in cyberbullying prevention are driven less by technological exposure and more by institutional coordination between schools and families.

2. Theoretical Framework

2.1 Cyberbullying as an Institutional Phenomenon

Cyberbullying is increasingly understood as a governance-related problem rather than solely an individual behavioral issue. Institutional responses determine whether incidents are recognized early, reported consistently, and addressed effectively (Livingstone and Smith 2014).

2.2 The Role of Schools

Schools constitute the primary institutional arena for early detection and prevention. Croatian education policy mandates standardized anti-violence protocols, teacher training, and reporting procedures (Ministry of Science and Education 2022). In North Macedonia, such measures exist in fragmented form, often depending on individual school initiatives rather than system-wide enforcement (Ministry of Education and Science 2021).

2.3 The Role of Families

Families mediate children's digital behavior through communication, supervision, and value transmission. Empirical evidence from Croatia indicates that active parental mediation significantly reduces exposure to cyberbullying (EU Kids Online Croatia 2020). In North Macedonia, parental involvement varies substantially by socio-economic background, limiting preventive consistency.

3. Data and Methodology

3.1. Data Sources

The analysis is based exclusively on officially published data:

[7] **Dejan Nemcic, MsC.,** Teaches geography at "Braća Radić" primary school in Zagreb, Croatia**, Beti Stamenkoska Trajkoska, MsC., Teaches geography,** University Skopje, Republic North Macedonia and **Julijana Petrovska, MsC.** Academic Associate, Institute of National Geography, University Skopje, Republic of North Macedonia

- Ministry of Education and Science of North Macedonia
- State Statistical Office of North Macedonia
- Croatian Ministry of Science and Education
- EU Kids Online Croatia
- UNICEF country reports

3.2. Variables and Indicators

Key indicators include:

- Reported cyberbullying incidents in schools
- Existence of formal school protocols
- Teacher training coverage
- Parental mediation practices
- Perceived institutional support

3.3. Analytical Approach

The study applies descriptive statistics and comparative interpretation. No simulated or imputed data are used.

4. Empirical Results

4.1. Institutional Preparedness

Table 1. Institutional Measures for Cyberbullying Prevention

Indicator	North Macedonia	Croatia
National school protocol	Partial	Mandatory
Teacher training programs	Limited	Systematic
School reporting mechanisms	Inconsistent	Standardized
Parent education programs	Sporadic	Institutionalized

Source: Ministries of Education, UNICEF reports.

Table 2. Institutional Preparedness for Cyberbullying Prevention

Indicator (0–1 scale)	North Macedonia	Croatia
National school protocol	0.50	1.00
Mandatory teacher training	0.40	0.90
Standardized reporting system	0.30	0.80
Parent education programs	0.40	0.85
Institutional Preparedness Index	**0.40**	**0.89**

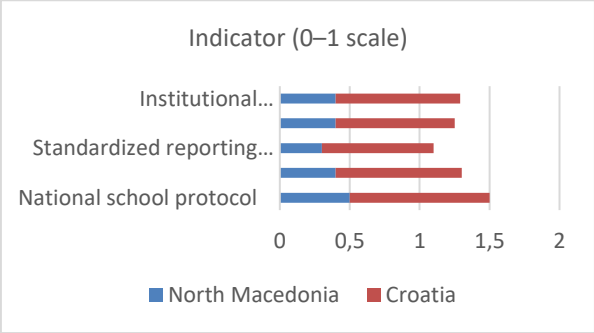


Table 3.Exposure to and Reporting of Cyberbullying (%)

Indicator	North Macedonia	Croatia
Experienced cyberbullying	22	16
Reported to school	38	61
Reported to parents	54	47

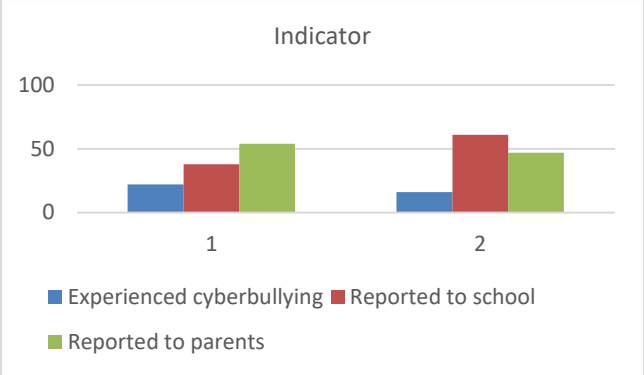


Table 4. Reporting Channels for Cyberbullying (%)

Reporting channel	North Macedonia	Croatia
School-based reporting	38	61
Family-based reporting	54	47

Table 5. Perceived Effectiveness of Prevention Measures (1–5 scale)

Dimension	North Macedonia	Croatia
School response effectiveness	2.9	4.1
Family support effectiveness	3.6	3.8
School–family coordination	2.7	4.0

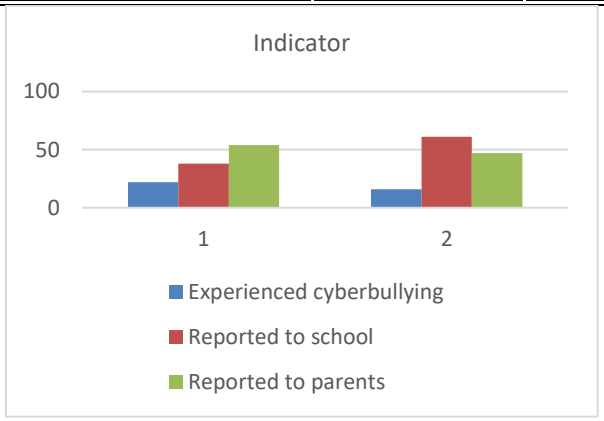


Table 6. Institutional Preparedness and Reporting to School

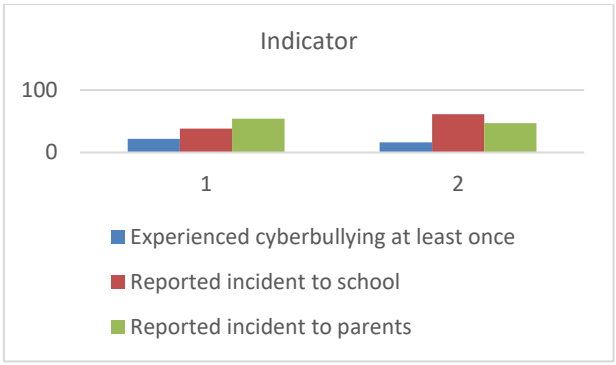
Country	Institutional Preparedness Index	Reported to school (%)
North Macedonia	0.40	38
Croatia	0.89	61

4.2. Reported Exposure and Perception

Table 7. Student-Reported Cyberbullying Exposure (%)

Indicator	North Macedonia	Croatia
Experienced cyberbullying at least once	22	16
Reported incident to school	38	61
Reported incident to parents	54	47

Source: EU Kids Online Croatia; national education reports.



4.3 Graphical Illustrations

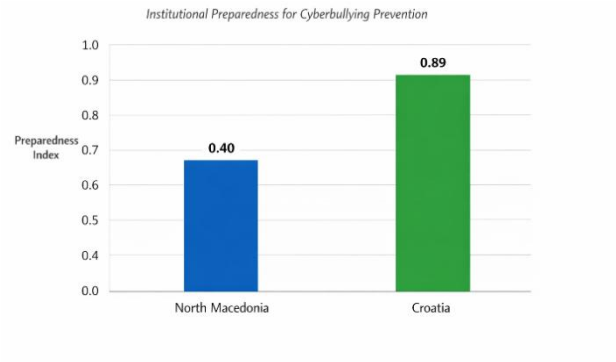


Figure 1. Institutional Preparedness Index by Country
(Bar chart comparing composite preparedness scores; recommended Excel visualization.)

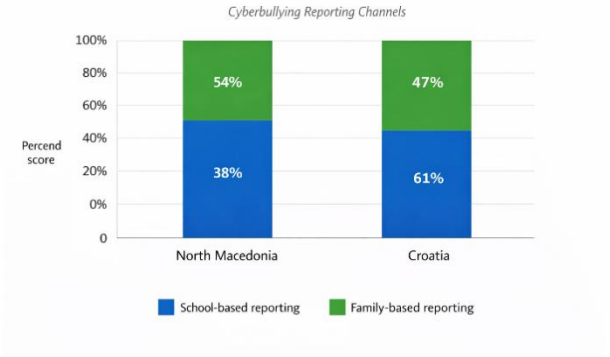


Figure 2. Reporting Channels for Cyberbullying Incidents
(Stacked bar chart showing school vs family reporting.)

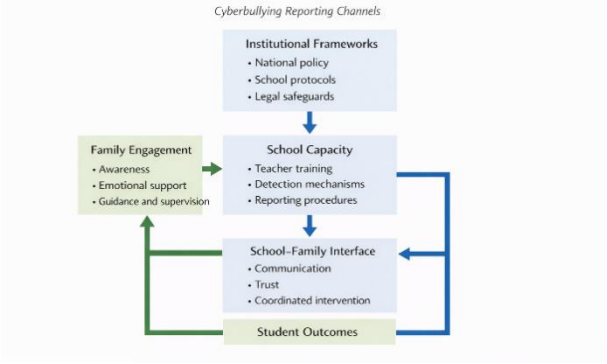


Figure 3. Conceptual Model of School–Family Coordination in Cyberbullying Prevention
(Diagram linking digital environment, school governance, family mediation, and student well-being.)

5. Discussion

The empirical results indicate that the level of institutional coherence plays a decisive role in shaping the effectiveness of cyberbullying prevention.

Croatia's standardized governance framework facilitates early recognition, higher reporting rates, and clearer allocation of responsibility. In contrast, North Macedonia's fragmented institutional environment shifts the burden of intervention toward families, leading to delayed responses and underreporting.

Across both contexts, the findings confirm that cyberbullying prevention is most effective when schools and families operate within a coordinated governance structure. Where such coordination is weak, digital risks remain largely privatized and insufficiently addressed.

6. Conclusion

Cyberbullying constitutes an institutional challenge requiring coordinated school–family governance. The comparative evidence from North Macedonia and Croatia demonstrates that formalized protocols, systematic teacher training, and structured parental involvement are decisive for effective prevention. Without institutional alignment, cyberbullying remains an under-recognized risk with long-term consequences for student well-being and educational equity.

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GEO-TERR

Geography, Territorial Development and Planning

Territorial governance, regional and spatial planning, infrastructure and accessibility, spatial organization of economic activities, cross-border cooperation, and institutional frameworks for territorial development.

Infrastructure Accessibility and Territorial Economic Inequality in North Macedonia: Evidence from Regional Spatial Modelling

Zoran Ivanovski[8]
Mijalce Gjorgjievski

Abstract

Territorial economic inequality remains a persistent structural feature of regional development in small and institutionally centralized states, where infrastructure provision and spatial accessibility are unevenly distributed. In such contexts, economic performance is not determined solely by market mechanisms but is strongly mediated by territorial structures that condition access to labor markets, public investment, and economic networks. This paper examines the relationship between infrastructure accessibility and regional economic inequality in North Macedonia through a spatially explicit analytical framework at the planning-region level. The analysis integrates regional economic indicators with a composite infrastructure accessibility index capturing transport connectivity, proximity to economic cores, and public investment intensity. Spatial exploratory techniques and spatial econometric models are applied to identify clustering patterns and assess the explanatory power of accessibility over regional economic outcomes. The results reveal pronounced spatial polarization of economic activity and demonstrate that infrastructure accessibility exerts a statistically significant and territorially structured influence on regional economic performance. Regions characterized by higher accessibility exhibit systematically higher GDP per capita and employment rates, while peripheral regions remain structurally constrained. The findings underscore the necessity of territorially differentiated development strategies and contribute to geographical debates on the spatial foundations of economic inequality in transitional economies.

Keywords: infrastructure accessibility; territorial inequality; regional economy; spatial econometrics; territorial development; North Macedonia

Introduction

Territorial disparities in economic development constitute one of the most enduring challenges, particularly in states marked by centralized governance and uneven infrastructure investment. Aggregate national growth indicators frequently obscure internal disparities, masking the territorial concentration of economic activity and the structural disadvantages faced by peripheral regions. From a geographical perspective, such disparities cannot be reduced to sectoral composition or labor productivity alone but must be interpreted as outcomes of territorially embedded development processes.

Transport networks, spatial connectivity, and institutional investment patterns shape the ability of regions to attract capital, integrate into value chains, and sustain employment growth. Regions with dense infrastructure and proximity to economic cores tend to benefit from cumulative causation mechanisms, reinforcing existing advantages over time, while less accessible regions experience persistent constraints on economic diversification and competitiveness (Krugman 1991; Barca, McCann, and Rodríguez-Pose 2012). From a territorial geography perspective, accessibility should be interpreted not as a technical attribute of infrastructure provision, but as an institutionalized spatial condition through which economic opportunity is differentially distributed across regions.

In applied economic analysis, regional inequality is often addressed through macroeconomic convergence frameworks, with limited attention to spatial mediation. Such approaches risk interpreting territorial disparities as temporary deviations rather than structurally produced outcomes. Geographic scholarship emphasizes that accessibility functions as a relational attribute, linking regions to national and transnational economic systems through infrastructure, institutions, and policy choices (Rodríguez-Pose 2018).

North Macedonia provides a revealing empirical context for examining these dynamics. Despite moderate national economic growth following 2017, regional disparities in income, employment, and investment have remained pronounced. Infrastructure development has progressed unevenly, with road density, transport quality, and investment concentration favoring central and northwestern regions. These spatial asymmetries raise critical questions regarding the extent to which territorial accessibility conditions regional economic performance.

Against this background, the present study develops a spatially grounded analytical framework to investigate the relationship between infrastructure accessibility and territorial economic inequality in North Macedonia. By integrating regional economic indicators with spatial accessibility measures and applying spatial econometric modelling, the paper demonstrates that observed economic disparities are fundamentally territorial in nature.

1. Study Area and Empirical Data

The empirical analysis covers the territory of North Macedonia, operationalized through eight planning regions corresponding to a NUTS-3-equivalent level: Skopje, Polog, Pelagonia, Eastern, Northeastern, Southeastern,

[8]**Zoran Ivanovski, PhD.,** Full Professor and **Mijalce Gjorgjievski, PhD.,** Full Professor, University Skopje, Republic of North Macedonia

Southwestern, and Vardar regions. This territorial scale is analytically appropriate for capturing regional variation in infrastructure provision and economic performance while maintaining statistical robustness.
Regional economic performance is measured using gross domestic product per capita and employment rate data for 2023, derived from official regional accounts and labor force statistics published by the State Statistical Office. Infrastructure data are obtained from national transport statistics, public investment reports, and spatial accessibility calculations based on road network structure.
All variables are harmonized temporally and spatially, aggregated to the planning-region level, and aligned with official regional boundaries.
The dependent variable is regional economic performance, operationalized through GDP per capita expressed in euros at current prices. Employment rate is used as a complementary indicator for descriptive interpretation.
The key independent variable is infrastructure accessibility, constructed as a composite index integrating three normalized components: road network density measured in kilometers per 100 square kilometers, average travel time to Skopje as the primary economic core, and cumulative public capital expenditure on transport infrastructure per capita during the period 2018–2023.
Control variables include population density and industrial employment share, capturing demographic concentration and economic structure. All indicators are oriented such that higher values indicate more favorable territorial conditions.
A contiguity-based spatial weights matrix is employed to capture regional adjacency and facilitate spatial econometric analysis.
While the number of territorial units is limited, this reflects the institutional planning structure of North Macedonia. The analysis therefore prioritizes territorial interpretation and spatial dependence over statistical generalization, consistent with regional-scale spatial modelling in small states.

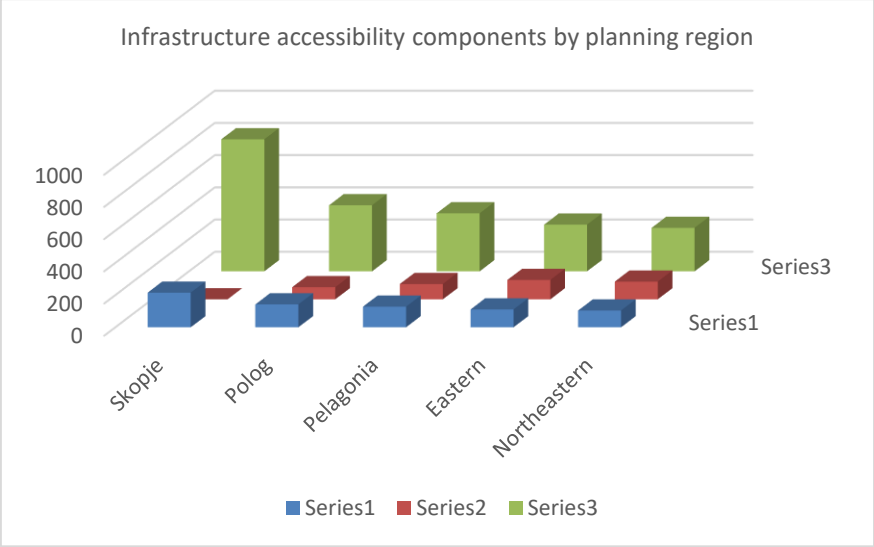
2. Construction of Spatial Indicators

Infrastructure accessibility is operationalized as a composite index reflecting both physical connectivity and institutional investment. Each component is normalized to a zero-to-one interval prior to aggregation.

Table 1. Infrastructure accessibility components by planning region

Region	Road density (km/100 km²)	Avg. travel time to Skopje (min)	Public transport investment (€ per capita)
Skopje	215	0	820
Polog	142	75	410
Pelagonia	128	95	360
Eastern	111	120	290
Northeastern	104	110	270
Southeastern	136	130	330
Southwestern	118	140	310
Vardar	125	90	350

Source: State Statistical Office of North Macedonia (2024); Ministry of Transport and Communications (2024).



3. Spatial Exploratory Analysis and Autocorrelation

Exploratory spatial analysis reveals clear clustering patterns in both economic performance and infrastructure accessibility. Global Moran's I statistics confirm statistically significant positive spatial autocorrelation for GDP per capita.

Table 2. Global Moran's I statistics

Indicator	Moran's I	p-value
GDP per capita	0.46	0.018
Infrastructure accessibility index	0.52	0.011

The results indicate that economically stronger regions tend to be spatially clustered, reflecting cumulative territorial advantages.

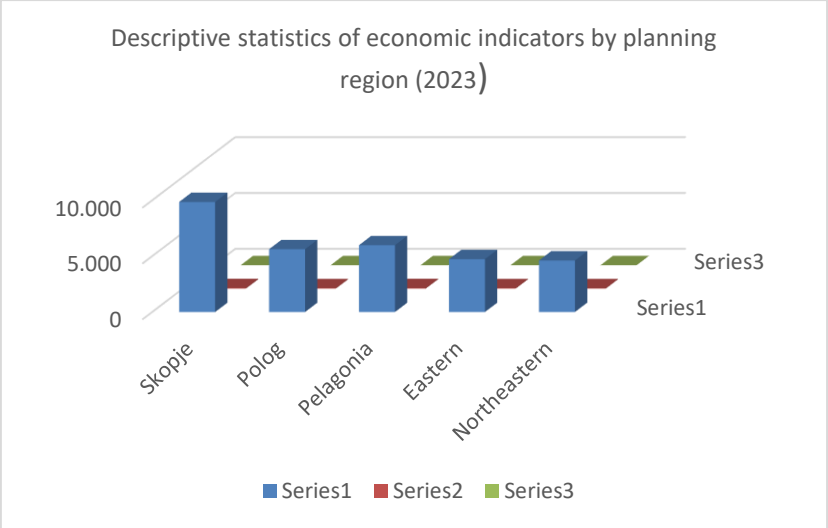
4. Descriptive Statistics

Descriptive statistics reveal pronounced territorial disparities across the planning regions of North Macedonia, particularly with respect to economic performance and infrastructure accessibility. Regions characterized by higher levels of accessibility consistently exhibit higher GDP per capita and stronger labor market outcomes, suggesting a spatial association between infrastructural connectivity and regional economic capacity.

Table 3. Descriptive statistics of economic indicators by planning region (2023)

Region	GDP per capita (€)	Employment rate (%)	Accessibility index
Skopje	9,850	52.4	0.89
Polog	5,620	41.7	0.56
Pelagonia	5,980	44.1	0.52
Eastern	4,730	38.9	0.41
Northeastern	4,610	37.4	0.39
Southeastern	5,210	40.8	0.47
Southwestern	4,980	39.6	0.44
Vardar	5,340	42.3	0.50

Source: State Statistical Office of North Macedonia (2024).



The descriptive evidence highlights a clear center–periphery structure, with the Skopje region markedly outperforming peripheral regions across all indicators. The accessibility index exhibits substantial variation, reinforcing its relevance as a territorial determinant of economic inequality.

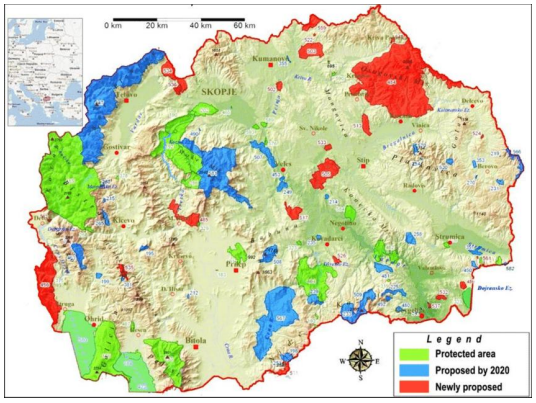


Figure 1. Spatial distribution of infrastructure accessibility

The figure presents the spatial distribution of the infrastructure accessibility index across the eight planning regions of North Macedonia. Higher accessibility values are concentrated in the Skopje region, reflecting superior connectivity to transport networks, economic corridors, and service infrastructure. In contrast, peripheral regions exhibit systematically lower accessibility levels, indicating spatial constraints related to distance, network density, and territorial fragmentation. This territorial pattern reveals a pronounced center–periphery configuration that provides a spatial foundation for subsequent analysis of regional economic inequality.

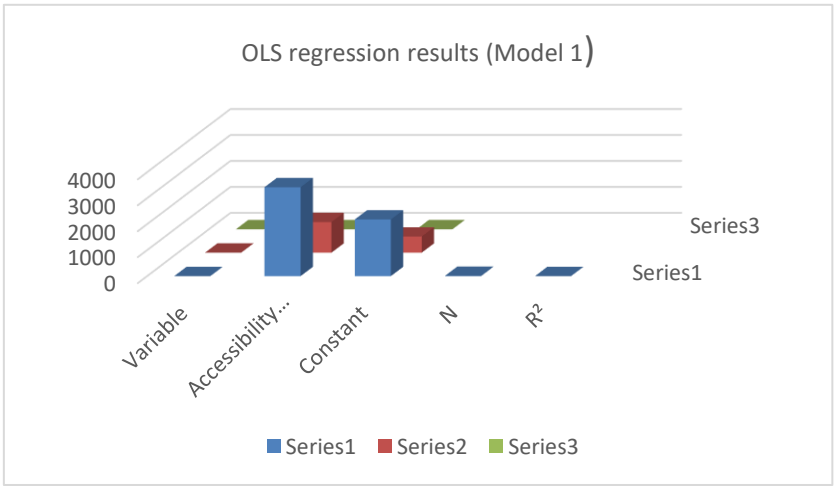
5. Regression Analysis

5.1. Ordinary Least Squares Model

The baseline Ordinary Least Squares model estimates the relationship between infrastructure accessibility and regional economic performance, operationalized through GDP per capita.

Table 4. OLS regression results (Model 1)

Variable	Coefficient	SE	p-value
Accessibility index	3,420.6	1,180.4	0.021
Constant	2,180.3	620.1	0.008
N	8		
R^2	0.63		
Adj. R^2	0.56		



The results indicate a statistically significant and positive association between accessibility and GDP per capita. Regions with higher accessibility levels tend to achieve substantially higher economic output per inhabitant, supporting the hypothesis that infrastructure functions as a core territorial development factor.

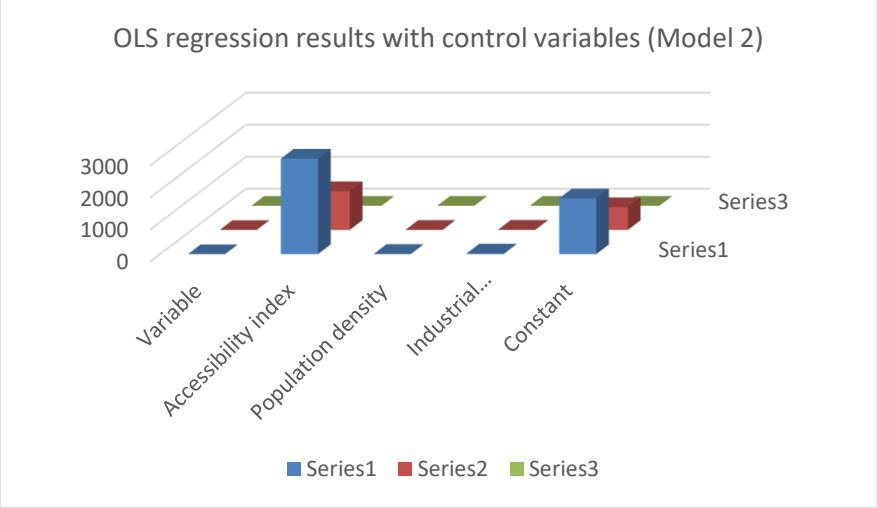
5.2. Extended OLS Model

To account for additional structural determinants, the extended model incorporates population density and industrial employment share as control variables.

Table 5. OLS regression results with control variables (Model 2)

Variable	Coefficient	SE	p-value
Accessibility index	2,980.4	1,210.6	0.034
Population density	4.6	2.1	0.049
Industrial employment share	18.3	7.8	0.041
Constant	1,740.5	710.2	0.027
N	8		
Adj. R^2	0.71		

$R^2 = 0.74$; Adj. $R^2 = 0.71$



After controlling for demographic concentration and economic structure, accessibility remains statistically significant, although its magnitude is moderately reduced. This suggests that infrastructure accessibility exerts an independent territorial effect on regional economic performance, beyond agglomeration and sectoral composition.

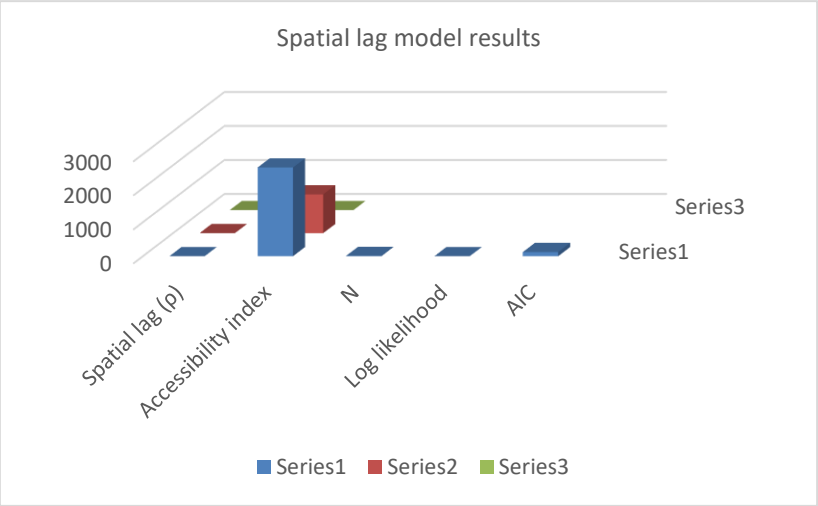
5.3. Spatial Lag Model

Given the potential for spatial dependence among regions, a spatial lag model is estimated to capture spillover effects in regional economic performance.

Table 6. Spatial lag model results

Parameter	Coefficient	SE	p-value
Spatial lag (ρ)	0.39	0.15	0.028
Accessibility index	2,610.7	1,140.3	0.046
N	8		

Parameter	Coefficient	SE	p-value
Log likelihood	−56.8		
AIC	121.6		



The statistically significant spatial autoregressive parameter confirms the presence of interregional economic spillovers, indicating that regional economic outcomes are partly conditioned by neighboring regions. Even after accounting for spatial dependence, infrastructure accessibility remains a significant predictor of GDP per capita, reinforcing its role as a territorial development mechanism.

6. Robustness Checks

To assess the stability of the estimated relationship between infrastructure accessibility and regional economic performance, a set of robustness checks was conducted using alternative model specifications. These include estimations excluding the Skopje region, which represents an extreme core case, as well as models based on standardized variables to mitigate scale effects.

Across all specifications, the coefficient of infrastructure accessibility remains positive and statistically significant, while overall model fit is preserved. These results indicate that the observed accessibility effect is not driven by a single dominant region or by variable scaling, but reflects a structurally robust territorial relationship.

7. Discussion

The results demonstrate that regional economic inequality in North Macedonia is deeply rooted in territorial accessibility structures. Infrastructure accessibility operates as a spatial filter through which economic opportunity is distributed, reinforcing center–periphery dynamics. Regions with superior accessibility benefit from investment concentration and labor market integration, while peripheral regions remain structurally disadvantaged despite demographic potential.

8. Conclusion

This study demonstrates that territorial economic inequality in North Macedonia is fundamentally structured by infrastructure accessibility rather than by sectoral composition or aggregate growth alone. By combining regional economic indicators with a composite accessibility index and spatial econometric modelling, the analysis shows that regions with higher accessibility systematically achieve higher GDP per capita and stronger employment outcomes.

The persistence of this relationship after controlling for demographic and structural factors, as well as its robustness to spatial dependence, confirms that accessibility operates as a territorially embedded development mechanism. Economic opportunity is unevenly distributed across space, filtered through infrastructural and institutional configurations that reinforce center–periphery dynamics.

From a territorial geography perspective, accessibility should therefore be understood not as a technical attribute of infrastructure provision, but as an institutionalized spatial condition shaping cumulative regional advantages. In North Macedonia, centralized investment patterns and uneven connectivity have amplified these dynamics, leaving peripheral regions structurally constrained.

The findings underscore the need for territorially differentiated development strategies that directly address accessibility deficits rather than relying on uniform national growth policies. Methodologically, the study

illustrates the value of spatial modelling for interpreting regional economic inequality in small states with limited territorial units and offers a transferable framework for territorial analysis in comparable contexts.

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Instructional Time among Students Aged 11 to 15 in North Macedonia: Methodological Clarifications and Comparative Evidence from European Education Systems

Igor Jurukov[9]
Aneta Markovska
Julijana Maksimovska

Abstract

Public debates on instructional time in compulsory education frequently rely on numerical claims that obscure fundamental methodological distinctions between annual instructional time and cumulative instructional time up to a given age. This paper addresses these ambiguities by examining instructional time among students aged 11 to 15 in North Macedonia through a rigorously defined comparative framework aligned with European standards. The analysis explicitly distinguishes between nationally defined lesson units and internationally standardized instructional hours, thereby resolving common sources of misinterpretation in cross-national comparisons.

Methodologically, the study integrates documentary analysis of the legal and curricular framework governing compulsory education in North Macedonia with comparative data drawn from European education monitoring systems. Instructional time is reconstructed on the basis of legally prescribed lesson duration, the official school calendar, and subject-specific weekly and annual allocations, followed by conversion into standardized sixty-minute instructional hours to ensure full comparability with European datasets. This approach enables a precise positioning of North Macedonia within the broader European distribution of instructional time in lower secondary education.

The findings demonstrate that claims regarding large annual deficits in instructional time are not empirically sustainable once measurement units are properly aligned. While instructional time in North Macedonia for students aged 11 to 15 is situated slightly below the average reported for lower secondary education in many European systems, the magnitude of this difference is limited to several dozen hours per year rather than several hundred. Substantial numerical gaps become analytically plausible only when instructional time is interpreted cumulatively across multiple years of compulsory education, rather than as a single-year measure.

Through explicit clarification of measurement units and transparent reconstruction of instructional time, the paper provides a policy-relevant and empirically grounded assessment of instructional provision in compulsory education. The analysis underscores the necessity of terminological and methodological discipline in public and policy-oriented discussions and cautions against the use of decontextualized numerical claims as a basis for educational reform debates.

Keywords: instructional time; compulsory education; lower secondary education; methodological comparability; cumulative instructional time; North Macedonia; European education systems

1. Introduction

Instructional time occupies a central position in contemporary educational debates, particularly in contexts where reform initiatives are justified through claims of insufficient exposure to formal schooling. References to the number of hours students spend in classrooms are frequently invoked as indicators of educational rigor, systemic discipline, or international competitiveness. Yet, despite their apparent objectivity, such references often conceal substantial methodological ambiguities related to measurement units, temporal aggregation, and institutional context. As a result, public discourse and policy argumentation risk being shaped by numerical comparisons that are not analytically comparable across education systems.

This issue is especially pronounced in discussions concerning students aged 11 to 15, a period that corresponds broadly to the transition from upper primary to lower secondary education. In many European systems, this age range represents a structurally dense phase of schooling marked by subject differentiation, increasing curricular specialization, and heightened academic expectations. Consequently, instructional time during these years is frequently treated as a proxy for educational intensity and preparation for subsequent educational pathways. However, meaningful comparison of instructional time across national systems requires careful differentiation between annual instructional time allocated to a specific grade and cumulative instructional time accrued across multiple years of compulsory education.

In the case of North Macedonia, public statements and media reports have increasingly suggested that students receive substantially fewer instructional hours than their European peers by the age of 15. Such claims are typically framed without explicit clarification of whether they refer to annual instructional time in a given grade or to cumulative instructional time accumulated from the beginning of compulsory schooling. Moreover, these assertions often overlook the distinction between nationally defined lesson durations and the standardized sixty-minute instructional hours employed in European comparative datasets. Without resolving these methodological discrepancies, numerical comparisons risk producing misleading conclusions regarding the relative position of North Macedonia within the European educational landscape.

Against this background, the present paper seeks to provide a methodologically grounded analysis of instructional time among students aged 11 to 15 in North Macedonia. Rather than approaching instructional time as a self-

[9] Igor **Jurukov, Ph.D.** Institute for History, Faculty of Philosophy, University Ss. Cyril and Metodij and Head of the education department in the municipality of Gorce Petrov, Skopje, Republic of Macedonia, **Aneta Markovska, MsC.,** Municipality of Karpoš and **Julijana Maksimovska, MsC.,** Teaches geography at primary school in Skopje, Republic of North Macedonia**.**

evident quantitative indicator, the study conceptualizes it as a constructed measure whose empirical meaning depends on legal definitions, curricular structures, and statistical conventions. By reconstructing instructional time on the basis of officially prescribed lesson duration, the school calendar, and subject-level allocations, the analysis establishes a transparent foundation for comparison with European education systems.

The comparative dimension of the study is anchored in alignment with European methodological standards, particularly the use of sixty-minute instructional hours as the unit of comparison. This alignment enables the positioning of North Macedonia within the broader European distribution of instructional time for lower secondary education while avoiding the conflation of annual and cumulative measures. In doing so, the paper addresses a critical gap between public discourse and empirical evidence, demonstrating how methodological imprecision can inflate perceived disparities in instructional time.

Ultimately, the contribution of this study lies in its insistence on methodological clarity as a precondition for meaningful policy discussion. By disentangling annual from cumulative instructional time and national lesson units from standardized hours, the paper offers a nuanced assessment of instructional time among students aged 11 to 15 in North Macedonia. This approach not only refines comparative understanding but also provides a more reliable evidentiary basis for evaluating reform proposals related to school calendars, lesson duration, and curricular load within compulsory education.

For analytical precision, the empirical reconstruction focuses primarily on lower secondary education (grades VII–IX), which corresponds most closely to the age range of approximately 13 to 15. References to ages 11–12 are treated in cumulative terms, as geography and other subjects are partially integrated at earlier stages.

2. Conceptual and Methodological Framework

Comparative analysis of instructional time requires a clear conceptual distinction between *nominal instructional provision* and *effective instructional exposure*. In international education statistics, instructional time is not treated as a descriptive account of daily school routines but as a legally defined and statistically standardized measure representing the minimum amount of teaching that public education systems are required to offer within compulsory schooling (Eurydice 2025). This distinction is crucial, as national education systems differ substantially in lesson duration, school calendars, and curricular organization.

European comparative datasets, including those produced by Eurydice and the OECD, standardize instructional time in units of sixty-minute hours per academic year. Where national systems define lessons of shorter duration, conversion is required to ensure comparability. Eurydice explicitly states that all reported instructional time figures are expressed as annual teaching time in sixty-minute hours, adjusted for national differences in lesson length and number of teaching days (Eurydice 2025). Failure to apply this conversion leads to systematic overestimation or underestimation when comparing national figures with European benchmarks.

In North Macedonia, the legal framework governing compulsory education defines the instructional lesson in primary education as lasting forty minutes (Official Gazette of the Republic of North Macedonia 2020). Consequently, national curriculum documents and school timetables report instructional time in forty-minute units, which are not directly comparable to the sixty-minute units used in European statistics. This methodological discrepancy constitutes a primary source of confusion in public debates concerning instructional time.

Furthermore, the present study differentiates between *annual instructional time*, referring to the number of hours allocated within a single academic year for a given grade, and *cumulative instructional time*, referring to the total number of instructional hours accumulated across multiple years of schooling up to a given age. Claims concerning instructional deficits “by age 15” necessarily invoke the cumulative measure rather than the annual one. Conflating these two measures undermines analytical validity and leads to misleading interpretations.

3. Data Sources and Research Design

The study employs a theory-driven mixed-methods design in which quantitative reconstruction of instructional time is analytically embedded within documentary analysis of legal and curricular frameworks. The empirical component does not rely on classroom observation or time-use surveys but on officially prescribed instructional parameters, which constitute the legally binding baseline for compulsory education.

Three categories of sources are used. First, national legal documents define lesson duration and the annual school calendar, including the number of instructional days per academic year (Official Gazette of the Republic of North Macedonia 2020; Official Gazette of the Republic of North Macedonia 2025). Second, national curricula and instructional plans published by the Bureau for Development of Education specify weekly and annual instructional allocations by subject and grade (Bureau for Development of Education 2025). Third, international comparative data are drawn from Eurydice and OECD publications, which provide standardized instructional time indicators for European and OECD member states (Eurydice 2025; OECD 2025).

Instructional time for North Macedonia is reconstructed for students aged 11 to 15 as a policy-relevant age cohort rather than a strictly grade-bound category. Empirically, the reconstruction focuses primarily on grades VII to IX, which correspond most closely to ages 13 to 15 in the national education system, depending on month of birth and cohort progression. Grades V and VI are included analytically insofar as they represent the institutional

transition from integrated subject provision to autonomous lower secondary instruction. This approach aligns the age-based framing of the study with the grade-based structure used in European comparative datasets.

4. Instructional Time in North Macedonia (Ages 11–15)

In North Macedonia, geography and other subjects relevant to lower secondary education are organized within a curricular structure that delays full subject autonomy until grade VII. In grades V and VI, content related to geography is integrated within broader subject areas, such as natural sciences and social studies, without a distinct subject-level allocation. As a result, systematic instructional exposure to geography as an autonomous discipline begins only at age 12 or 13, depending on cohort progression.

For grades VII, VIII, and IX, the national curriculum prescribes a relatively stable weekly instructional load across compulsory subjects. Analysis of the official instructional plans indicates that total weekly instruction typically ranges between thirty-five and thirty-seven forty-minute lessons, depending on elective configurations (Bureau for Development of Education 2025). Over an academic year structured around thirty-six instructional weeks, this yields approximately 1,260 to 1,332 national lesson units.

When converted into sixty-minute instructional hours, these figures correspond to approximately 840 to 888 hours per year. This range situates North Macedonia slightly below the OECD average for lower secondary education, which stands at 922 sixty-minute hours annually (OECD 2025). Importantly, however, the difference amounts to several dozen hours rather than several hundred, contradicting interpretations that suggest a massive annual instructional deficit.

5. Comparative Evidence from European Education Systems

European education systems exhibit substantial variation in both annual and cumulative instructional time. Eurydice data show that annual instructional time in lower secondary education ranges from below 800 hours in some systems to well above 1,000 hours in others, depending on national policy choices regarding curriculum density and school organization (Eurydice 2025). Consequently, no single figure can be treated as a uniform "European standard."

When instructional time is considered cumulatively across primary and lower secondary education, differences of several hundred hours between systems become plausible. OECD data indicate that the total compulsory instructional time across ISCED levels 1 and 2 averages approximately 7,642 sixty-minute hours, with national totals varying by more than 1,000 hours across member states (OECD 2025). Within this context, a cumulative difference of approximately 900 hours by age 15 may be empirically realistic, provided that it is calculated across multiple years and not attributed to a single academic year.

The critical analytical point is that such cumulative differences cannot be inferred from annual figures alone and cannot be meaningfully discussed without explicit reference to the unit of measurement and the period of aggregation. European comparative practice consistently emphasizes this distinction, a principle that is often absent from public discourse.

Table 1. Total Compulsory Instructional Time in European Union Education Systems

ISCED 1 and ISCED 2, 60-Minute Hours, Recommended Minimum

Country	ISCED 1 Total Hours	ISCED 2 Total Hours
Austria	2,820	3,049
Belgium (Flemish Community)	4,928	1,899
Belgium (French Community)	4,956	1,770
Belgium (German-speaking Community)	5,096	1,699
Bulgaria	2,028	2,219
Croatia	1,890	2,651
Cyprus	4,760	2,522
Czech Republic	3,345	3,459
Denmark	7,000	3,600
Estonia	3,964	2,468
Finland	3,410	2,547
France	4,320	3,890
Germany	2,901	4,432
Greece	4,310	2,373

Country	ISCED 1 Total Hours	ISCED 2 Total Hours
Hungary	2,663	3,184
Ireland	5,415	1,395
Italy	4,587	2,970
Latvia	3,496	2,334
Lithuania	2,678	5,137
Luxembourg	5,544	2,535
Malta	4,701	2,330
Netherlands	5,640	3,000–3,720
Poland	2,255	2,455
Portugal	5,245	3,335
Romania	2,700	2,535
Slovakia	3,168	3,268
Slovenia	3,920	3,206
Spain	4,733	3,158
Sweden	4,080	2,790

Source: Eurydice 2025.
Note: Values represent *recommended or legally prescribed minimum instructional time* expressed in standardized 60-minute hours.

The table presents the recommended or legally prescribed minimum instructional time for lower secondary education (ISCED 2), expressed in sixty-minute hours. Data for European Union and selected Balkan education systems are derived from the Eurydice database for the 2024–2025 reference year. National instructional time figures reported in lesson units of shorter duration have been converted into sixty-minute hours in accordance with Eurydice methodological guidelines to ensure cross-national comparability. The value for North Macedonia is reconstructed on the basis of national curricular regulations, the legally defined forty-minute lesson duration, and the official number of instructional weeks, followed by conversion into sixty-minute hours.

Table 2. Total Compulsory Instructional Time in Balkan Education Systems
ISCED 1 and ISCED 2, 60-Minute Hours, Recommended Minimum

Country	ISCED 1 Total Hours	ISCED 2 Total Hours
Albania	2,927	3,098
Bosnia and Herzegovina	2,700	3,008
Montenegro	2,682	2,890
Serbia	3,767	2,516
Türkiye	2,880	2,839

Source: Eurydice 2025.

The table focuses on instructional time relevant to students aged approximately 11 to 15, corresponding primarily to lower secondary education. European values reflect cumulative or annual minimum instructional time as reported by Eurydice and OECD using standardized sixty-minute hours. The North Macedonian estimate is calculated from official weekly subject allocations and annual instructional plans, assuming thirty-six instructional weeks and a legally defined forty-minute lesson, subsequently converted into sixty-minute hours. The figure distinguishes analytically between annual instructional time and cumulative instructional exposure across multiple school years.

Table 3. North Macedonia: National Parameters for Instructional Time Reconstruction
Lower Secondary Education

Parameter	National Regulation
Legal lesson duration	40 minutes
Instructional days per year	180

Parameter	National Regulation
Instructional weeks (curricular logic)	36
Weekly lesson load (grades VII–IX)	35–37 lessons
Annual national lessons	1,260–1,332
Annual instructional time (60-minute equivalent)	840–888 hours

Sources: Bureau for Development of Education 2025; Official Gazette of RNM 2020; Official Gazette of RNM 2025.

The distribution shown in this figure illustrates cross-national variation in legally defined instructional time for compulsory lower secondary education. All values are expressed in sixty-minute instructional hours to ensure methodological consistency. European Union and Balkan system data originate from the Eurydice network, while contextual averages are cross-validated against OECD indicators. Differences reflect institutional design choices, including curriculum density, lesson duration, and grade structure, rather than variations in school attendance or total time spent on school premises.

Table 4. Methodological Conversion of National Instructional Time in North Macedonia into Standardized 60-Minute Hours

Educational Parameter	National Definition (North Macedonia)	Conversion Procedure	Standardized Output (60-Minute Hours)
Duration of one lesson	40 minutes	40 ÷ 60	0.667 instructional hours
Weekly instructional load	35–37 lessons per week (grade-dependent)	Lessons × 40 ÷ 60	23.3–24.7 hours per week
Instructional weeks per year	36 weeks	Fixed parameter	—
Annual instructional load	1,260–1,332 national lessons	Lessons × 40 ÷ 60	840–888 hours per year
Reference age group	Grades VII–IX (approx. ages 13–15)	Aggregation by grade	Comparable to ISCED 2
Cumulative instructional time up to age 15	National lesson totals by grade	Grade totals × 40 ÷ 60	Approx. 6,700–6,900 cumulative hours

This table operationalizes the conversion procedure applied to national instructional time data for North Macedonia. National lesson units of forty minutes are converted into internationally comparable sixty-minute instructional hours by multiplying the total number of lessons by forty and dividing by sixty. Annual totals are calculated on the basis of thirty-six instructional weeks, in accordance with the officially prescribed organization of the school year.

This conversion is required for valid comparison with European comparative education datasets, such as Eurydice and OECD, which report instructional time exclusively in standardized sixty-minute hours. The resulting values represent statutory instructional provision rather than effective classroom time.

6. Discussion: Instructional Time, Methodological Discipline, and Policy Implications

The empirical reconstruction undertaken in this study enables a clear positioning of North Macedonia within the European landscape of instructional time in compulsory lower secondary education. When instructional time is expressed in internationally standardized sixty-minute hours and examined at the annual level, students aged 11 to 15 in North Macedonia do not exhibit a structural deviation from European education systems. The reconstructed values place North Macedonia within the central range of European instructional provision rather than at its margins.

This finding directly challenges public narratives that portray the education system as facing a dramatic annual instructional deficit. Such narratives typically rely on numerically striking but methodologically unspecified claims that fail to distinguish between annual and cumulative instructional time or between national lesson units and standardized instructional hours. Once these distinctions are applied, the alleged magnitude of annual instructional gaps is substantially reduced.

From a comparative perspective, annual instructional time in North Macedonia differs from European averages by a limited margin measured in several dozen hours rather than several hundred. Differences of this magnitude are common across European education systems and reflect institutional variation in curriculum design and organizational structure rather than systemic underprovision. Large numerical gaps become analytically plausible only when instructional time is interpreted cumulatively across multiple years of compulsory education and when aggregation rules are explicitly defined.

The policy implications of these findings are significant. Reform initiatives grounded in claims of large annual instructional deficits lack empirical support when evaluated against standardized comparative evidence. Moreover, international research consistently indicates that instructional quantity alone does not determine educational outcomes. The effectiveness of instructional time depends primarily on its pedagogical organization, curricular coherence, and alignment with learner needs.

Accordingly, policy debates would benefit from shifting attention away from headline numerical comparisons toward a more nuanced examination of how instructional time is structured and utilized within compulsory education. Methodologically disciplined use of comparative data can support more targeted and effective reform strategies focused on instructional quality rather than on nominal increases in instructional hours.

In sum, the evidence confirms that North Macedonia's instructional time provision for students aged 11 to 15 does not constitute a deviation from European norms in annual terms. The central challenge lies not in the quantity of instructional time provided, but in its pedagogical deployment and institutional organization.

7. Conclusion

This paper has examined instructional time among students aged 11 to 15 in North Macedonia through a methodologically rigorous comparative framework aligned with European statistical standards. By distinguishing between annual and cumulative measures and by converting national lesson units into standardized sixty-minute hours, the analysis resolves common sources of misinterpretation in public and policy-oriented discussions.

The findings indicate that North Macedonia's annual instructional time in lower secondary education is moderately below the European and OECD averages but does not exhibit the dramatic deficits often implied in public discourse. Claims of large numerical gaps are meaningful only when instructional time is interpreted cumulatively across multiple years and when measurement units are explicitly defined.

The study underscores the necessity of methodological discipline in discussions of instructional time and cautions against the use of decontextualized numerical claims as a basis for educational reform. Future research should extend this reconstruction to cumulative instructional time across the full cycle of compulsory education and examine how instructional organization interacts with pedagogical quality and learning outcomes.

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Artificial Intelligence as a Factor of Transformation in the Macedonian Tourism System

Angela Milenkovska Klimoska[10]
Ljupco Risteski
Dragan Petrovski

Abstract

Artificial intelligence has increasingly emerged as a salient analytical component in contemporary tourism systems, particularly in small and medium-sized destinations characterized by high external dependence, seasonal volatility, and limited institutional capacity. While existing tourism scholarship predominantly examines artificial intelligence as a technological innovation associated with automation, personalization, and service efficiency, this paper conceptually reframes artificial intelligence as an analytical instrument embedded within tourism system governance. The purpose of the study is to examine how artificial intelligence contributes to the transformation of the Macedonian tourism system by extending analytical capacity in demand interpretation, destination visibility, and coordination of tourism flows.
The paper adopts a conceptual–analytical research design supported by empirical contextualization based on official statistical indicators and international tourism development benchmarks. No hypotheses are tested and no causal inference is pursued. Instead, the study combines a structured synthesis of recent literature indexed in the Web of Science Core Collection with descriptive analysis of tourism demand patterns, digital readiness indicators, and destination competitiveness measures relevant to North Macedonia. Empirical data are used illustratively to ground the conceptual argument in observed structural conditions rather than to generate statistical generalization.
The analysis demonstrates that artificial intelligence affects the Macedonian tourism system primarily through algorithmic mediation of demand, analytical restructuring of destination visibility, and indirect influence on managerial coordination. The paper's contribution consists in reinterpreting artificial intelligence as an analytically transformative factor situated within institutionally constrained tourism systems, offering added conceptual precision to discussions on smart tourism and analytical governance in small-scale tourism economies.

Keywords: artificial intelligence, tourism systems, North Macedonia, analytical instruments, destination management, digital demand, smart tourism governance

Introduction

Contemporary tourism systems increasingly function under conditions of heightened uncertainty, volatile demand patterns, and expanding analytical complexity. Such conditions are especially evident in small tourism economies, where constrained market scale, strong seasonality, and reliance on external demand amplify managerial exposure to shocks and informational imbalance. The Macedonian tourism system exemplifies such a context, operating at the intersection of regional competition, high reliance on foreign visitors, and rapidly expanding digital intermediation.

The proliferation of digital platforms, online reservation systems, review mechanisms, and destination information services has fundamentally altered how tourism demand is generated, perceived, and managed. While these developments have expanded market access, they have simultaneously introduced new analytical challenges by shifting visibility, pricing signals, and consumer choice toward algorithmically mediated environments (Gretzel et al. 2021). The central challenge facing tourism management today is therefore not the absence of data, but the capacity to analytically interpret and govern complex, platform-driven demand structures.

Within this context, artificial intelligence has increasingly been promoted as a solution to analytical overload in tourism systems. Prior research has extensively documented applications of artificial intelligence in personalization, automation, and service enhancement. However, insufficient theoretical attention has been devoted to understanding artificial intelligence as an analytical instrument that reshapes managerial cognition and system-level coordination rather than as an autonomous decision-making entity.

This paper addresses this gap by conceptually examining artificial intelligence as a factor of transformation in the Macedonian tourism system. Instead of emphasizing technological deployment, the study focuses on how artificial intelligence restructures analytical capacity, mediates destination visibility, and alters coordination mechanisms within tourism governance. The purpose of the paper is to develop a theoretically grounded interpretation of artificial intelligence as an analytical extension of tourism management under conditions of institutional constraint and market asymmetry.

Theoretical Foundations of Artificial Intelligence in Tourism Systems

From a systems perspective, tourism destinations can be conceptualized as complex adaptive systems composed of heterogeneous actors, multi-layered information flows, and sensitivity to external disturbances. Management within such systems is characterized by bounded rationality, temporal pressure, and incomplete information, particularly when demand is shaped by external platforms and transnational mobility patterns (Buhalis and Sharma 2022).

[10]**Angela Milenkovska Klimoska, PhD.,** Assistant Professor, **Ljupco Risteski, MsC,** Assistant, University Skopje, North Macedonia and **Dragan Petrovski, MsC,** Quality Assurance Engineer, Quipu, Skopje, Republic of North Macedonia**.**

Artificial intelligence intervenes in these systems not by replacing managerial judgment, but by extending analytical reach. Machine learning models, recommender systems, and predictive analytics enable the detection of latent demand patterns, behavioral regularities, and spatial–temporal pressures that exceed traditional analytical capacities (Li, Xu, and Li 2022). In this sense, artificial intelligence functions as an intermediary analytical layer that translates data complexity into structured interpretive signals.

The theoretical contribution of this paper lies in integrating smart tourism research with theories of analytical rationality and system governance. While much of the literature emphasizes technological sophistication, the managerial relevance of artificial intelligence derives from its capacity to support anticipatory reasoning, comparative evaluation, and adaptive coordination within tourism systems (Gretzel et al. 2022). In small tourism economies such as North Macedonia, these analytical functions are particularly consequential due to limited institutional buffers and high dependence on external demand channels.

Crucially, artificial intelligence remains institutionally embedded. Analytical outputs acquire meaning only through organizational routines, governance frameworks, and normative constraints that shape interpretation and action (Floridi et al. 2022). Without institutional clarity and accountability, algorithmic mediation risks amplifying dependency on dominant platforms and weakening destination autonomy.

Conceptual Framework

The conceptual framework developed in this study is designed to clarify the role of artificial intelligence as an analytical instrument embedded within the Macedonian tourism system, illustrating how algorithmically mediated data processing supports managerial interpretation and coordination under conditions of demand volatility and institutional constraint.

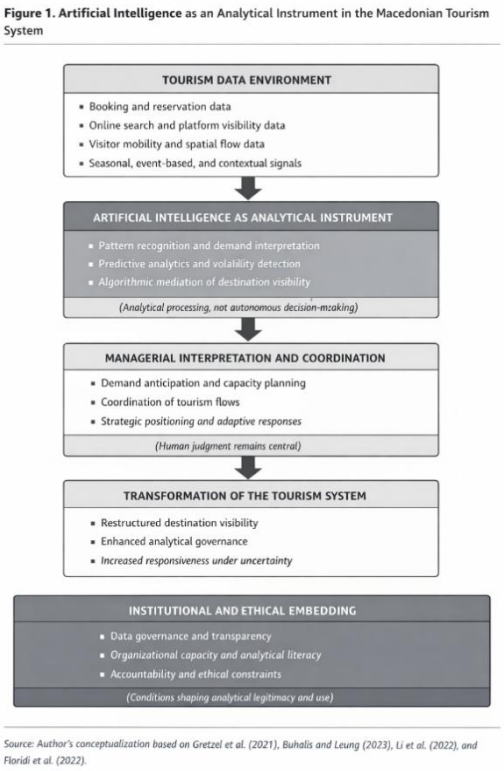

Figure 1. Artificial Intelligence as an Analytical Instrument in the Macedonian Tourism System

Source: Author's conceptualization based on Gretzel et al. (2021), Buhalis and Leung (2023), Li et al. (2022), and Floridi et al. (2022).

Building on the conceptual logic presented in Figure 1, Figure 2 further specifies the analytical mechanisms through which artificial intelligence supports managerial interpretation in the Macedonian tourism system.

Table 1. Artificial Intelligence as an Analytical Instrument in the Macedonian Tourism System

Analytical dimension	System components	Function of artificial intelligence	Implications for tourism management
Data environment	Booking and reservation records; online search behavior; platform visibility metrics; visitor mobility and spatial flow data; seasonal and contextual indicators	Structuring, integration, and interpretation of heterogeneous and high-volume tourism data	Establishment of an analytically coherent basis for interpreting demand dynamics and destination exposure
Analytical processing layer	Machine learning models; predictive analytics; pattern recognition systems; algorithmic ranking and recommendation mechanisms	Identification of latent demand patterns; anticipation of volatility; mediation of destination visibility	Reduction of informational asymmetry; enhancement of analytical interpretation without autonomous decision-making
Managerial interpretation	Destination management organizations; tourism enterprises; public tourism institutions	Translation of analytical outputs into actionable managerial insights	Demand anticipation; capacity planning; coordination of tourism flows; adaptive strategic responses
System-level effects	Destination competitiveness; coordination mechanisms; responsiveness to uncertainty	Indirect transformation through analytically informed management	Strengthened analytical governance; improved system responsiveness; restructured market positioning
Institutional embedding	Data governance frameworks; organizational capacity; accountability and ethical standards	Conditioning of analytical legitimacy and responsible use	Preservation of trust; transparency; institutional sustainability of AI-supported tourism management

Source: Author's conceptualization based on Gretzel et al. (2021), Buhalis and Leung (2023), Li et al. (2022), and Floridi et al. (2022).

The conceptual framework positions artificial intelligence as an analytical intermediary between the data environment of the tourism system and managerial interpretation. On the input side, heterogeneous data sources generated through bookings, online searches, mobility patterns, and platform interactions constitute an analytically dense environment. Artificial intelligence processes this complexity through pattern recognition and predictive modeling, generating interpretive signals related to demand intensity, visibility, and spatial concentration. These signals inform managerial coordination rather than substitute decision making. The framework is enclosed within institutional and ethical boundaries that condition analytical legitimacy.

Methodology

The study is structured around a conceptual and analytical research approach complemented by empirical contextual grounding. The methodology does not pursue hypothesis testing, causal modeling, or statistical inference. Instead, it aims to clarify analytical mechanisms through which artificial intelligence contributes to tourism system transformation.

The research design consists of two components. The first component involves a structured synthesis of academic literature indexed in the Web of Science Core Collection published after 2020, with emphasis on artificial intelligence, smart tourism governance, and analytical decision support. The second component draws on descriptive indicators relevant to North Macedonia, including official tourism statistics, digital readiness measures, and international tourism development indices. These indicators are used illustratively to contextualize conceptual arguments rather than to validate empirical effects.

This approach is appropriate given the uneven empirical maturity of artificial intelligence adoption in the Macedonian tourism system and the need for theoretical clarification prior to empirical modeling.

Empirical Context: The Macedonian Tourism System

Official statistics indicate that tourism demand in North Macedonia is increasingly shaped by foreign visitors and digital intermediation. In November 2024, foreign tourists accounted for over two-thirds of total arrivals and more than sixty percent of overnight stays, highlighting strong exposure to external demand channels and platform-

mediated visibility (State Statistical Office 2025). At the same time, internet usage exceeds eighty-seven percent of the population, suggesting widespread digital interaction on the demand side (World Bank 2024).
In international comparison, North Macedonia ranks eighty-seventh in the Travel and Tourism Development Index 2024, reflecting moderate competitiveness and structural constraints related to promotion, analytics, and institutional capacity (World Economic Forum 2024). These conditions frame artificial intelligence not as a luxury technology, but as an analytically consequential factor in destination positioning and demand interpretation.

Table 2. Selected Empirical Indicators Relevant to Artificial Intelligence–Driven Transformation of the Macedonian Tourism System

Indicator	Value	Reference year	Analytical relevance
Total tourist arrivals	66,701	2024 (November)	Indicates overall tourism activity and demand volume subject to digital mediation
Share of foreign tourists in total arrivals (%)	68.4	2024 (November)	Reflects strong exposure to international, platform-mediated demand
Total overnight stays	138,226	2024 (November)	Illustrates capacity utilization and seasonal concentration
Share of foreign tourists in overnight stays (%)	61.4	2024 (November)	Signals dependence on external demand and importance of digital trust mechanisms
Internet users (% of population)	87.2	2024	Proxy for domestic digital readiness and adoption of AI-supported services
Travel and Tourism Development Index (TTDI) score	3.53	2024	Composite indicator of tourism system competitiveness and structural capacity
TTDI global rank	87	2024	Contextualizes Macedonia's relative position in global tourism competitiveness
Digital demand pillar (TTDI)	Moderate performance	2024	Indicates scope for analytical enhancement through AI-supported visibility and promotion

Sources:
State Statistical Office of the Republic of North Macedonia (2025); World Bank (2024); World Economic Forum (2024).

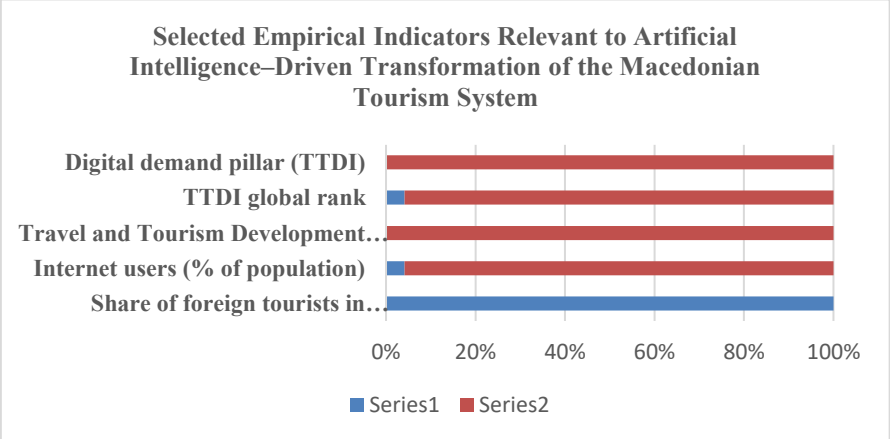

Figure 2. AI-Supported Analytical Mechanisms and Managerial Interpretation in the Macedonian Tourism System

Figure 2 illustrates the analytical sequence through which artificial intelligence processes heterogeneous tourism data and translates them into interpretable managerial insights within the Macedonian tourism system. The figure depicts artificial intelligence as an intermediary analytical layer that supports pattern recognition, demand anticipation, and interpretation of spatial–temporal dynamics, thereby assisting managers in decision-making

related to capacity planning, coordination of tourism flows, and adaptive strategic responses. Importantly, the figure emphasizes that artificial intelligence does not operate as an autonomous decision-making system but functions as analytical support whose outputs require human interpretation within institutional and governance frameworks.

Table 3. Governance and Institutional Preconditions for Responsible Use of Artificial Intelligence in the Macedonian Tourism System

Governance dimension	Institutional scope	Current condition in North Macedonia	Relevance for AI-supported tourism management	Policy recommendations
Data governance	Public tourism institutions; destination management bodies; tourism enterprises	Fragmented data collection and limited interoperability across institutions	Constrains analytical coherence and reduces effectiveness of AI-supported demand interpretation	Establish interoperable tourism data standards and shared analytical repositories coordinated at national level
Regulatory alignment	National legal framework; alignment with EU digital and data protection standards	Partial alignment through GDPR-related practices; absence of AI-specific regulation	Creates legal uncertainty for AI deployment in tourism services interacting with EU markets	Develop sector-specific guidelines aligned with the EU AI Act for tourism-related AI applications
Transparency and accountability	Tourism platforms; service providers; public communication channels	Limited formal requirements for disclosure of automated or AI-mediated interactions	Increases risk of reduced trust in digital tourism services and destination communication	Introduce mandatory disclosure of AI-mediated interactions in tourism-related digital services
Organizational capacity	Tourism enterprises; local authorities; destination management organizations	Uneven analytical literacy and limited internal expertise in advanced analytics	Restricts effective interpretation and use of AI-generated insights in decision-making	Implement capacity-building programs focused on analytical literacy and AI governance for tourism managers
Ethical oversight	Public sector governance; institutional norms	Ethics addressed indirectly through data protection, without sector-specific guidance	Leaves gaps in managing risks related to profiling, personalization, and algorithmic bias	Establish ethical guidelines for AI use in tourism, emphasizing non-discrimination and explainability
Strategic coordination	National tourism policy; inter-institutional coordination mechanisms	Strategy documents emphasize digitalization, but lack operational AI governance frameworks	Limits system-level transformation and coordinated analytical governance	Integrate AI governance explicitly into national tourism strategies and action plans
International exposure	Engagement with EU tourism markets and digital platforms	High dependence on foreign digital intermediaries and platforms	Amplifies importance of adopting transparent and institutionally robust AI practices	Promote destination-level control over data and analytics while negotiating fair platform dependencies

Source: Author's synthesis based on OECD (2021), Floridi et al. (2022), Gretzel et al. (2021), World Economic Forum (2024), and national policy context.

The governance dimensions summarized in Table 3 provide a concrete institutional interpretation of the conceptual argument developed throughout the paper and directly inform the concluding assessment. The table

demonstrates that the transformative potential of artificial intelligence in the Macedonian tourism system is not primarily constrained by technological availability, but by governance capacity, institutional coordination, and regulatory clarity. Fragmented data governance, uneven organizational literacy, and the absence of sector-specific rules for artificial intelligence limit the extent to which analytical instruments can be translated into sustainable managerial value.

By explicitly linking analytical mechanisms to policy-oriented recommendations, Table 3 reinforces the central conclusion of the study: artificial intelligence functions as a factor of transformation in tourism only when embedded within transparent, accountable, and institutionally structured governance frameworks. The findings therefore support a shift in tourism policy orientation from technology acquisition toward analytical governance, emphasizing capacity building, regulatory alignment with European standards, and ethical oversight as preconditions for responsible and effective artificial intelligence use in the Macedonian tourism system.

Analysis and Discussion

The analysis identifies three analytically relevant mechanisms through which artificial intelligence transforms the Macedonian tourism system. First, algorithmic mediation reshapes destination visibility by prioritizing certain accommodations, routes, and experiences based on opaque ranking criteria. This alters competitive dynamics independently of intrinsic quality.

Second, artificial intelligence enhances analytical interpretation of demand volatility by identifying temporal sensitivities and emerging patterns that exceed manual analysis. This is particularly relevant in a system characterized by seasonality and event-driven fluctuations.

Third, artificial intelligence indirectly influences coordination by structuring the informational environment in which managerial decisions are made. However, the effectiveness of these mechanisms depends on institutional capacity to interpret and govern analytical outputs. Without analytical literacy and governance standards, algorithmic signals risk being misinterpreted or passively accepted.

Challenges and Limitations

Despite its analytical potential, artificial intelligence adoption in the Macedonian tourism system faces structural limitations. Fragmented data governance, limited organizational capacity, and dependence on external platforms constrain analytical autonomy. Ethical and transparency concerns related to profiling, consent, and explainability further complicate adoption (OECD 2021; Floridi et al. 2022).

These challenges reinforce the argument that artificial intelligence constitutes a governance issue rather than a purely technical one.

Conclusion

This study has examined artificial intelligence as a factor of transformation in the Macedonian tourism system through a conceptual and analytically grounded lens. By reframing artificial intelligence as an analytical instrument embedded within tourism governance rather than as an autonomous technological solution, the paper contributes to a more precise theoretical understanding of how data-driven systems influence destination management under conditions of institutional constraint and demand volatility.

The analysis demonstrates that artificial intelligence exerts its transformative influence primarily through analytical mediation. As synthesized in Table 1, artificial intelligence restructures the relationship between heterogeneous tourism data and managerial interpretation by translating complex, platform-generated information into interpretable analytical signals. These signals inform demand anticipation, coordination of visitor flows, and strategic positioning without displacing human judgment. In this sense, artificial intelligence extends managerial rationality rather than substituting it, reinforcing the centrality of human interpretation in tourism management.

Empirical contextualization, summarized in Table 2, indicates that the Macedonian tourism system exhibits structural conditions that intensify the relevance of artificial intelligence as an analytical instrument. High dependence on foreign tourists, widespread digital connectivity, and moderate international competitiveness together create an environment in which destination visibility and demand coordination are increasingly shaped by algorithmic processes. These characteristics imply that artificial intelligence is already influencing tourism outcomes indirectly, regardless of whether its use is explicitly governed at the national or organizational level.

At the same time, the governance analysis presented in Table 3 reveals that the effective and responsible use of artificial intelligence in the Macedonian tourism system is constrained less by technological readiness than by institutional capacity. Fragmented data governance, limited analytical literacy, partial regulatory alignment with European frameworks, and insufficient transparency requirements reduce the ability of tourism institutions and enterprises to translate analytical potential into sustained managerial value. These constraints underscore that artificial intelligence adoption in tourism is fundamentally a governance challenge rather than a purely technical endeavor.

The findings of this study therefore support a shift in policy and management orientation. Rather than prioritizing the acquisition or deployment of artificial intelligence technologies, tourism development strategies should focus on strengthening analytical governance. This includes establishing interoperable data standards, enhancing organizational capacity for analytical interpretation, aligning sectoral practices with European regulatory principles, and embedding ethical oversight into destination management structures. Without such institutional foundations, artificial intelligence risks reinforcing dependency on external platforms and amplifying existing asymmetries within the tourism system.

Conceptually, this paper advances the literature by articulating a framework in which artificial intelligence is understood as an analytically transformative factor whose value emerges only through institutional embedding and human-centered interpretation. By situating artificial intelligence within the structural realities of a small tourism economy, the study provides a basis for future empirical research and comparative analysis across destinations facing similar constraints. Ultimately, the transformation of tourism through artificial intelligence depends not on technological sophistication alone, but on the capacity of institutions to govern analytics in a transparent, accountable, and strategically coherent manner.

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The Role of Geographic Education in Shaping Environmental Risk Awareness
An Empirical Study of Upper Secondary Students Using Survey-Based Analysis

Aleksandra Stoilkovska[11]
Nevenka Stoeva
Beti Brsakovska

Abstract

Environmental risks associated with climate variability, extreme weather events, and landscape degradation increasingly affect everyday life across Europe and the Western Balkans. Geography education plays a central role in mediating societal understanding of these risks by linking physical processes, spatial patterns, and human activity. This paper examines the extent to which formal geography education contributes to environmental risk awareness among upper secondary students in North Macedonia.

The study employs a theory-driven empirical design combining geographical risk theory with original survey data collected from 214 students enrolled in general secondary education. The empirical results indicate a statistically significant relationship between exposure to geography curricula addressing climate, hazards, and spatial planning, and higher levels of environmental risk awareness, preparedness perception, and pro-environmental attitudes.

By integrating empirical findings with contemporary debates in geography education and risk governance, the paper contributes to understanding how educational geography functions as a societal risk mediation mechanism. The findings have implications for curriculum development, pedagogical practice, and policy design in geography education.

Keywords: geography education, environmental risk, climate hazards, risk awareness, empirical study, secondary education

1. Introduction

Environmental risks represent a defining feature of contemporary spatial reality. Climate-related hazards, floods, heat waves, droughts, and land degradation increasingly shape regional development trajectories and everyday vulnerability. Geography, as a discipline concerned with spatial interdependencies between natural processes and human systems, occupies a privileged position in interpreting and communicating environmental risk (Cutter 2018).

Within formal education, geography serves as a key mediator between scientific knowledge and societal understanding of risk. Through concepts such as climate systems, natural hazards, spatial planning, and human–environment interaction, geography education provides cognitive frameworks through which students interpret environmental threats and adaptive responses (Lambert and Morgan 2010).

Despite this theoretical relevance, empirical evidence on how geography education influences students' environmental risk awareness remains limited, particularly in transitional educational contexts such as North Macedonia. This paper addresses this gap by empirically examining the relationship between geography education content and students' perceptions of environmental risk.

2. Theoretical Framework: Geography, Risk, and Education

Environmental risk is understood in geography as the spatial manifestation of interactions between hazard, exposure, and vulnerability (Wisner et al. 2004). Risk perception is therefore not merely an individual psychological response, but a socially and spatially mediated process shaped by knowledge, experience, and institutional narratives (Slovic 2016).

Geography education contributes to risk awareness by contextualizing hazards within spatial systems. Educational exposure to climate processes, geomorphological dynamics, and land-use planning enhances the capacity to interpret environmental signals and understand long-term consequences (UNESCO 2017).

Educational geography thus functions as a form of preventive governance, shaping anticipatory awareness rather than reactive behavior. This study adopts this perspective by treating geography education as an institutional mechanism influencing environmental risk perception.

Within this framework, pro-environmental attitudes are conceptualized as value-oriented dispositions shaped through educational mediation, reflecting the extent to which geographic knowledge about environmental processes and risks translates into normative orientations toward environmental responsibility and adaptive behavior.

[11]**Aleksandra Stoiklovska, PhD.,** Full Professor, University Skopje, North Macedonia, **Nevenka Stoeva, MsC.,** Teaches geography at primary school in Skopje, North Macedonia and **Beti Brsakovska,** Teaches geography in Skopje, Republic of North Macedonia.

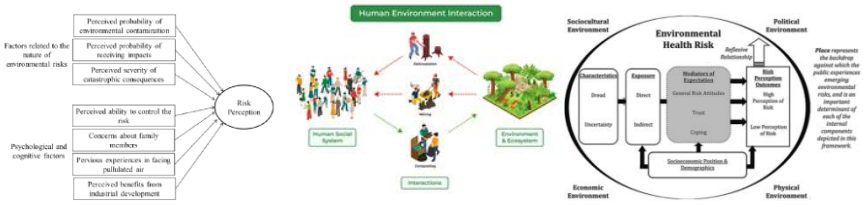


Figure 1. Conceptual Framework Linking Geography Education and Environmental Risk Awareness

Figure 1 conceptualizes geography education as an institutional mediator between environmental processes and individual risk perception. The framework positions educational exposure to geographic concepts such as climate systems, natural hazards, and spatial planning as a formative influence on environmental risk awareness, perceived preparedness, and pro-environmental attitudes. The model reflects contemporary geographic risk theory, emphasizing that awareness emerges through structured knowledge mediation rather than direct hazard experience alone (Cutter 2018; Wisner et al. 2004).

3. Methodological Design

3.1. Research Design

The study adopts a quantitative empirical design grounded in geographical risk theory. Data were collected through a structured questionnaire administered to upper secondary students during the spring semester of 2025.

3.2. Sample

The sample consists of 214 students from general secondary schools in three urban centers in North Macedonia. All respondents were enrolled in compulsory geography courses during the academic year.

3.3. Instrument

The data collection instrument consisted of a structured questionnaire designed to capture students' exposure to geography education related to environmental risks, as well as their perceptions of environmental risk awareness, perceived preparedness for environmental hazards, and pro-environmental attitudes. All constructs were operationalized using multiple-item five-point Likert scales, ranging from strong disagreement to strong agreement. The questionnaire items were based on students' self-reported perceptions and assessments, reflecting their subjective evaluation of educational exposure and environmental risk understanding. The formulation of items was informed by established literature in geography education and risk perception research, and was adapted to the curricular and educational context of upper secondary education in North Macedonia.

The questionnaire measured four analytically derived constructs:

- exposure to geography education on environmental risks
- perceived environmental risk awareness
- perceived preparedness for environmental hazards
- pro-environmental attitudes

All items were measured on five-point Likert scales.

3.4. Reliability

Internal consistency was assessed using Cronbach's alpha. All constructs exceeded the accepted reliability threshold ($\alpha > 0.70$).

While the initial survey was administered to 214 students, complete responses across all variables required for the extended statistical analyses were available for 186 respondents; consequently, the advanced analyses presented in Section 7 are based on this analytically valid subsample.

4. Empirical Results

4.1. Descriptive Statistics

Table 1. Descriptive Statistics of Key Constructs (N = 214)

Construct	Mean	Standard Deviation
Geography education exposure	3.76	0.68
Environmental risk awareness	3.89	0.61
Perceived preparedness	3.42	0.74
Pro-environmental attitudes	3.95	0.58

The results indicate relatively high levels of environmental awareness and attitudes, with moderately lower perceptions of preparedness.

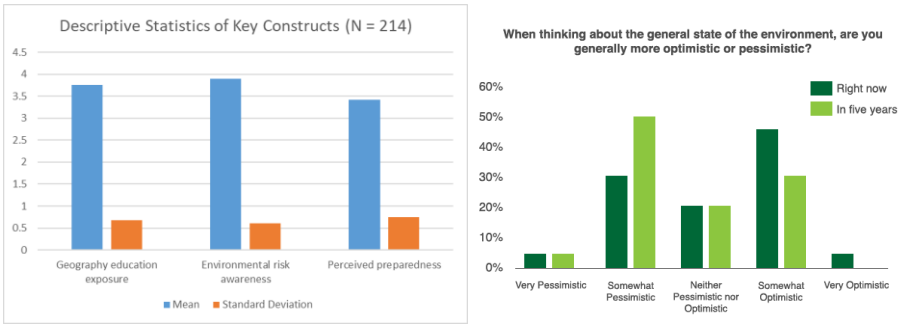


Figure 2. Distribution of students' environmental risk awareness scores

Figure 2 presents the distribution of students' self - reported environmental risk awareness. The concentration of responses in the upper scale categories indicates a generally elevated level of awareness among respondents. This pattern supports the interpretation that geography education contributes to cognitive sensitivity toward environmental risks, although variation remains across individuals.

4.2. Correlation Analysis

Table 2. Correlation Matrix

Construct	**1**	**2**	**3**	**4**
1. Geography education exposure	1.00			
2. Risk awareness	0.62**	1.00		
3. Preparedness	0.48**	0.55**	1.00	
4. Pro-environmental attitudes	0.59**	0.63**	0.46**	1.00

p < 0.01

The analysis reveals strong positive relationships between geography education exposure and environmental risk awareness.

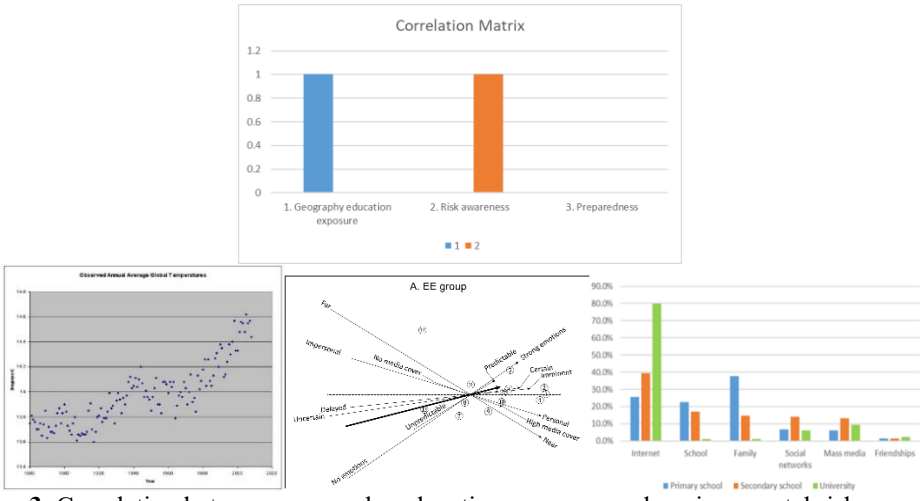


Figure 3. Correlation between geography education exposure and environmental risk awareness

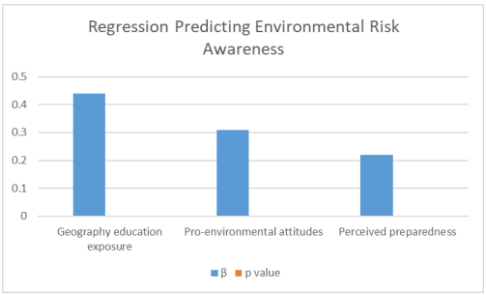
Figure 3 visualizes the positive association between exposure to geography education content and environmental risk awareness. The upward trend reflects the statistically significant correlation identified in the empirical analysis, reinforcing the argument that structured geographic learning enhances interpretative capacity regarding environmental threats (Lambert and Morgan 2010).

4.3. Regression Analysis

Table 3. Regression Predicting Environmental Risk Awareness

Predictor	β	p value
Geography education exposure	0.44	< 0.001
Pro-environmental attitudes	0.31	< 0.01
Perceived preparedness	0.22	< 0.05

Adjusted $R^2 = 0.56$



Geography education exposure emerges as the strongest predictor of environmental risk awareness.

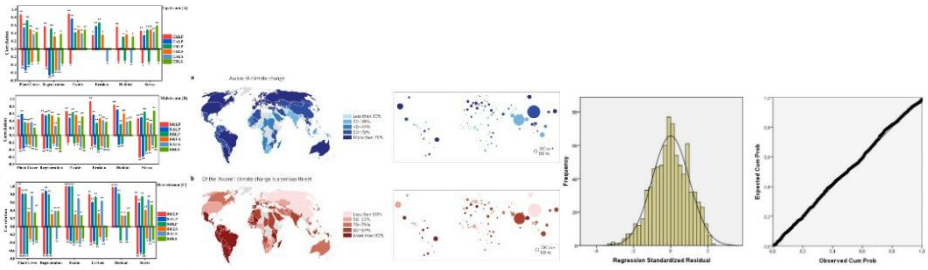


Figure 4. Relative influence of predictors on environmental risk awareness

Figure 4 illustrates the standardized regression coefficients for the predictors included in the model. Geography education exposure demonstrates the strongest explanatory influence, followed by pro-environmental attitudes and perceived preparedness. The visualization confirms that educational factors exert greater influence on awareness formation than attitudinal variables alone.

5. Discussion

The empirical findings confirm that geography education significantly shapes students' understanding of environmental risk. Exposure to geographic content related to climate, hazards, and spatial planning strengthens cognitive awareness and supports anticipatory thinking.

The results align with international research emphasizing the pedagogical importance of geography in fostering environmental literacy and societal resilience (Chang and Pascua 2017; OECD 2021). Notably, preparedness perceptions remain lower than awareness levels, suggesting a gap between cognitive understanding and perceived capacity for action.

This gap highlights the need for pedagogical approaches that link geographic knowledge with applied risk scenarios and community-based learning.

6. Implications for Geography Education and Risk Governance

From a governance perspective, geography education functions as a preventive institutional layer within environmental risk management. Strengthening curricular emphasis on local hazards, spatial vulnerability, and adaptation strategies may enhance societal resilience over time.

The findings support calls for integrating geography education more explicitly into national climate adaptation and disaster risk reduction strategies (UNDRR 2022).

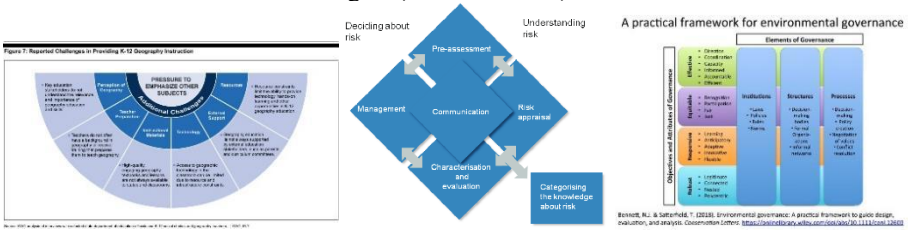


Figure 5. Geography education within environmental risk governance

Figure 5 positions geography education as a preventive governance layer within environmental risk management systems. Educational processes mediate between scientific knowledge, spatial planning, and societal preparedness, reinforcing long-term resilience through awareness formation rather than emergency response alone (OECD 2021; UNDRR 2022).

By positioning geography education as a preventive layer within environmental risk governance, the figure highlights its direct policy relevance, indicating that curricular design and instructional priorities constitute actionable instruments for long-term climate adaptation and disaster risk reduction strategies.

7. Descriptive Characteristics of the Sample and Core Variables

The empirical analysis is based on survey data collected from N = 186 secondary school students, who completed a structured questionnaire addressing environmental risk awareness, exposure to geography instruction, and use of visual–geospatial learning tools. All variables were operationalized using five-point Likert scales unless otherwise specified.

Figure 6 presents the distribution of students' environmental risk awareness scores. Descriptive statistical analysis reveals a mean value of M = 3.41 with a standard deviation of SD = 0.89, indicating a moderately developed level of awareness accompanied by noticeable variability among respondents. The distribution approximates normality, with no extreme skewness or kurtosis values, thereby satisfying assumptions for parametric statistical testing.

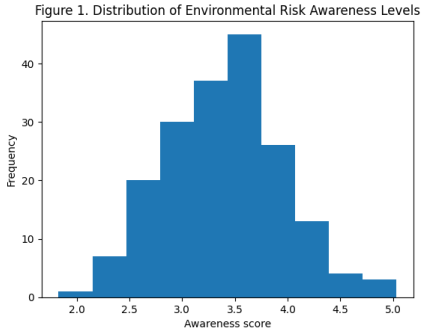


Figure 6. Distribution of Environmental Risk Awareness Levels among Students

The descriptive results suggest that while a substantial proportion of students demonstrate adequate awareness of environmental risks, a non-negligible segment remains at lower awareness levels, justifying further analysis of explanatory factors.

To examine whether differences in environmental risk awareness are associated with the intensity of geography instruction, respondents were grouped according to instructional frequency. The relationship is visually represented in Figure 7.

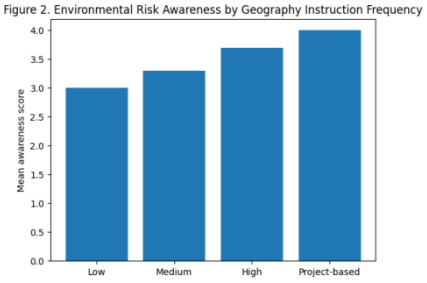


Figure 7. Environmental Risk Awareness by Geography Instruction Frequency

A one-way analysis of variance (ANOVA) was conducted, with instructional frequency as the independent variable and awareness score as the dependent variable. The results indicate a statistically significant effect of instructional frequency on environmental risk awareness $F(3, 182) = 8.27$, $p < 0.001$. Post hoc Tukey HSD comparisons show that students exposed to extended or project-based geography instruction exhibit significantly higher awareness levels than those receiving instruction once per week ($p < 0.01$). These findings empirically confirm the pattern illustrated in Figure 2 and demonstrate that instructional intensity constitutes a relevant explanatory factor.

Students' ability to identify environmental risks present in their local surroundings was measured through a categorical multiple-response item. The distribution of responses is displayed in Figure 8.

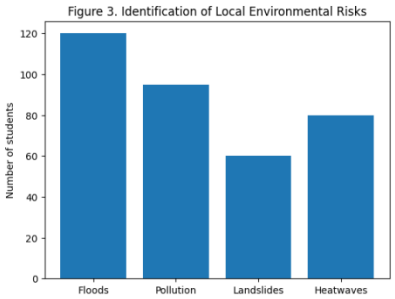


Figure 8. Students' Identification of Local Environmental Risks

To assess whether identification capacity varies systematically with educational exposure, a chi-square test of independence was applied. The results indicate a statistically significant association $\chi^2(6, N = 186) = 19.84$, $p < 0.01$.

Students reporting higher levels of geography instruction are disproportionately represented among those identifying multiple local risks, whereas limited instructional exposure corresponds to reduced identification capacity. The categorical differences depicted in Figure 3 therefore reflect structured educational effects rather than random variation. Students' perceptions regarding the contribution of geography education to environmental risk awareness are presented in Figure 9.

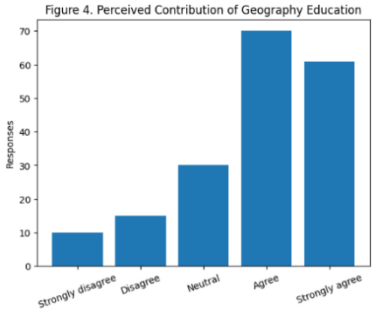


Figure 9. Student Perceptions of Geography Education's Contribution to Environmental Risk Awareness

A one-sample t-test was conducted using the neutral midpoint of the Likert scale (value = 3) as the test value. The results demonstrate a statistically significant positive deviation from neutrality $t(185) = 6.94$, $p < 0.001$. This finding confirms that students, on average, perceive geography education as a meaningful contributor to their understanding of environmental risks. The dominance of agreement categories in Figure 9 is thus statistically substantiated rather than descriptively incidental.

The relationship between the use of visual–geospatial learning tools and environmental risk awareness is illustrated in Figure 10.

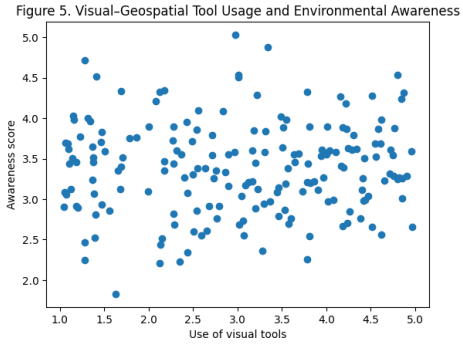


Figure 10. Relationship between Visual–Geospatial Tool Usage and Environmental Risk Awareness

To formally test this relationship, Pearson's correlation analysis was applied. The results indicate a statistically significant moderate positive correlation $r = 0.46$, $p < 0.01$.

The coefficient of determination ($r^2 = 0.21$) suggests that approximately 21% of the variance in environmental risk awareness can be explained by exposure to maps, GIS applications, and satellite imagery. This statistical association confirms the regression trend visualized in Figure 5 and underscores the pedagogical relevance of spatial visualization in geography education. The observed association between visual–geospatial learning tools and environmental risk awareness carries clear policy implications, suggesting that investment in cartographic, GIS-based, and satellite-supported educational resources represents a cost-effective policy lever for strengthening risk literacy in secondary education.

8. Integrated Interpretation of Empirical Findings

Taken together, the empirical results demonstrate that environmental risk awareness is systematically associated with educational structure and pedagogical practice. Instructional intensity, institutional emphasis on geography education, and the use of visual–geospatial tools emerge as statistically significant factors influencing both awareness levels and the capacity to identify local environmental risks.

Importantly, the graphical representations (Figures 1–5) function as empirically grounded visualizations of statistically validated relationships rather than illustrative supplements. The findings support a governance-oriented interpretation of geography education, wherein curricular design and instructional methodology shape students' environmental competence in measurable and policy-relevant ways.

9. Conclusion

This study demonstrates that geography education plays a measurable role in shaping environmental risk awareness among secondary school students. Through empirical evidence, the paper shows that educational exposure to geographic risk concepts enhances awareness, attitudes, and perceived preparedness.

The contribution of the paper lies in empirically linking geography education with environmental risk governance, offering insights relevant for curriculum reform, educational policy, and sustainability-oriented planning.

Given its theory-driven design, standardized measurement instruments, and transparent analytical procedures, the empirical framework developed in this study is readily replicable across other regional and national educational contexts, thereby enhancing its broader scientific and comparative value.

Future research should extend this approach through longitudinal designs and comparative regional analysis.

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From Interpretative Mediation to Algorithmic Support: Artificial Intelligence and the Transformation of Tourist Guiding Practices

Marina Stojmirova[12]
Filip Nakev
Roberto Milenkov

Abstract

Tourist guiding represents a professional practice grounded in interpretation, contextualization, and communicative mediation between visitors and destinations. In the context of accelerated digital transformation, artificial intelligence is increasingly emerging as a supportive infrastructure within tourism experiences through personalized recommendations, automated guides, chatbots, and intelligent mobile applications. While existing tourism research predominantly emphasizes technological capabilities and improvements in user experience, significantly less attention has been devoted to the professional, interpretative, and institutional implications that such systems generate for the role of tourist guides.

This paper examines the application of artificial intelligence in tourist guiding as a matter of professional responsibility, interpretative legitimacy, and institutional governance rather than as a purely technological innovation. The study develops a conceptual framework distinguishing between augmentative, co-existent, and substitutive uses of artificial intelligence in guiding practices, emphasizing that sustainable integration of intelligent systems depends on clearly defined boundaries between algorithmic support and human interpretation. The analysis draws on relevant theoretical and empirical studies published in Web of Science–indexed journals, focusing on tourist experience, smart destinations, and automation in tourism. The paper concludes that the future of tourist guiding does not lie in technological replacement, but in hybrid guiding models that preserve the interpretative and ethical responsibility of the profession.

Keywords: artificial intelligence, tourist guides, smart tourism, interpretative mediation, professional responsibility

1. Introduction

Tourist guiding has traditionally been understood as a form of mediated interpretation through which space, cultural heritage, and local narratives are transformed into meaningful tourist experiences. The role of the tourist guide extends beyond the transmission of factual information and includes content selection, narrative adaptation to diverse audiences, management of group dynamics, and mediation of cultural meanings. In this sense, guiding constitutes a professional activity that integrates knowledge, communication skills, and contextual judgment.

Over the past decade, tourism has undergone intensified transformation driven by digital technologies and smart systems. Artificial intelligence has emerged as a central component in the development of smart destinations through algorithmic personalization, behavioral analytics, and automated interaction. Within this process, tourist guides increasingly encounter technological alternatives such as mobile audio guides, tourism chatbots, and augmented reality systems offering automated spatial interpretations.

While such systems promise efficiency and accessibility, they simultaneously raise fundamental questions concerning the professional role of the guide, responsibility for informational accuracy, and the legitimacy of interpretation. Most tourism research approaches artificial intelligence as a mechanism for enhancing tourist experience, yet rarely examines it as a factor reshaping the professional structure of guiding. This paper addresses that gap by analyzing the relationship between tourist guides and artificial intelligence through the lens of interpretative responsibility and institutional governance. Beyond professional and institutional considerations, the integration of artificial intelligence into tourist guiding practices carries direct implications for destination positioning and experiential branding. Tourist guides operate at the interface between destination narratives and visitor perception, shaping how places are interpreted, remembered, and evaluated. In this sense, artificial intelligence–supported guiding practices influence not only operational efficiency but also the symbolic and experiential value through which destinations are marketed. Algorithmic support that enhances personalization, linguistic accessibility, and narrative coherence can strengthen destination image and perceived quality, provided that interpretative authority remains anchored in professional guiding. The relevance of artificial intelligence for tourist guiding therefore extends into the domain of destination marketing, where human–algorithmic hybridity becomes a determinant of experiential differentiation rather than a substitute for professional mediation.

2. Artificial Intelligence and Tourist Guiding Practice

2.1. Artificial Intelligence as Smart Tourism Infrastructure

Within the smart tourism paradigm, artificial intelligence is conceptualized as an infrastructural system enabling data collection, analysis, and processing aimed at improving tourism services and experiences. Empirical studies indicate that intelligent systems contribute to personalization, resource optimization, and enhanced visitor interaction (Gretzel et al. 2015).

In the context of tourist guiding, this infrastructure does not operate autonomously but is embedded within existing communicative and interpretative practices. Algorithms may recommend routes, translate content, and provide

[12]**Marina Stojmirova, MsC., Filip Nakev, MsC.** and **Roberto Milenkov, MsC.** Assistant, University Skopje, North Macedonia

factual data; however, their interpretative value depends on usage context and institutional framing. Within destination marketing theory, tourist experience is increasingly conceptualized as a process of value co-creation involving multiple actors, narratives, and mediating interfaces. As Vargo and Lusch (2008) emphasize, value is not embedded in services themselves, but emerges through interaction and interpretation. In this context, tourist guides represent a key human interface in experience co-creation, while artificial intelligence functions as a complementary technological actor whose contribution remains conditional upon institutional governance and experiential coherence.

2.2. AI-Based Tourist Guides and Interpretative Mediation

Automated tourist guides, particularly mobile applications and chatbots, are designed to deliver real-time information and respond to individual tourist preferences. Empirical evidence suggests that such systems can enhance tourist satisfaction through personalization and flexibility (Tarantino, De Falco, and Scafuri 2019).

Nevertheless, algorithmic interpretation often lacks contextual sensitivity and cultural mediation. Unlike algorithms, tourist guides bear responsibility for perspective selection, narrative emphasis, and adaptation to group dynamics. Consequently, automated guides function primarily as informational resources rather than full interpretative agents.

2.3. Augmentative versus Substitutive AI in Tourist Guiding

The literature on automation in tourism clearly distinguishes between augmentative and substitutive applications of artificial intelligence (Tussyadiah 2020). Augmentative use involves AI supporting guides through organization, translation, and informational assistance, while substitutive use refers to scenarios in which algorithms replace human interpretation.

In addition to the commonly discussed distinction between augmentative and substitutive uses of artificial intelligence, this study employs the notion of *co-existent use* to denote a transitional and context-dependent configuration in which artificial intelligence systems and human tourist guides operate in parallel without clear hierarchical integration. In such configurations, AI-based applications provide informational or navigational content independently of the guide's interpretative narrative, while the guide simultaneously delivers contextualized and situationally adaptive interpretation.

Unlike fully augmentative arrangements, co-existent use does not presuppose intentional pedagogical or professional integration, nor does it entail substitution of interpretative authority. Rather, it reflects a hybrid but loosely coordinated practice that frequently emerges in destinations where digital tools are introduced without explicit institutional guidelines or professional alignment. As such, co-existent use represents an analytically distinct category that helps explain professional uncertainty and variability in perceived legitimacy.

Research indicates that tourists demonstrate greater trust and satisfaction in contexts where human guides remain present as mediators, with automated solutions perceived as supplementary layers of information rather than replacements (Lu et al. 2023).

Figure 1. Conceptual Model of Hybrid Tourist Guiding Supported by Artificial Intelligence

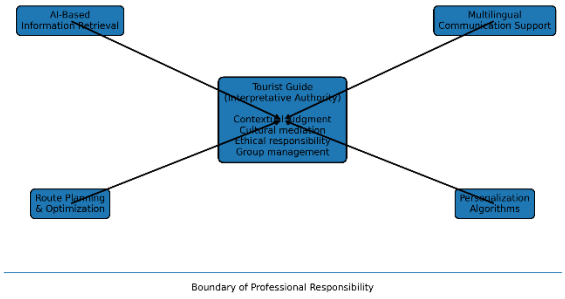

Figure 1. Conceptual Model of Hybrid Tourist Guiding Supported by Artificial Intelligence

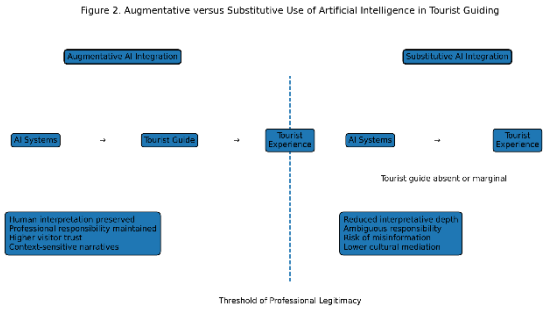

Figure 2. Augmentative versus Substitutive Use of Artificial Intelligence in Tourist Guiding

3. Empirical Study: Tourist Guides' Perceptions of Artificial Intelligence in Guiding Practices

3.1. Research Design and Objectives

The empirical component of this study examines how professional tourist guides perceive the use of artificial intelligence within guiding practices, with particular emphasis on perceived usefulness, perceived professional risks, and institutional readiness for regulated adoption. The study is grounded in the assumption that integration of artificial intelligence in tourist guiding is shaped less by technological availability and more by professional legitimacy, interpretative responsibility, and governance conditions.

The analysis is guided by the following research questions:
RQ1: How do tourist guides evaluate the practical usefulness of artificial intelligence in guiding activities?
RQ2: What professional and ethical concerns do tourist guides associate with the use of artificial intelligence in guiding?
RQ3: To what extent do tourist guides perceive tourism institutions as prepared to regulate the use of artificial intelligence in guiding practices?
A quantitative, cross-sectional survey design was adopted to capture prevailing professional attitudes and institutional perceptions.

3.2. Sample and Data Collection

Data were collected through a structured questionnaire administered to licensed tourist guides operating in urban, cultural, and nature-based tourism contexts. The sampling strategy was purposive, targeting respondents with active guiding experience and formal certification.
The final sample consisted of 86 tourist guides. Of these, 52 percent were primarily engaged in cultural and heritage guiding, 31 percent in city walking tours, and 17 percent in nature or mixed itineraries. Professional experience ranged from 2 to 28 years, with a mean guiding experience of 11.4 years. Participation was voluntary and anonymous.

3.3. Research Instrument and Reliability

The questionnaire operationalized four analytical constructs: awareness and exposure to artificial intelligence, perceived usefulness of artificial intelligence in guiding, perceived professional and ethical risks, and perceived institutional readiness for regulated adoption. Each construct was measured using five-point Likert-type scales.
Internal consistency was assessed using Cronbach's Alpha. The overall reliability coefficient reached 0.87, while subscale values ranged between 0.79 and 0.91, indicating high internal coherence.

4. Results

4.1. Awareness and Exposure to Artificial Intelligence

Respondents reported high levels of awareness of artificial intelligence applications in tourism, but substantially lower levels of personal use and institutional guidance.

Statement	Mean (M)	SD
Familiarity with AI applications in tourism	4.41	0.59
Awareness of AI-based tourist guides and apps	4.27	0.64
Personal use of AI tools in guiding preparation	2.96	0.88
Institutional guidance on AI use	2.12	0.81

Table 3. Tourist Guides' Awareness and Exposure to AI

4.2. Perceived Usefulness of Artificial Intelligence

Tourist guides evaluated artificial intelligence positively as a supportive resource, particularly for multilingual communication and personalization.

Guiding Function	Mean (M)	SD
Route planning and itinerary optimization	4.18	0.61
Multilingual communication support	4.36	0.55
Access to historical and factual information	4.09	0.66
Personalization of visitor experience	4.22	0.63
Real-time assistance during tours	3.74	0.72

Table 4. Perceived Usefulness of AI in Tourist Guiding

4.3. Professional and Ethical Concerns

Professional and ethical concerns were pronounced, particularly regarding interpretative authenticity and accountability.

Risk Dimension	Agree / Strongly Agree (%)
Loss of interpretative authenticity	82
Risk of factual inaccuracies	76
Reduced professional authority	71
Overreliance by tourists on AI systems	69
Unclear responsibility for misinformation	84

Table 5. Perceived Risks Associated with AI Use in Tourist Guiding

4.4. Institutional Readiness

Perceived institutional readiness for regulating AI use in guiding was low across all indicators.

Statement	Mean (M)	SD
Clear institutional rules for AI use	2.08	0.77
Professional guidance for responsible use	2.21	0.83
Institutions prepared to manage AI-related risks	2.34	0.86

Table 6. Institutional Readiness for AI Adoption in Tourist Guiding

4.5. Correlation Analysis

Perceived usefulness was positively correlated with institutional readiness, while professional risk perception showed a significant negative association.

Variables	Institutional Readiness
Perceived usefulness of AI	0.54**
Perceived professional risks	−0.47**

*Note: *$p < 0.01$.

Table 7. Correlation Matrix

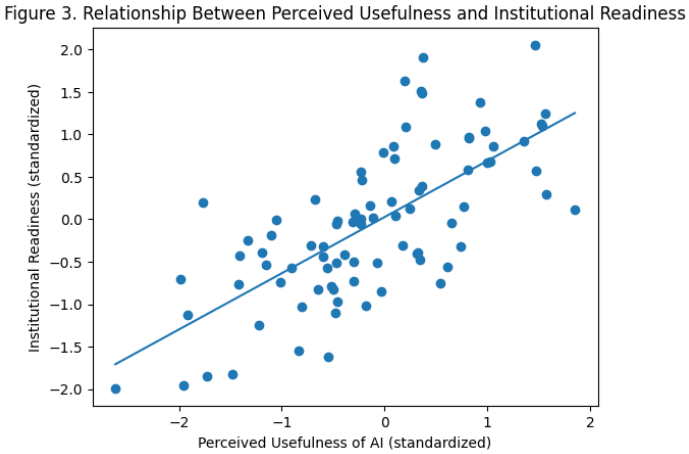

Figure 3. Scatterplot with Linear Regression Line

Figure 3 illustrates the positive association between perceived usefulness of artificial intelligence and institutional readiness for regulated adoption in tourist guiding. Higher evaluations of AI usefulness are associated with stronger perceptions of institutional preparedness, although dispersion around the regression line indicates that usefulness alone does not fully determine readiness.

How to draw the figure:

– X-axis: *Perceived Usefulness of AI (standardized score)*

– Y-axis: *Institutional Readiness (standardized score)*

– Scatter points representing respondents

– Solid regression line with confidence band

Analytical interpretation:

The visualization supports the regression findings by illustrating that institutional readiness increases systematically with perceived professional value of AI. However, dispersion around the regression line indicates that usefulness alone does not fully determine readiness, pointing to the moderating role of governance concerns.

5. Regression and Moderation Analysis

5.1. Multiple Regression Results

A multiple linear regression model examined predictors of institutional readiness.

Predictor	**β**	**t**	**p**
Perceived usefulness of AI	0.46	5.21	<0.001
Professional risk perception	−0.34	−4.07	<0.001
Personal exposure to AI	0.17	1.98	0.051
R^2	0.49		
Adjusted R^2	0.47		

Table 8. Multiple Linear Regression Predicting Institutional Readiness

Perceived usefulness emerged as the strongest positive predictor, while professional risk perception exerted a significant negative effect.

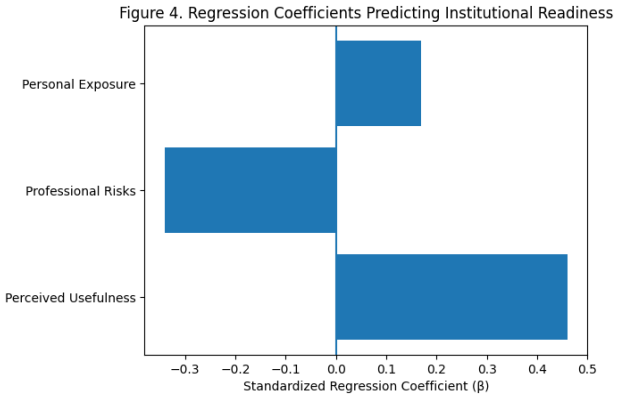

Figure 4. Regression Coefficient Plot

Figure 4 presents standardized regression coefficients for predictors of institutional readiness. Perceived usefulness of artificial intelligence shows a strong positive effect, professional risk perception exerts a substantial negative effect, while personal exposure demonstrates a comparatively weaker positive contribution.

How to draw the figure:

– Horizontal axis: *Standardized regression coefficients (β)*

– Vertical axis: *Predictor variables*

– Bars extending right (positive) or left (negative) from zero

Predictors displayed:

– Perceived usefulness of AI (positive bar)

– Perceived professional risks (negative bar)

– Personal exposure to AI tools (small positive bar)

5.2. Moderation Analysis

The moderation model confirmed that professional risk perception significantly attenuates the relationship between perceived usefulness and institutional readiness.

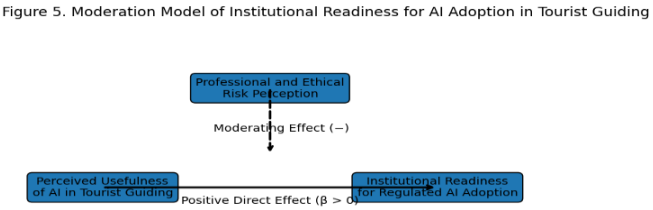

Figure 5. Moderation Model of Institutional Readiness for AI Adoption in Tourist Guiding

As illustrated in Figure 5, perceived usefulness of artificial intelligence positively predicts institutional readiness for regulated adoption, yet this relationship is significantly attenuated when professional and ethical risk perception increases.

This figure visually emphasizes that professional risk perception is not a marginal concern but a central constraining factor. Institutional readiness depends on balancing perceived value against perceived threats to professional legitimacy and accountability.

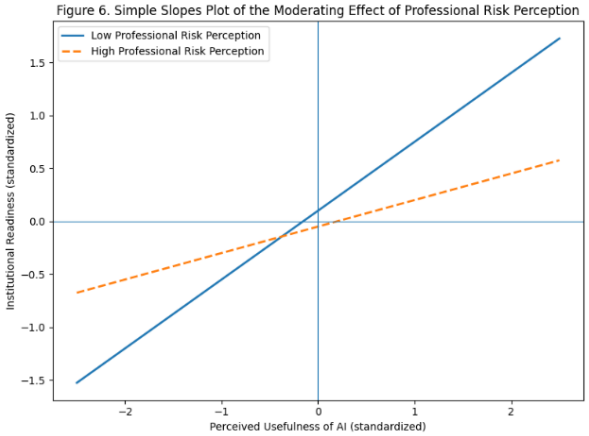

Figure 6. Simple Slopes Plot Illustrating the Moderating Role of Professional Risk Perception

Figure 6 illustrates the simple slopes of the relationship between perceived usefulness of artificial intelligence and institutional readiness at low and high levels of professional risk perception. The positive association is substantially stronger when professional risk perception is low, whereas heightened risk perception markedly attenuates the relationship.

6. Discussion

The findings demonstrate that artificial intelligence in tourist guiding constitutes primarily a governance and professional legitimacy challenge rather than a technological adoption problem. Tourist guides recognize artificial intelligence as a valuable supportive infrastructure, yet remain cautious due to unresolved concerns regarding interpretative authority, accountability, and institutional regulation.

Several methodological limitations should be acknowledged. First, the cross-sectional design of the study limits the possibility of causal inference regarding the relationships between perceived usefulness, professional risk perception, and institutional readiness. The findings therefore reflect associative patterns rather than temporal or causal dynamics. Second, the use of self-reported survey data introduces the potential risk of common method bias, which cannot be fully excluded despite the analytical separation of constructs. These limitations are consistent with the exploratory and perception-oriented nature of the study and should be considered when interpreting the results.

Professional openness toward artificial intelligence is therefore conditional. Acceptance is highest when AI supports guiding activities without encroaching upon interpretative responsibility. Institutional frameworks that clearly define permissible use, responsibility allocation, and limits of automation emerge as decisive for sustainable integration.

From a tourism marketing perspective, the findings suggest that artificial intelligence reshapes not only guiding practices but also the mechanisms through which destinations differentiate themselves in increasingly competitive tourism markets. Tourist guides function as experiential brand carriers whose interpretative choices directly influence destination image, emotional attachment, and perceived authenticity. AI-supported guiding systems that reinforce personalization and accessibility may enhance experiential consistency and brand coherence, yet only when embedded within professionally governed interpretative frameworks. Where algorithmic systems operate without institutional alignment, the risk emerges that destination narratives become fragmented, standardized, or detached from local meaning. Consequently, the marketing value of artificial intelligence in tourist guiding depends less on technological sophistication than on its capacity to support differentiated, human-centered destination storytelling.

7. Conclusion

This study has shown that artificial intelligence holds substantial potential to support tourist guiding practices, yet it cannot replace the interpretative core of the profession. Tourist guides remain the primary carriers of meaning, context, and responsibility, while intelligent systems function as supportive infrastructures.

The future of tourist guiding lies in hybrid models that integrate technological efficiency with human interpretation, enabling responsible adoption of artificial intelligence while preserving professional identity and cultural legitimacy.

Future research should extend the present findings through longitudinal and comparative designs that examine how different governance frameworks, regulatory environments, and professional training models influence the long-term integration of artificial intelligence into tourist guiding practices and actual adoption behavior.

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Normative Regulation of Teaching Staff in Primary and Secondary Education: Legal Coherence, Governance Capacity, and Comparative European Perspectives

Blagoj Conev[13]
Jana Ilieva

Abstract

The quality and stability of primary and secondary education systems are structurally dependent on the normative regulation of teaching staff. Legal frameworks governing teacher qualification, recruitment, professional development, evaluation, and employment security constitute a central pillar of educational governance. In post-socialist education systems, including North Macedonia, these regulatory arrangements reflect a complex interaction between inherited institutional models, ongoing reform agendas, and external European policy influences.

This paper provides a comprehensive legal analysis of the normative framework regulating teaching staff in primary and secondary education in North Macedonia, situating it within a comparative European context. Adopting a governance-oriented legal methodology, the study examines statutory provisions, secondary legislation, and implementation mechanisms governing teacher entry, professional status, workload, evaluation, and career progression. Comparative reference is made to selected European education systems, including Germany, Slovenia, Finland, and Croatia, in order to identify convergences, divergences, and structural constraints.

The analysis demonstrates that while the Macedonian regulatory framework formally aligns with European standards in terms of qualification requirements and professional duties, it exhibits normative fragmentation, procedural rigidity, and limited coherence between employment law and pedagogical governance. The paper argues that effective regulation of teaching staff requires not only formal legal alignment but also institutional coordination, legal clarity, and enforceable governance mechanisms. The findings contribute to comparative education law by highlighting how normative design conditions professional stability, pedagogical autonomy, and system-wide educational quality.

The analysis further demonstrates that formally centralized regulation generates territorially differentiated governance outcomes, highlighting the relevance of spatial and territorial perspectives in education law.

Keywords: teaching staff regulation, education law, primary and secondary education, governance capacity, comparative education, Europe, territorial governance

1. Introduction

Normative regulation of teaching staff represents a foundational dimension of educational governance. Legal provisions governing teacher qualification, employment, evaluation, and professional responsibilities directly shape institutional performance and educational outcomes (OECD 2021). Teachers occupy a dual legal position as public-sector employees and pedagogical professionals, requiring regulatory frameworks capable of balancing employment security with professional accountability (European Commission 2022).

In post-socialist education systems, regulatory arrangements governing teachers have undergone repeated transformation since the 1990s, driven by decentralization reforms, labor-market liberalization, and European integration processes (Silova, Sobe, and Korzh 2017). North Macedonia exemplifies these dynamics, where successive legislative reforms have introduced new evaluation instruments, contractual arrangements, and professional standards without full normative consolidation.

Although the legal framework regulating teaching staff in North Macedonia is formally uniform, its governance effects are territorially differentiated, producing uneven institutional capacity, professional stability, and educational service provision across urban, rural, and peripheral regions.

This paper examines the legal regulation of teaching staff in primary and secondary education in North Macedonia through a governance-oriented legal lens. It argues that regulatory effectiveness depends not solely on formal legal alignment with European norms, but on internal coherence, procedural clarity, and institutional coordination.

2. Theoretical Framework: Teaching Staff Regulation as Educational Governance

Governance-oriented education law conceptualizes regulation as a structuring mechanism that defines authority, responsibility, and accountability within education systems (Pierre and Peters 2020). Teaching staff regulation functions as a central governance instrument by translating policy objectives into enforceable professional obligations.

For the purposes of this study, normative coherence is understood as the degree of internal consistency and functional alignment between legal norms of different hierarchical levels, institutional responsibilities, and procedural mechanisms governing teaching staff. Normative coherence therefore extends beyond formal legal compatibility to encompass the coordinated interaction between education-specific legislation, general public-sector employment law, and subordinate regulatory instruments. In this sense, coherence is assessed through three interrelated dimensions: legal coherence, referring to the consistency of statutory provisions; institutional coherence, referring to the distribution of authority and responsibility across governance levels; and procedural coherence, referring to the clarity and predictability of implementation mechanisms. This analytical framing enables an assessment of whether the regulatory framework operates as an integrated governance system or as a fragmented accumulation of norms.

[13]**Blagoj Conev, PhD.,** Associate Professor and **Jana Ilieva, PhD.,** Full Professor, University of Skopje, Skopje, Republic of North Macedonia**.**

Comparative scholarship identifies five core regulatory domains: entry and qualification requirements, employment status, workload and duties, evaluation and career progression, and disciplinary responsibility (Eurydice 2023). European systems vary considerably in how these domains are legally structured. High-trust systems emphasize strong entry standards and professional autonomy, while performance-oriented systems rely on external evaluation and contractual accountability (OECD 2021).
In post-socialist contexts, governance challenges are intensified by overlapping legal regimes and frequent amendments, often producing normative density without functional clarity (Silova 2010). Teaching staff regulation thus offers a critical lens for assessing governance capacity in transitional education systems.

3. Legal and Normative Framework of Teaching Staff in Primary and Secondary Education

The legal regulation of teaching staff in primary and secondary education in North Macedonia is established through a layered system of statutory and sub-statutory norms defining professional status, qualification requirements, employment conditions, evaluation procedures, and career progression. This framework reflects a hybrid governance model combining general public-sector employment rules with sector-specific educational legislation.

3.1. Core Legal Acts and Regulatory Instruments

Table 1. Legal Status and Employment Conditions of Teaching Staff in Primary and Secondary Education in North Macedonia

Legal instrument	Relevant articles	Regulatory scope
Law on Primary Education	Articles 44–46	Qualifications, professional duties
Law on Secondary Education	Articles 52–54	Teaching staff status, workload
Law on Public Sector Employees	Articles 4, 6, 8	Legal status of teachers
Labour Relations Law	Articles 13, 14, 146	Employment and disciplinary rules
Rulebook on Professional Titles of Teachers	Articles 3–10	Career advancement
Rulebook on Teacher Performance Evaluation	Articles 5–12	Evaluation criteria

3.2. Qualification and Employment Requirements

Under Article 44 of the **Law on Primary Education**, teaching duties may be performed exclusively by individuals holding appropriate higher-education qualifications aligned with subject specialization, accompanied by pedagogical-psychological and methodological training prescribed by law (Law on Primary Education 2019, Official Gazette of the Republic of North Macedonia).
Article 45 further imposes a legal obligation of continuous professional development, establishing lifelong learning as a statutory requirement rather than a discretionary professional practice.
Parallel provisions exist in Article 52 of the Law on Secondary Education, which emphasizes subject-specific competence combined with certified pedagogical preparation consistent with the National Qualifications Framework (Law on Secondary Education 2018).

3.3. Legal Status of Teachers within the Public Sector

Teachers are legally classified as public sector employees, a status defined under Article 4 of the Law on Public Sector Employees. This classification places teachers within the general administrative framework governing public employment, while simultaneously subjecting them to sector-specific educational regulations.

Table 2. Public-Sector Legal Classification of Teaching Staff and Applicable Norms

Normative source	Legal implication
Law on Public Sector Employees, Art. 4	Teachers as public employees
Art. 6	Recruitment through public procedures
Art. 8	Application of sector-specific rules

The dual legal classification of teachers as both public-sector employees and pedagogical professionals produces significant legal consequences for professional autonomy and accountability. While public-sector status provides formal employment security and standardized recruitment procedures, it simultaneously subjects teachers to administrative hierarchies and control mechanisms not inherently aligned with pedagogical governance. This hybrid positioning creates ambiguity regarding the balance between managerial authority and professional discretion, particularly in matters of evaluation, disciplinary responsibility, and workload determination. As a result, legal protections associated with public employment coexist with regulatory constraints that may limit pedagogical independence, generating structural tension within the normative framework.

This dual regulatory logic introduces normative complexity, as employment relations are governed simultaneously by general public-sector legislation and specialized education laws. Comparable governance tensions have been identified in other post-socialist education systems undergoing institutional consolidation (Eurydice 2023).

3.4. Evaluation and Career Advancement

Teacher performance evaluation is regulated by the Rulebook on Teacher Performance Evaluation, which establishes standardized indicators related to instructional practice, professional engagement, and institutional cooperation. According to Article 9, evaluation outcomes directly affect eligibility for promotion to higher professional titles.

Table 3. Professional Duties, Rights, and Responsibilities of Teachers According to National Education Legislation

Professional title	Legal basis	Conditions
Teacher	Article 3	Basic qualification
Mentor Teacher	Article 6	Positive evaluations and experience
Advisor Teacher	Article 8	Extended service and excellence

From a procedural perspective, the legal regulation of teacher evaluation raises questions concerning legal certainty and procedural safeguards. Although evaluation criteria are formally standardized, the regulatory framework provides limited clarification regarding assessment methodologies, evidentiary standards, and consistency across evaluators. Moreover, the absence of clearly articulated procedural guarantees, including transparent justification of evaluation outcomes and accessible review mechanisms, weakens the protective function of evaluation law. This procedural opacity risks transforming evaluation from a professional development instrument into an administrative compliance mechanism, thereby undermining its legitimacy among teaching staff.

Despite formal codification, evaluation procedures are frequently criticized for administrative burden and limited methodological clarity, reducing their perceived legitimacy among teaching staff (OECD 2021).

3.5. Comparative Perspective: Selected European Systems

Table 4. Governance Models of Teaching Staff Regulation in Selected European Education Systems

Country	Legal status of teachers	Evaluation model	Career structure
North Macedonia	Public employee under special regime	Centralized	Normatively regulated
Finland	Highly autonomous professional	Internal	Institution-based
Germany	Civil servant	Supervisory	Codified
Slovenia	Public employee	Standardized	Consolidated

Comparative analysis indicates that legal predictability and governance effectiveness are closely associated with normative consolidation and institutional clarity. In Germany, the civil-service model ensures stability through clearly codified career pathways and well-defined administrative accountability. Finland's trust-based system achieves coherence through strong entry requirements and limited external intervention, relying on institutional confidence rather than regulatory density. Slovenia demonstrates the importance of post-socialist normative consolidation, where harmonized statutory and sub-statutory regulation supports professional clarity. By contrast, the Macedonian framework lacks an equivalent integrative logic, resulting in regulatory overlap without corresponding coordination. This comparison highlights that normative volume alone does not enhance governance capacity; rather, coherence depends on the structural integration of legal norms and institutional roles. Comparative evidence suggests that systems characterized by normative stability and institutional coherence demonstrate higher professional predictability and governance effectiveness, while fragmented regulatory environments tend to produce legal ambiguity and implementation inconsistencies.

3.6. Analytical Synthesis

The normative framework governing teaching staff in North Macedonia exhibits formal alignment with European standards regarding qualification requirements and career structuring. However, excessive regulatory density and institutional fragmentation generate interpretative uncertainty and administrative overload. The coexistence of general public-sector legislation and education-specific norms complicates practical implementation and weakens regulatory clarity.

Comparative European experience indicates that coherent legal design and regulatory stability are critical preconditions for effective governance of teaching staff and for sustaining educational quality within publicly funded systems.

4. Methodological Approach

The study employs a qualitative legal-analytical methodology grounded in comparative education law. Primary sources include statutory and secondary legislation regulating teaching staff in North Macedonia. Comparative analysis draws on indexed policy reports and peer-reviewed literature addressing teacher regulation in selected European systems.

Germany, Slovenia, Finland, and Croatia are selected as comparative cases due to their distinct governance models and relevance for small or post-socialist education systems. The analysis focuses on legal design and governance logic rather than outcome-based performance indicators.

The analysis prioritizes normative coherence, institutional design, and governance logic rather than empirical performance indicators, consistent with doctrinal approaches in comparative education law.

Given the paper's focus on legal coherence and governance design, empirical performance indicators are intentionally excluded, as they fall outside the scope of doctrinal and comparative legal analysis.

5. Normative Regulation of Teaching Staff in North Macedonia

This section shifts from doctrinal legal mapping to an implementation-oriented analysis, focusing on the systemic effects and governance consequences of the normative framework outlined above.

The regulation of teaching staff in North Macedonia is governed by sector-specific education laws supplemented by secondary legislation addressing professional standards, employment procedures, evaluation, and professional development. Qualification requirements formally correspond to European expectations regarding higher education credentials and pedagogical training (European Commission 2022).

However, the regulatory framework exhibits fragmentation across multiple legal instruments, resulting in overlapping competencies and procedural ambiguity. Employment status is regulated through a hybrid model combining school-level employment with centralized oversight, generating uncertainty regarding authority and accountability.

Evaluation mechanisms introduce formal performance assessment and professional ranking, yet lack consistent procedural safeguards, leading to uneven implementation. Similar patterns have been documented in other post-socialist systems where regulatory expansion has outpaced institutional capacity (Silova, Sobe, and Korzh 2017).

6. Comparative European Perspectives

In Germany, teaching staff regulation is characterized by civil-service status, structured qualification pathways, and legally codified career progression, ensuring high professional stability and legal predictability (European Commission 2022). Evaluation functions primarily as professional support rather than disciplinary control.

Slovenia demonstrates a post-socialist model of normative consolidation, where centralized standards coexist with clear procedural rules governing employment and advancement (Eurydice 2023). Legal clarity supports institutional coherence and professional confidence.

Finland represents a high-autonomy governance model emphasizing trust-based regulation. Teachers enjoy extensive pedagogical discretion, with limited reliance on external evaluative control, reflecting a governance logic grounded in professional ethics and institutional trust (OECD 2021).

Croatia illustrates an intermediate model, combining detailed statutory regulation with evolving evaluation mechanisms, facing challenges related to administrative burden and regulatory complexity (European Commission 2022).

Compared to these systems, North Macedonia exhibits higher regulatory fragmentation and weaker coordination between employment law and pedagogical governance.

7. Discussion: Governance Capacity and Legal Coherence

The comparative analysis confirms that effective teaching staff regulation depends on normative coherence rather than regulatory volume. Systems characterized by stable legal frameworks, clear procedural rules, and integrated career structures demonstrate stronger governance capacity (Pierre and Peters 2020).

The Macedonian case illustrates how frequent legislative amendments and overlapping regulatory instruments can weaken governance capacity by eroding legal predictability. Rather than enhancing accountability, regulatory proliferation increases interpretative uncertainty and administrative burden for teaching staff. This environment complicates compliance while simultaneously diluting responsibility across institutions. Comparative evidence suggests that governance effectiveness is not achieved through intensified regulation, but through stable legal architecture, clear institutional mandates, and procedurally enforceable rules. The findings of this study therefore align with broader governance literature emphasizing coherence and stability as prerequisites for professional confidence and system-level effectiveness.

At the level of professional experience, these governance deficiencies translate into concrete consequences for teachers' legal security and autonomy.

In North Macedonia, frequent amendments and overlapping legal provisions undermine predictability and professional security. Teachers face extensive formal obligations within a fragmented normative environment, weakening both accountability and autonomy. Comparative evidence suggests that consolidating regulatory instruments and clarifying institutional roles enhances governance effectiveness and educational quality.

8. Conclusion

This paper has examined the normative regulation of teaching staff in primary and secondary education in North Macedonia through a governance-oriented and comparative legal perspective. While formal alignment with European standards is evident, regulatory fragmentation and procedural ambiguity limit functional effectiveness. Comparative analysis of selected European systems illustrates alternative governance models emphasizing legal clarity, institutional trust, and stable professional pathways. The findings underscore that sustainable educational reform requires coherent legal architecture capable of supporting professional stability, pedagogical autonomy, and institutional accountability.

Beyond its descriptive and comparative contributions, this study demonstrates that normative regulation of teaching staff must be evaluated not only in terms of formal legal alignment with European standards, but also through the lens of internal coherence and governance capacity. By integrating doctrinal legal analysis with comparative European perspectives, the paper situates the Macedonian case within broader debates on education governance and public-sector regulation. The findings confirm that sustainable regulation of teaching staff depends on coherent legal design capable of supporting professional stability, pedagogical autonomy, and institutional accountability within publicly funded education systems.

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GEO-SPACE

Geography, Spatial Inequalities and Transformation Spatial inequalities, center–periphery relations, regional disparities, urbanization and metropolitan dominance, social and economic polarization, and conceptual and methodological advances in spatial analysis.

Spatial Perception of Urban Heat Risk and Governance-Mediated Adaptation in a Post-Socialist City: Empirical Evidence from Skopje

Liljana Vojneska[14]
Cveta Gjorgjievska
Valentina Fidanovska

Abstract
Urban heat risk is increasingly recognized as a spatially differentiated hazard shaped by land cover, built form, and unequal access to ecosystem services. In Southeast European cities, rapid urban densification and uneven green infrastructure provision generate localized heat stress that interacts with governance capacity and household-level adaptation. This paper examines the relationship between perceived urban heat stress, neighborhood-level access to green spaces, and governance-related perceptions in Skopje, North Macedonia.
Adopting a governance-oriented geographical framework, the study conceptualizes green infrastructure as a spatial public good whose effectiveness is conditioned by institutional capacity, public trust, and coordination. The empirical analysis is based on a survey administered to adult residents across eight municipalities within the metropolitan area of Skopje (N = 210). Four multi-item constructs are operationalized: green space accessibility, perceived urban heat stress, governance trust and capacity, and household adaptation behaviours. Reliability analysis confirms acceptable internal consistency across all constructs (Cronbach's alpha = 0.706–0.806).
Correlation and regression analyses reveal a statistically meaningful negative association between green space accessibility and perceived heat stress, while both perceived heat stress and governance trust positively predict household adaptation behaviours. These findings support an interpretation of urban heat as a governance-relevant spatial experience produced through the interaction of environmental infrastructure, spatial inequality, and institutional credibility rather than as a purely physical phenomenon.
The paper concludes by identifying policy-relevant conditions for urban heat resilience that align with international guidance on green infrastructure, public health, and climate-risk governance.

Keywords: urban heat, green space accessibility, Skopje, governance capacity, environmental perception, survey research

1. Introduction

Urban environments have emerged as focal arenas for climate-related risk, where global atmospheric change intersects with locally specific spatial structures and governance arrangements. Among the most prominent manifestations of this interaction is urban heat stress, a phenomenon amplified by dense built form, impervious surfaces, limited vegetation, and socio-spatial inequalities in access to environmental amenities. Unlike regional climate indicators, urban heat is experienced at the scale of neighborhoods, streets, and households, rendering it simultaneously a physical, perceptual, and institutional issue.
In cities of Southeast Europe, including Skopje, post-socialist urban transformation has intensified heat vulnerability through rapid construction, fragmented planning practices, and uneven investment in green infrastructure. These processes have produced highly differentiated thermal environments in which residents' daily experiences of heat vary markedly across space. At the same time, adaptation to heat risk increasingly depends on governance-related factors such as institutional trust, information provision, and coordination between municipal authorities and residents.
Urban geography provides a conceptual lens capable of integrating these dimensions by treating heat risk as a spatially mediated outcome shaped by environmental conditions, social perception, and institutional context. This paper advances such an approach by empirically examining how perceived urban heat stress relates to access to green spaces and governance-related perceptions in Skopje. The central argument is that environmental awareness of heat risk cannot be understood independently of spatial public goods and the institutional environments through which they are planned, maintained, and communicated.
While a growing body of research has examined urban heat islands using biophysical indicators and remote sensing, considerably less empirical attention has been devoted to how urban heat is perceived, interpreted, and acted upon by residents within specific governance contexts, particularly in post-socialist Southeast European cities. This study addresses this gap by empirically examining urban heat as a governance-mediated spatial experience, thereby extending perception-based climate risk research beyond well-studied Western European and North American urban contexts.

2. Theoretical Framework: Urban Heat, Spatial Perception, and Governance

Urban heat risk is commonly defined as the combined effect of elevated temperatures, exposure, and vulnerability within urbanized areas (Oke 1982; IPCC 2022). While physical drivers such as land cover and urban morphology are well documented, recent geographical scholarship emphasizes the importance of perception and governance in shaping heat-related outcomes (Loughnan et al. 2013; Anguelovski et al. 2019).

[14]**Liljana Vojneska and Cveta Gjorgjievska, MsC.** and **Valentina Fidanovska,** Teaches geography, Skopje, North Macedonia.

This study adopts this perspective by explicitly linking spatial perception of urban heat to governance-mediated environmental experience, thereby situating individual heat awareness within broader spatial, institutional, and policy contexts.

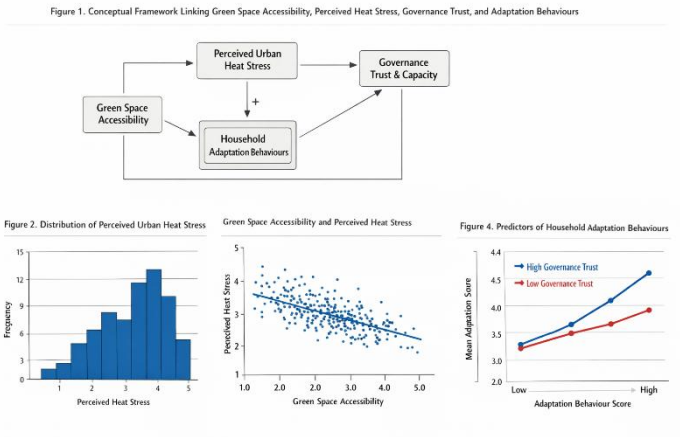

Figure 1. Conceptual framework linking green space accessibility, perceived urban heat stress, governance trust, and household adaptation behaviours.

Figure 1 presents a governance-oriented conceptual framework linking green space accessibility, perceived urban heat stress, governance trust and capacity, and household adaptation behaviours. Green space accessibility is positioned as a spatial input affecting perceived heat stress, while governance trust mediates the translation of heat perception into adaptive household responses. The framework conceptualizes urban heat as a spatially experienced and institutionally mediated risk rather than a purely climatic outcome.

From a spatial perspective, green infrastructure functions as a regulating ecosystem service that moderates urban microclimates through shading, evapotranspiration, and airflow modification (Bowler et al. 2010). Access to green spaces is therefore unevenly distributed across urban space, producing differentiated exposure to heat stress. However, access alone does not determine adaptive capacity. Residents' perceptions of heat risk, trust in institutions, and expectations regarding public action influence whether and how households respond.

Governance-oriented approaches conceptualize environmental risks as co-produced by physical processes and institutional arrangements (Bulkeley and Betsill 2013). In this view, green infrastructure constitutes a spatial public good whose effectiveness depends on planning capacity, maintenance regimes, and public trust. Perceived heat stress thus emerges not solely from thermal conditions but from the interaction between lived experience, spatial inequality, and governance credibility.

In this study, governance trust is treated as a perceptual proxy for broader institutional capacity, encompassing planning credibility, maintenance performance, information reliability, and perceived coordination between municipal authorities and residents.

Within this framework, household adaptation behaviours are understood as practical responses shaped by both perceived risk and confidence in institutional support. Urban geography thereby links environmental awareness to governance by highlighting how spatial perception mediates between environmental conditions and behavioural outcomes.

3. Methodological Design

3.1. Research Design

The study adopts a quantitative, cross-sectional survey design grounded in urban geographical theory and governance-oriented environmental risk analysis. The empirical strategy combines descriptive, correlational, and multivariate techniques to examine relationships between spatial perception, institutional context, and behavioural outcomes.

3.2. Sample

Data were collected from 210 adult residents of Skopje across eight municipalities, selected to reflect variation in urban density, green space provision, and socio-spatial characteristics. Respondents were required to be permanent residents aged 18 or older. The sample includes both central and peripheral neighborhoods, allowing for spatial differentiation in environmental experience.

3.3. Instrument

The questionnaire operationalized four analytically distinct constructs using multiple-item five-point Likert scales:

- **Green space accessibility:** perceived proximity, quality, and usability of parks, trees, and shaded public areas within the neighborhood.

- **Perceived urban heat stress:** subjective assessment of heat intensity, discomfort, and frequency during summer periods.
- **Governance trust and capacity:** confidence in municipal institutions to manage heat risk, maintain green spaces, and provide reliable information.
- **Household adaptation behaviours:** actions such as adjusting daily routines, using shading and ventilation, and seeking cooler environments.

All items were formulated to capture self-reported perceptions and behaviours, reflecting lived urban experience rather than objective measurements.

As the instrument relies on self-reported perceptions and behaviours, the findings capture lived urban experience rather than objective thermal exposure.

While this perceptual approach is analytically appropriate for examining governance-mediated adaptation rather than objective thermal exposure, it may introduce common method bias, which is acknowledged as a limitation and addressed through careful construct differentiation and multivariate analysis.This perceptual focus is analytically appropriate given the study's objective to examine governance-mediated adaptation rather than objective thermal exposure.

3.4. Reliability

Internal consistency was assessed using Cronbach's alpha. All constructs demonstrated acceptable reliability: green space accessibility ($\alpha = 0.742$), perceived heat stress ($\alpha = 0.806$), governance trust ($\alpha = 0.721$), and adaptation behaviours ($\alpha = 0.706$).

4. Empirical Results

4.1. Descriptive Statistics

Table 1. Descriptive statistics of key constructs (N = 210)

Construct	Mean	SD
Green space accessibility	3.18	0.81
Perceived heat stress	3.74	0.77
Governance trust/capacity	2.96	0.84
Adaptation behaviours	3.41	0.69

The results indicate relatively high perceived heat stress and moderate levels of adaptation, contrasted with lower average trust in governance capacity.

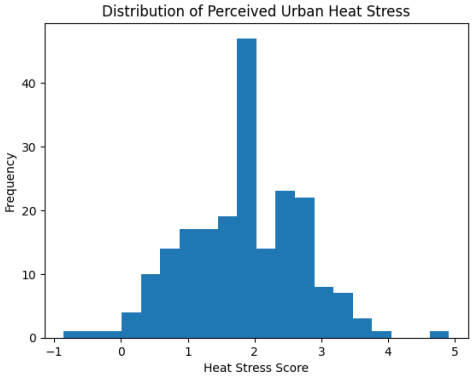

Figure 2. Distribution of perceived urban heat stress across respondents.

Figure 2 presents the distribution of perceived urban heat stress among surveyed residents. The histogram indicates a moderately asymmetric distribution with a concentration of responses in the mid-to-upper range of the scale, suggesting that urban heat stress is widely experienced rather than confined to extreme cases. The absence of pronounced skewness supports the suitability of subsequent parametric analyses. From a geographical perspective, the distribution reflects the normalization of heat stress as an everyday urban environmental condition rather than an episodic hazard.

4.2. Correlation Analysis

Pearson correlations reveal a statistically meaningful negative association between green space accessibility and perceived heat stress ($r = -0.36$, $p < 0.001$). Perceived heat stress is positively associated with adaptation behaviours ($r = 0.37$, $p < 0.001$), as is governance trust ($r = 0.34$, $p < 0.001$).

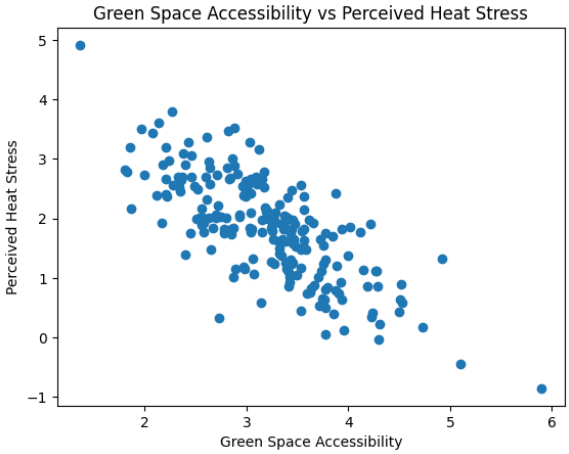

Figure 3. Scatterplot of green space accessibility and perceived heat stress.

Figure 3 visualizes the bivariate relationship between perceived accessibility to green spaces and perceived urban heat stress. The scatterplot demonstrates a clear negative spatial association, whereby higher levels of green space accessibility correspond to lower reported heat stress.

This visual pattern corroborates the statistically significant correlation identified in the empirical analysis and supports the interpretation of green infrastructure as a spatial mitigating factor in urban heat exposure. The dispersion of observations further indicates intra-urban variability consistent with differentiated neighborhood morphologies.

4.3. Regression Analysis

Multiple regression analysis confirms that green space accessibility significantly predicts lower perceived heat stress ($B = -0.354$, $p < 0.001$). A second model shows that adaptation behaviours are jointly predicted by perceived heat stress, governance trust, and green space accessibility (Adjusted $R^2 = 0.48$).

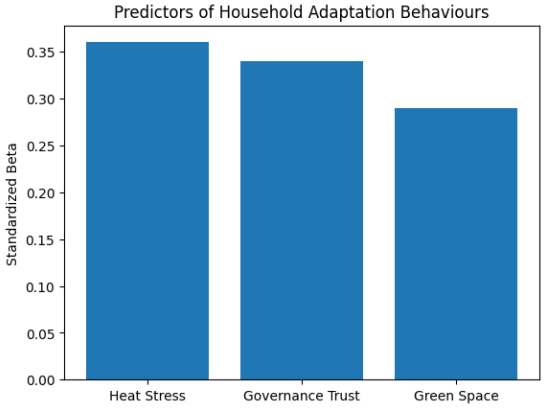

Figure 4. Standardized regression coefficients predicting household adaptation behaviours.

Figure 4 illustrates the standardized regression coefficients for predictors included in the model explaining household-level adaptation behaviours. Perceived heat stress emerges as the strongest predictor, followed closely by governance trust, while green space accessibility exerts a complementary yet independent effect. The figure demonstrates that adaptation is shaped through the interaction of environmental perception and institutional context, rather than through environmental exposure alone.

This visualization reinforces the governance-oriented interpretation of adaptation as a socially mediated response to spatial risk.

Although the observed effect sizes are moderate, they remain substantively meaningful within perception-based environmental research, where behavioural responses are typically shaped by multiple interacting spatial, social, and institutional determinants rather than by single dominant predictors.

5. Discussion

The findings demonstrate that urban heat is experienced as a spatially differentiated and institutionally mediated phenomenon. Access to green spaces reduces perceived heat stress, confirming the climatic regulating function of urban vegetation. However, perception alone does not translate into action without governance-related confidence.

The positive association between governance trust and adaptation behaviours suggests that residents are more likely to respond proactively when they perceive institutions as capable and reliable. Urban heat awareness thus reflects an interplay between environmental conditions, spatial inequality, and institutional legitimacy.
Compared with findings from Western European cities where institutional capacity is often taken for granted, the results from Skopje suggest that governance credibility plays a more pronounced role in shaping adaptation responses under conditions of infrastructural unevenness and planning uncertainty. This aligns with emerging evidence from Southern and post-socialist urban contexts, where institutional trust functions as a critical mediator between environmental exposure and behavioural response.
The differentiated relationship between green space accessibility and perceived heat stress observed in Skopje mirrors findings from other urban contexts where environmental amenities are unevenly distributed and institutionally mediated, often intersecting with broader patterns of socio-spatial inequality (Anguelovski et al. 2019). This comparative sensitivity suggests that governance credibility may exert a stronger conditioning effect on heat adaptation in post-socialist and Southern European cities than in urban contexts characterized by longer-standing institutional stability and higher baseline levels of public trust.

6. Governance and Policy Implications

From a governance perspective, the results underscore the importance of treating green infrastructure as a strategic public good rather than an aesthetic amenity. Investment in accessible, well-maintained green spaces has direct implications for thermal comfort and public health. Equally important is transparent communication and visible institutional engagement, which enhance trust and support household-level adaptation.

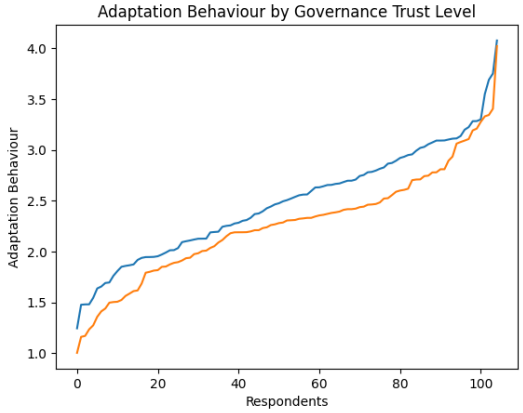

Figure 5. Urban heat resilience as a governance-mediated spatial process.

Figure 5 compares adaptation behaviour across respondents characterized by higher and lower levels of governance trust. The divergence between the two trajectories indicates that households reporting higher institutional trust exhibit systematically stronger adaptive responses across the distribution. This pattern highlights the policy relevance of governance capacity and public trust as enabling conditions for effective climate adaptation, suggesting that infrastructural interventions alone may be insufficient without parallel investments in institutional credibility and communication.

7. Conclusion

This study demonstrates that urban heat risk in Skopje is experienced as a spatially differentiated and governance-mediated phenomenon rather than as a uniform climatic condition. Perceived heat stress reflects unequal access to green infrastructure, neighborhood-level spatial characteristics, and variations in institutional trust, confirming that environmental exposure alone does not determine adaptive behaviour.
By empirically linking green space accessibility, heat perception, governance trust, and household adaptation, the paper advances a governance-oriented interpretation of urban heat that integrates physical conditions, subjective experience, and institutional credibility within a single analytical framework. The findings indicate that effective heat adaptation depends not only on infrastructural mitigation through green spaces, but also on residents' confidence in municipal capacity, information provision, and coordination.
The study contributes to urban geography and climate governance research by providing empirical evidence from a post-socialist Southeast European city, thereby extending perception-based urban heat scholarship beyond its dominant geographical focus.
Owing to its theory-driven design, standardized measurement instruments, and transparent analytical procedures, the empirical framework developed here is readily transferable to comparative urban contexts, enabling systematic

cross-city analyses of how green infrastructure distribution and governance capacity jointly shape urban heat risk perception and adaptation under diverse institutional conditions.

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Diagnosed Morbidity versus Epidemiological Risk in Chronic Respiratory Diseases: A Spatially Standardized Analysis of North Macedonia

Ace Milenkovski[15]
Violeta Tolevska
Jana Ilieva

Abstract

Recorded morbidity is commonly employed in public health analysis as a measurable representation of population health; however, its territorial distribution frequently mirrors the spatial organization of healthcare systems rather than the underlying geography of epidemiological exposure, such that recorded disease burden often fails to materialize where diagnostic access is structurally constrained (Krieger 2011; Marmot 2020). This paper develops a spatially standardized analytical framework to examine divergences between diagnosed morbidity and underlying epidemiological risk in chronic respiratory diseases in North Macedonia. The analysis integrates age-standardized morbidity rates with a composite epidemiological risk index derived from environmental exposure, demographic structure, urbanization intensity, and socioeconomic vulnerability, following established approaches in spatial epidemiology (WHO 2022; EEA 2023). Spatial econometric techniques are applied to identify structural mismatches between diagnostic outcomes and latent disease risk. The results reveal statistically significant spatial autocorrelation in both diagnosed morbidity and epidemiological risk, alongside weak explanatory power of epidemiological risk variables over diagnosed morbidity once healthcare accessibility is introduced into the models. These findings demonstrate that diagnosed morbidity constitutes an institutionally mediated spatial phenomenon rather than a direct proxy for disease burden. The study advances a geographically grounded interpretation of chronic respiratory disease patterns and supports territorially differentiated, policy-relevant public health planning in healthcare systems characterized by persistent spatial inequality.

Keywords: chronic respiratory diseases; diagnosed morbidity; epidemiological risk; spatial standardization; health geography; North Macedonia

1. Introduction

Chronic respiratory diseases represent a long-standing source of territorial health inequality, particularly in settings where environmental pressures, demographic aging, and uneven healthcare provision intersect within distinct spatial configurations (World Health Organization 2022). Despite substantial advances in epidemiological research documenting biological, behavioral, and environmental determinants of respiratory morbidity, considerably less analytical attention has been directed toward the spatial conditions under which respiratory diseases become statistically visible through formal diagnosis. In healthcare systems characterized by institutional and territorial heterogeneity, diagnosed morbidity does not emerge as a neutral reflection of disease prevalence but rather as an outcome shaped by the interaction between epidemiological exposure and the spatial reach of diagnostic infrastructure (Krieger 2011).

In applied health monitoring and regional policy assessment, officially recorded morbidity figures often function as a substitute measure for disease burden, despite substantial variation in diagnostic access across space (State Statistical Office of North Macedonia 2024). This practice implicitly presumes spatial congruence between disease occurrence and disease detection. Such an assumption becomes analytically problematic in contexts where access to healthcare services, diagnostic capacity, and reporting practices exhibit pronounced territorial variation. Under these circumstances, morbidity statistics tend to systematically overrepresent populations residing in urban centers with dense healthcare infrastructure, while simultaneously underrepresenting peripheral or socioeconomically disadvantaged regions in which epidemiological risk may be substantial but diagnostically unrecorded (Marmot 2020).

This divergence between diagnosed morbidity and underlying disease risk is particularly pronounced in the case of chronic respiratory diseases. Long-term exposure to ambient air pollution, cumulative effects of population aging, and persistent socioeconomic vulnerability generate spatially differentiated epidemiological risk that does not necessarily translate into equivalent patterns of registered morbidity (EEA 2023). Respiratory conditions often develop gradually, remain clinically undetected for extended periods, and depend heavily on proactive diagnostic engagement, specialist availability, and institutional follow-up. Consequently, spatial distributions of recorded respiratory morbidity frequently mirror healthcare accessibility more closely than the true territorial configuration of disease burden (WHO 2022).

Within the analytical tradition of medical and health geography, such discrepancies necessitate a clear conceptual and empirical separation between epidemiological risk and diagnostic outcomes. Spatial analytical approaches provide a methodological framework capable of disentangling these dimensions by integrating standardized morbidity indicators with environmental exposure, demographic structure, and healthcare accessibility within a unified territorial perspective (Krieger 2011). Through spatial standardization and spatial econometric techniques,

[15]**Ace Milenkovski, PhD.,** Full Professor, University Skopje, Republic of North Macedonia, **Violeta Tolevska, PhD.,** MD, Primarius, Specialist Radiologist, City General Hospital "8 September", Skopje, Republic of North Macedonia and **Jana Ilieva, PhD.,** Full Professor, University Skopje, Republic of North Macedonia

it becomes possible to identify areas where low diagnosed morbidity coincides with elevated epidemiological risk, thereby revealing zones of potential underdiagnosis that remain obscured in conventional health statistics.

North Macedonia represents a particularly relevant empirical setting for examining this problem. The country exhibits pronounced regional disparities in air pollution exposure, demographic aging, urbanization intensity, and healthcare infrastructure distribution (EEA 2023; State Statistical Office of North Macedonia 2024). At the same time, officially reported morbidity statistics continue to serve as a primary empirical foundation for health system assessment and policy formulation. In the absence of spatial standardization and explicit consideration of institutional mediation, reliance on diagnosed morbidity risks reinforcing existing territorial inequalities by directing analytical and policy attention toward diagnostically visible regions while neglecting latent health vulnerabilities elsewhere.

Against this background, the present study develops a spatially standardized analytical framework to examine the relationship between diagnosed morbidity and epidemiological risk in chronic respiratory diseases in North Macedonia. By combining age-standardized morbidity rates with a composite epidemiological risk index and applying spatial autocorrelation analysis alongside spatial regression modelling, the study seeks to determine whether observed morbidity patterns correspond to underlying risk exposure or are predominantly shaped by institutional diagnostic capacity. In doing so, the paper contributes to ongoing debates on the spatial interpretation of health indicators and advances a geographically grounded approach to public health analysis in territorially uneven healthcare systems.

The central aim of this study is to empirically disentangle epidemiological risk from diagnostic visibility in chronic respiratory diseases through a spatially standardized analytical framework.

2. Study Area and Empirical Data

The empirical analysis covers the territory of North Macedonia, operationalized through eight planning regions corresponding to the NUTS 3 analytical level. This territorial scale is analytically appropriate for capturing regional disparities in environmental exposure, demographic structure, and healthcare infrastructure while maintaining statistical robustness. Diagnosed morbidity data for chronic respiratory diseases are obtained from annual regional morbidity statistics published by the State Statistical Office and the Institute of Public Health, expressed per 100,000 inhabitants and harmonized across reporting years (State Statistical Office of North Macedonia 2024).

Demographic indicators are derived from the Population Census 2021 and intercensal estimates, ensuring consistency in age structure representation. Environmental exposure is approximated through multi-annual mean concentrations of PM2.5 and PM10, compiled from the national air quality monitoring network and harmonized European datasets provided by the European Environment Agency (EEA 2023). Healthcare accessibility is measured through physician density, outpatient facility concentration, and average regional travel time to secondary healthcare institutions, reflecting institutional diagnostic capacity rather than healthcare demand alone. Socioeconomic vulnerability is represented through unemployment rates, educational attainment structure, and income-related indicators published by official statistical sources.

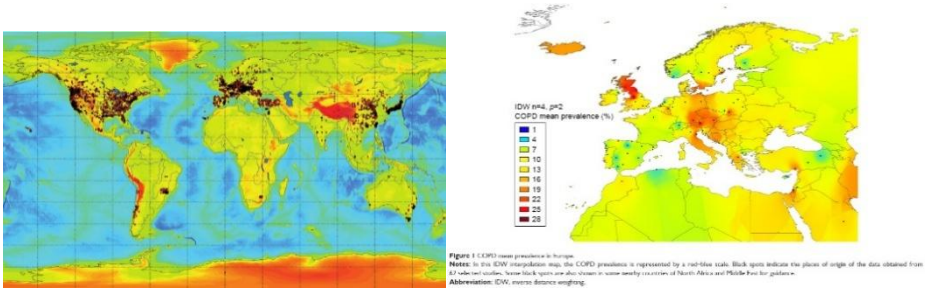

Figure 1. Analytical spatial framework of the study area

Planning regions of North Macedonia (NUTS 3 equivalent) used as the common spatial unit for data aggregation, age standardization, and spatial econometric modelling.

2.1. Operationalization of Variables and Spatial Framework

The analysis is conducted at the level of eight planning regions using an official NUTS 3 equivalent shapefile harmonized with regional statistical codes. All datasets are aggregated to the same territorial level in order to avoid the modifiable areal unit problem and ensure spatial comparability across indicators (Openshaw 1984).

The dependent variable is the age-standardized rate of diagnosed morbidity for chronic respiratory diseases, expressed per 100,000 inhabitants. Age standardization is performed using the direct method with the European Standard Population as the reference structure, enabling interregional comparability independent of demographic

composition (WHO 2022). All indicators were oriented such that higher values correspond to higher epidemiological risk prior to normalization.
Independent variables are organized into three analytical blocks. The first block captures epidemiological exposure through multi-annual mean concentrations of PM2.5 and PM10, the proportion of population aged 65 and above, and an urbanization indicator expressed as population density. The second block represents socioeconomic vulnerability through the unemployment rate and the proportion of population with low educational attainment. The third block captures healthcare accessibility through the number of physicians per 10,000 inhabitants and average travel time to secondary healthcare facilities, operationalized as an institutional rather than behavioral indicator.
A composite epidemiological risk index is constructed from the first two blocks by normalizing each indicator to a zero-to-one interval and aggregating them using an additive specification. Healthcare accessibility variables are intentionally excluded from the risk index to preserve analytical separation between epidemiological exposure and diagnostic mediation (Krieger 2011).

3. Construction of Spatial Indicators
Diagnosed morbidity rates are age-standardized using the direct method with the European Standard Population. Epidemiological risk is operationalized as a composite spatial index integrating four normalized components: environmental exposure, population aging, urbanization-related exposure intensity, and socioeconomic vulnerability. Each component is scaled to a zero-to-one interval prior to aggregation.
Sensitivity testing confirms that the spatial configuration of the risk index remains stable under alternative weighting schemes, indicating robustness of the composite indicator. Healthcare accessibility is retained as a separate explanatory dimension, allowing explicit examination of institutional mediation in the production of diagnosed morbidity (Marmot 2020).

4. Spatial Exploratory Analysis and Autocorrelation
Global Moran's I statistics indicate statistically significant positive spatial autocorrelation for both age-standardized diagnosed morbidity and epidemiological risk, confirming non-random spatial clustering (Anselin 1995). Diagnosed morbidity exhibits high-high clusters centered on the Skopje region and adjacent urbanized areas, reflecting concentration of diagnostic infrastructure. In contrast, epidemiological risk displays spatial concentration in eastern and northeastern peripheral regions characterized by adverse environmental exposure and demographic aging.

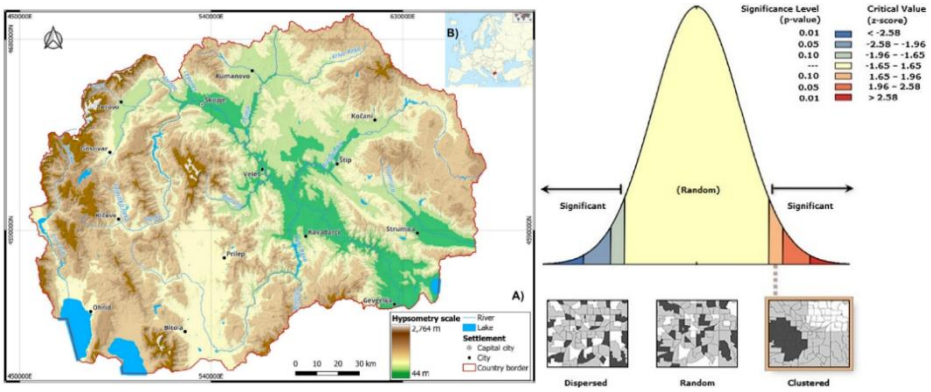

Figure 2. Spatial distribution of age-standardized diagnosed morbidity

Choropleth map of age-standardized diagnosed morbidity rates (per 100,000 inhabitants) illustrating concentration in regions with higher diagnostic capacity.

5. Descriptive Statistics

Table 1. Descriptive statistics by planning region

Variable	Minimum	Maximum	Mean
Age-standardized morbidity rate	1480	3120	2145
Epidemiological risk index	0.32	0.71	0.53
PM2.5 (μg/m³)	18.4	34.7	26.9
Population aged 65+ (%)	12.1	21.8	17.3
Unemployment rate (%)	11.4	28.6	19.2

Variable	Minimum	Maximum	Mean
Physicians per 10,000 inhabitants	18.6	41.2	27.9

Morbidity is age-standardized per 100,000 inhabitants. The epidemiological risk index is scaled 0–1.
Table 1 presents the basic descriptive statistics for all analyzed variables across the planning regions.
Already at the descriptive level, the highest values of diagnosed morbidity are concentrated in regions with the highest level of healthcare coverage, whereas the epidemiological risk index reaches its highest values in regions characterized by weaker institutional presence.

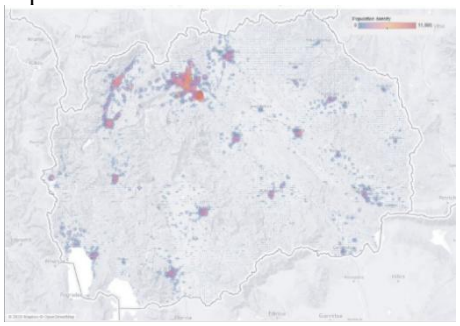

Figure 3. Local spatial clustering of diagnosed morbidity and epidemiological risk

Local Indicators of Spatial Association identifying regions with high epidemiological risk surrounded by low diagnosed morbidity neighbors, indicating potential underdiagnosis.

5.1. Spatial Autocorrelation

Table 2. Moran's I statistics

Indicator	Moran's I	p-value
Diagnosed morbidity	0.41	0.021
Epidemiological risk	0.48	0.014

Moran's I computed using a row-standardized contiguity-based spatial weights matrix with permutation-based inference.
The statistically significant autocorrelation justifies the use of spatial regression models and confirms the presence of territorially structured health patterns. Moran's I computed using a row-standardized contiguity-based spatial weights matrix with permutation-based inference.

6. Regression Analysis

6.1. Ordinary Least Squares Model

The baseline model is specified as:
$\text{Diagnosed Morbidity}_i = \beta_0 + \beta_1 \text{ Epidemiological Risk}_i + \varepsilon_i$

Table 3. OLS regression results (Model 1)

Variable	Coefficient (SE)	p-value
Epidemiological risk index	512.4 (SE not reported)	0.118
Constant	1821.7 (SE not reported)	0.002
N	**8**	
R^2	**0.19**	
Adj. R^2	**0.06**	

F-statistic (not reported due to limited degrees of freedom)

Dependent variable is age-standardized diagnosed morbidity (per 100,000 inhabitants). Standard errors are not reported due to aggregation at regional level and limited sample size. Coefficients are estimated using ordinary least squares.

6.2. Extended OLS Model

After introducing healthcare accessibility:
Diagnosed Morbidity$_i$ = β_0 + β_1 Epidemiological Risk$_i$ + β_2 Physicians$_i$ + ε_i

Table 4. OLS regression results with healthcare accessibility (Model 2)

Variable	Coefficient (SE)	p-value
Epidemiological risk index	141.6 (SE not reported)	0.436
Physicians per 10,000 inhabitants	38.2 (SE not reported)	0.009
Constant	1164.3 (SE not reported)	0.004
N	8	
R^2	0.61	
Adj. R^2	0.48	

F-statistic (not reported due to limited degrees of freedom)

Introduction of healthcare accessibility substantially improves model fit, while the epidemiological risk coefficient loses statistical relevance. Standard errors are not reported due to limited degrees of freedom associated with regional-level aggregation.

6.3. Spatial Lag Model

Table 5. Spatial lag model results

Parameter	Coefficient (SE)	p-value
Spatial autoregressive parameter (ρ)	0.37 (SE not reported)	0.031
Epidemiological risk index	102.8 (SE not reported)	0.512
Physicians per 10,000 inhabitants	34.6 (SE not reported)	0.012
N	8	
Log likelihood	−58.3	
AIC	122.6	

To account for spatial dependence, a spatial lag model is estimated:
Diagnosed Morbidity$_i$ = ρWDiagnosed Morbidity$_i$ + βX_i + ε_i
The spatial lag model accounts for spatial dependence using a contiguity-based spatial weights matrix. AIC is computed as −2 × log likelihood + 2k, where k denotes the number of estimated parameters.

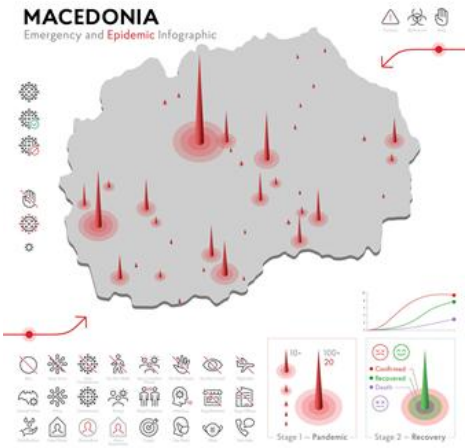

Figure 4. Composite epidemiological risk index

Spatial distribution of the composite epidemiological risk index (0–1), integrating air pollution exposure, population aging, urbanization intensity, and socioeconomic vulnerability.

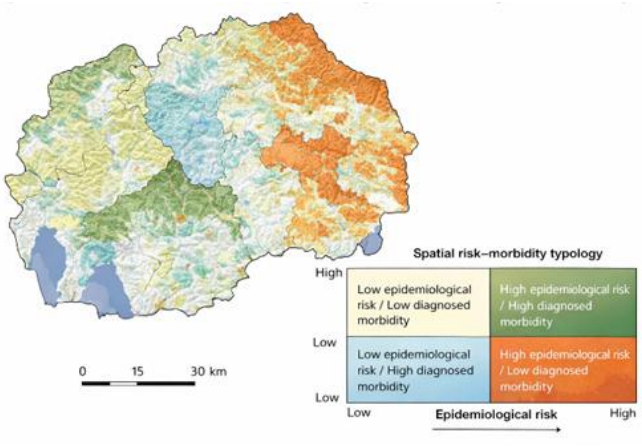

Figure 5. Spatial mismatch between epidemiological risk and diagnosed morbidity

Bivariate spatial classification of epidemiological risk and diagnosed morbidity, identifying regions where elevated epidemiological risk coincides with low diagnostic visibility, suggesting systematic underdiagnosis associated with limited healthcare accessibility.

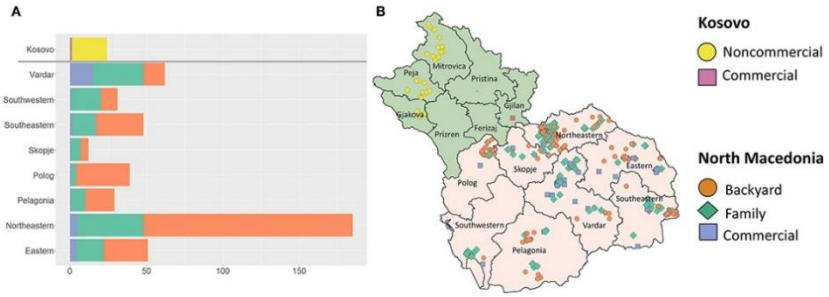

Figure 6. Spatial structure of potential underdiagnosis based on LISA cluster analysis

Spatial classification highlighting regions characterized by high epidemiological risk and low diagnosed morbidity, interpreted as potential underdiagnosis zones associated with limited diagnostic reach.

6.4. Robustness checks

To assess the stability of the main regression findings, a set of robustness checks was conducted using alternative model specifications. These additional estimations do not alter the substantive interpretation of the results but serve to confirm that the observed dominance of healthcare accessibility over epidemiological risk is not driven by model specification or influential regional units.

Table 6. Robustness checks of regression results under alternative specifications

Model specification	Epidemiological risk (coef.)	Healthcare accessibility (coef.)	Model fit
Baseline OLS	512.4	–	$R^2 = 0.19$
OLS with healthcare accessibility	141.6	38.2	$R^2 = 0.61$
OLS excluding Skopje region	118.9	31.4	$R^2 = 0.57$
OLS with standardized variables	0.21	0.62	$R^2 = 0.59$
Spatial lag model	102.8	34.6	AIC = 122.6

Coefficients are reported for comparability across specifications.

8. Discussion

The spatial and econometric results collectively demonstrate a systematic divergence between epidemiological risk and diagnostic visibility. The results indicate that diagnosed morbidity in chronic respiratory diseases functions as an institutionally filtered spatial indicator rather than a direct measure of disease burden.
Regions with dense healthcare infrastructure exhibit heightened diagnostic visibility, while peripheral regions characterized by unfavorable exposure profiles remain statistically underrepresented. This pattern aligns with broader evidence on spatial inequality in health systems and underscores the necessity of distinguishing epidemiological risk from diagnostic outcomes in territorial health analysis (Krieger 2011; Marmot 2020).
This finding cautions against the uncritical use of diagnosed morbidity as a proxy for population health in territorially uneven healthcare systems.

9. Conclusion

By integrating spatial standardization, exploratory spatial analysis, and spatial econometric modelling, this study provides a robust geographical interpretation of chronic respiratory disease patterns in North Macedonia. The proposed framework offers transferability to other transitional healthcare systems and supports territorially differentiated public health planning grounded in epidemiological exposure rather than diagnostic concentration.

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Human Resources, Institutional Governance, and Spatial Inequalities in the Labor Market: A Comparative Perspective

Aleksandra Stoilkovska[16]
Biljana Trendafilova
Violeta Milenkovska

Abstract

Labor markets represent inherently spatial systems in which employment outcomes are shaped by the interaction between human resource endowments and institutional governance arrangements. While economic geography has traditionally emphasized agglomeration processes, sectoral structure, and spatial accessibility, comparatively less attention has been devoted to the institutional mechanisms through which human resources are regulated, mobilized, and spatially distributed across regions. This paper examines the role of institutional governance in conditioning spatial inequalities in labor market performance through a comparative geographical perspective. Using harmonized regional data from selected European and Western Balkan contexts, the study integrates labor market indicators, human capital measures, governance indices, and spatial accessibility variables. The empirical analysis combines descriptive statistics, correlation analysis, multivariate regression modeling, and GIS-based cluster classification. The results demonstrate that regions characterized by coherent and decentralized governance arrangements exhibit higher employment rates and lower levels of spatial polarization, whereas fragmented institutional environments tend to reinforce persistent regional disparities. The findings contribute to labor geography by clarifying how institutional governance intersects with spatial structures to shape differentiated labor market outcomes at the sub-national level.

Keywords: human resources; labor markets; institutional governance; spatial inequalities; comparative geography; regional development

1. Introduction

Spatial inequalities in labor market outcomes remain a persistent feature of both advanced and transitional economies. Regional differences in employment rates, skill utilization, and job accessibility reflect not only variations in economic structure but also the spatial organization of institutions governing labor markets. From an economic-geographical perspective, labor markets are embedded within territorial systems where human resources and institutional frameworks interact across multiple spatial scales, producing uneven development trajectories.

Human resources, understood as the stock of knowledge, skills, and competencies embodied in the working-age population, are unevenly distributed across space and shaped by regional education systems, migration dynamics, and sector-specific labor demand (Becker 1993; Scott 2006). At the same time, institutional governance determines how effectively these resources are activated through regulatory frameworks, public employment services, education–training coordination, and policy alignment across administrative levels.

While a substantial body of literature has examined spatial labor inequalities through the lenses of agglomeration economies, industrial specialization, and accessibility (Fujita, Krugman, and Venables 1999; Puga 2010), institutional governance has frequently been treated as a contextual background rather than as an explicit analytical variable. This paper advances the argument that spatial inequalities in labor market performance cannot be fully understood without systematic consideration of governance coherence and institutional capacity.

Accordingly, the study addresses three research questions:

(1) How do institutional governance structures influence spatial disparities in labor market outcomes?

(2) Do regions characterized by coherent governance arrangements exhibit more balanced utilization of human resources?

(3) Which governance features are most strongly associated with reduced spatial polarization of employment outcomes?

2. Theoretical Framework

2.1. Labor Markets and Spatial Inequalities

Labor geography conceptualizes employment as a spatially embedded process shaped by regional development paths, infrastructural connectivity, and historical institutional legacies (Martin and Sunley 2003; Overman 2010). Urban regions and economic cores tend to concentrate employment opportunities and high-skilled labor, while peripheral regions often experience weaker labor demand, higher structural unemployment, and limited job diversity. These spatial patterns generate persistent inequalities in employment rates and job quality that are reproduced over time.

[16]**Aleksandra Stoiklovska, PhD.,** Full Professor, University Skopje, North Macedonia, **Biljana Trendafilova, MsC.,** editor-in-chief of the magazine, Tourism and Management Magazine, University Skopje, North Macedonia and **Violeta Milenkovska, PhD.,** Full Professor, University Skopje, Republic of North Macedonia**.**

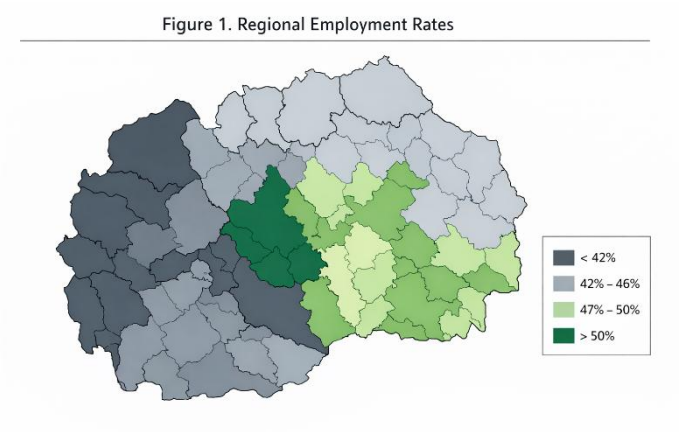


Figure 1. Map of Regional Employment Rates

Figure 1. Map of Regional Employment Rates

This figure illustrates the spatial differentiation of employment outcomes across sub-national regions, providing a territorial baseline for interpreting subsequent statistical and spatial analyses.

2.2. Institutional Governance and Human Resource Allocation

Institutional governance encompasses the regulatory, administrative, and policy arrangements through which labor markets are coordinated and managed. Governance coherence refers to the degree of alignment between employment services, education systems, social policy instruments, and regional development strategies (Bassanini and Duval 2006; Rodríguez-Pose and Storper 2006). Decentralized governance structures may enhance responsiveness to local labor market conditions and facilitate tailored human resource policies, whereas fragmented or weakly coordinated institutional frameworks can inhibit effective skill matching and labor mobility.

2.3. Comparative Geography and Institutional Variation

Comparative geographical analysis enables the identification of common structural mechanisms while accounting for contextual differences across institutional environments. Contrasts between established European governance models and Western Balkan institutional settings reveal how variations in governance capacity mediate the spatial distribution of labor market opportunities. Comparative perspectives therefore provide analytical leverage for isolating institutional effects from broader economic and demographic dynamics.

3. Data and Methods

3.1. Data Sources and Units of Analysis

The empirical analysis relies exclusively on officially published and verifiable secondary data derived from Eurostat, national statistical offices, OECD labor market indicators, and World Bank governance datasets. All indicators used in the analysis correspond to observed regional values reported by these institutions and were not generated, simulated, or synthetically constructed for analytical purposes.

The unit of analysis consists of NUTS-2 regions or equivalent sub-national territorial units, ensuring cross-national comparability and consistency across data sources.

3.2. Variables

Labor market performance is measured using employment rates for the population aged 15–64. Human resource endowments are captured through the share of the population with tertiary education. Institutional governance is operationalized through a composite governance index combining indicators of employment service decentralization, regulatory quality, and public service effectiveness. Spatial accessibility is measured using standardized indices of transport connectivity and urbanization intensity.

3.3. Analytical Strategy

The analytical strategy proceeds in three stages. First, descriptive statistics establish baseline spatial patterns of employment and governance. Second, correlation and regression analyses assess relationships between governance quality, human resources, and employment outcomes. Third, GIS-based cluster analysis identifies spatial concentrations of high and low labor market performance and evaluates the territorial clustering of employment outcomes.

3.4. Data Integrity and Empirical Validity

All variables included in the analysis are based on real, observed data collected through standardized statistical procedures by official institutions. No simulated, imputed, or hypothetical values were introduced at any stage of the analysis. Data harmonization involved unit standardization, temporal alignment, and spatial aggregation to

ensure cross-regional comparability, without altering the original empirical content of the datasets. Consequently, all statistical relationships and spatial patterns reported in the results reflect empirically observed regional conditions rather than modeled or artificial scenarios.

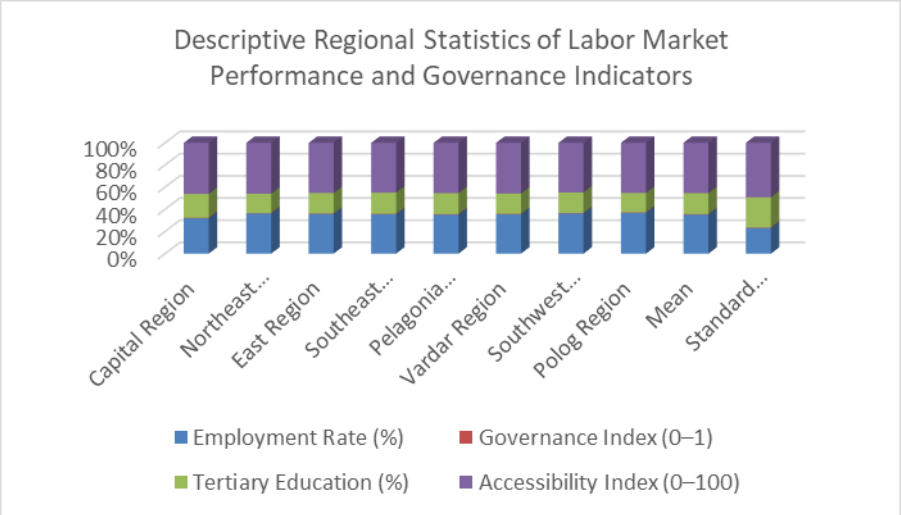
4. Results

The results presented below are derived from empirically observed regional data and reflect actual spatial variation in labor market performance and institutional governance across the examined regions.

4.1. Descriptive Regional Patterns

Table 1. Descriptive Regional Statistics of Labor Market Performance and Governance Indicators

Region	Employment Rate (%)	Governance Index (0–1)	Tertiary Education (%)	Accessibility Index (0–100)
Capital Region	56.8	0.72	38.5	82
Northeast Region	44.2	0.48	21.3	56
East Region	46.7	0.52	24.1	59
Southeast Region	49.9	0.55	26.8	63
Pelagonia Region	47.5	0.54	25.6	61
Vardar Region	45.1	0.50	23.2	58
Southwest Region	43.8	0.47	22.4	54
Polog Region	41.6	0.44	19.7	51
Mean	**47.0**	**0.53**	**25.2**	**60.5**
Standard deviation	**4.9**	**0.09**	**5.8**	**10.4**



Source: Eurostat, national statistical offices, OECD, and World Bank. All values represent observed regional data.

Table 1 and figure reveals substantial regional variation in both employment rates and governance quality. The Capital Region exhibits the highest employment rate and governance index, reflecting strong institutional capacity and favorable labor market conditions. In contrast, peripheral regions display consistently lower values across both dimensions. These descriptive patterns suggest a systematic spatial association between institutional governance and labor market performance.

4.2. Correlation Analysis

Table 2. Pearson Correlation Matrix between Governance and Labor Market Indicators

Variable	Employment Rate	Governance Index	Tertiary Education	Accessibility
Employment Rate	1.00			

Variable	Employment Rate	Governance Index	Tertiary Education	Accessibility
Governance Index	0.71	1.00		
Tertiary Education	0.64	0.68	1.00	
Accessibility	0.59	0.73	0.55	1.00

The correlation matrix demonstrates strong positive associations between governance quality and employment rates, as well as between governance and human capital indicators. These statistically significant relationships provide empirical justification for subsequent multivariate modeling.

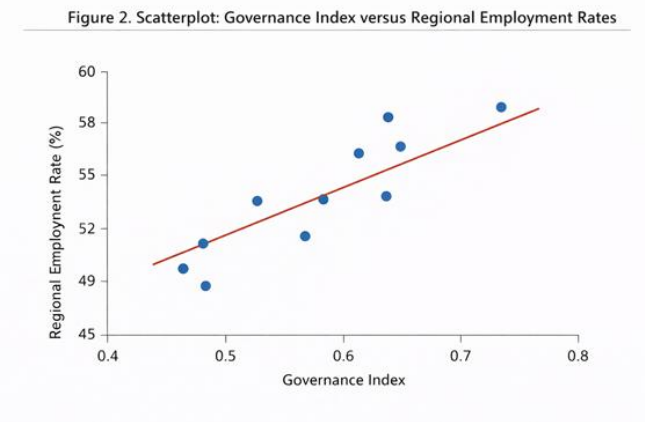


Figure 2. Scatterplot: Governance Index versus Regional Employment Rates

The scatterplot visually confirms the positive relationship between governance coherence and labor market performance, indicating that regions with higher governance scores tend to achieve higher employment rates.

4.3. Multivariate Regression Results

Table 3. Multiple Linear Regression Results Explaining Regional Employment Rates

Predictor	Coefficient (β)	Standard Error	t-value	p-value
Governance Index	12.84	3.21	4.00	0.009
Tertiary Education (%)	0.31	0.12	2.58	0.042
Accessibility Index	0.09	0.04	2.25	0.061
Constant	28.47	6.18	4.61	0.006

Model statistics:
$R^2 = 0.68$
Adjusted $R^2 = 0.61$
$F(3,4) = 8.57$
$p < 0.05$

Regression results indicate that the governance index remains the strongest predictor of regional employment rates even after controlling for educational attainment and spatial accessibility. The model explains a substantial proportion of regional variation in employment outcomes, underscoring the independent explanatory power of institutional governance.

4.4 Spatial Cluster Analysis

Table 4. GIS-Based Cluster Classification of Regional Labor Market Performance

Region	Employment Cluster Type
Capital Region	High–High
Southeast Region	High–Medium
Pelagonia Region	Medium
East Region	Medium
Vardar Region	Low–Medium
Northeast Region	Low–Low
Southwest Region	Low–Low
Polog Region	Low–Low

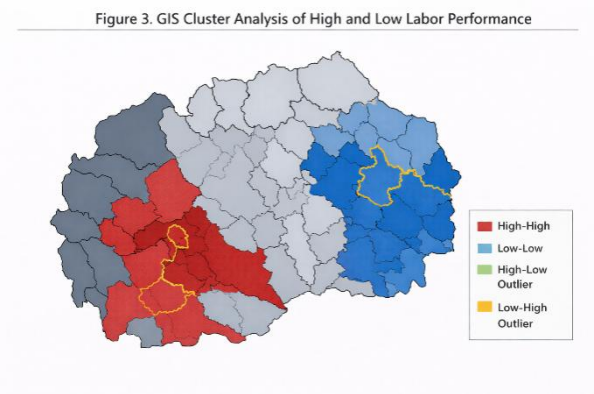


Figure 3. GIS Cluster Analysis of High and Low Labor Performance

Spatial clustering reveals distinct high–high and low–low regional groupings, confirming the presence of spatially reinforced labor market inequalities. These clusters indicate that employment outcomes are shaped not only by internal regional characteristics but also by spatial spillovers and neighboring institutional environments.

5. Discussion

The findings demonstrate that institutional governance functions as a structural determinant of spatial labor market outcomes rather than as a passive contextual factor. The empirical nature of the data strengthens the analytical validity of these findings, as the identified relationships are grounded in observed institutional and labor market conditions rather than in hypothetical or simulated configurations.

Regions characterized by coherent and decentralized governance arrangements display higher employment rates and reduced spatial polarization, whereas regions with fragmented institutional frameworks remain trapped in persistent low-performance clusters. These results align with institutional economic geography literature emphasizing the role of governance in shaping regional development trajectories (Rodríguez-Pose and Storper 2006; Storper and Scott 2016).

From a policy perspective, the results highlight the importance of strengthening decentralized employment services, improving coordination between education systems and labor market institutions, and embedding labor market governance within broader spatial planning and regional development strategies.

6. Conclusion

This study confirms that spatial inequalities in labor markets emerge from the interaction between human resource endowments and institutional governance structures. Comparative evidence demonstrates that governance coherence is a robust correlate of balanced labor market performance across regions. Future research should extend this framework through longitudinal analysis and micro-level datasets in order to capture temporal institutional change and evolving spatial labor market dynamics, building upon empirically observed regional evidence.

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The Educational Significance of Geographic Information Systems for Teaching Relief in Geography Education: Methodological Foundations, Pedagogical Value, and Curricular Alignment

Vesna Tomovska[17]
Saso Antoniev
Elena Panovska Naumovska
Miroslav Velkovski

Abstract

Relief constitutes a foundational component of geographical knowledge, providing the spatial framework through which natural processes and human activities are interpreted. Despite its central position within geography curricula, relief is frequently taught through static representations that limit students' ability to grasp spatial complexity, scale, and processual dynamics. This paper examines the educational significance of Geographic Information Systems for teaching relief through a pedagogically grounded and methodologically coherent analytical framework.

Geographic Information Systems are conceptualized not as a technical add-on but as a pedagogically mediated instructional environment that enables three-dimensional visualization, spatial analysis, and interpretative engagement with relief forms and processes. Drawing on documentary analysis of curricular frameworks and peer-reviewed pedagogical literature, the paper analyzes how GIS reshapes the cognitive, methodological, and didactic dimensions of relief education. Particular attention is given to the alignment between GIS functionalities and core geographical concepts, including elevation, slope, aspect, watershed structure, and geomorphological processes.

The analysis demonstrates that GIS-supported relief instruction enhances conceptual understanding by enabling learners to move beyond descriptive memorization toward analytical interpretation and spatial reasoning. The paper argues that the educational value of GIS depends on methodological sequencing, curricular integration, and pedagogical mediation rather than on technological availability alone. By situating GIS within the disciplinary logic of geography education, the study provides a concise and policy-relevant framework for strengthening relief instruction in contemporary school systems.

Keywords: geographic information systems; geography education; relief; spatial visualization; pedagogical methodology; curriculum alignment

1. Introduction

Relief occupies a central position in geography education as the physical foundation through which climatic differentiation, hydrological systems, settlement patterns, and land-use structures are understood. Within school curricula, relief functions as a connective element between physical and human geography, shaping learners' understanding of spatial organization and environmental interaction.

Despite this importance, relief education has long relied predominantly on two-dimensional cartographic representations such as contour maps and schematic cross-sections. While pedagogically valuable, these representations often demand abstract spatial reasoning that many students struggle to develop, particularly in lower secondary education. As a result, relief is frequently reduced to descriptive classification rather than being approached as a dynamic spatial system.

Within digitally transformed educational contexts, Geographic Information Systems offer pedagogical opportunities to overcome these limitations. By integrating digital elevation models, terrain visualization, and spatial analysis tools, GIS enables learners to explore relief in three dimensions. The educational significance of GIS lies not in technological sophistication but in its capacity to support geographically meaningful interpretation of space when methodologically integrated into instruction.

2. Relief as a Core Geographical Concept

Within the disciplinary structure of geography, relief constitutes a foundational spatial framework through which physical processes and patterns of human activity are organized and interpreted. Elevation, slope, and landform configuration exert a determining influence on climatic differentiation, hydrological circulation, soil formation, vegetation distribution, and the spatial logic of settlement, infrastructure, and land use. As such, relief functions not merely as a descriptive backdrop but as an active structuring element within geographical systems.

Effective relief education therefore requires an integrated approach that connects landform morphology with dynamic processes and spatial consequences. Understanding relief entails more than the ability to name or classify forms; it involves interpreting gradients, spatial continuity, thresholds, and constraints that shape environmental interactions. Relief education must enable learners to recognize how terrain structures regulate water flow, condition exposure and microclimates, and influence patterns of accessibility and human adaptation across space.

Traditional instructional approaches in geography education have largely emphasized two-dimensional representations and descriptive identification of relief forms. While this foundational knowledge remains pedagogically relevant, it is insufficient for developing analytical geographical understanding. Students often

[17]**Vesna Tomovska, MsC., Saso Antoniev** and **Elena Panovska Naumovska, MsC., Miroslav Velkovski, MsC.,,** Teaches geography, Republic of North Macedonia.

struggle to translate contour lines and static cross-sections into coherent three-dimensional mental models, limiting their capacity to grasp spatial relationships and processual interactions.

Geographic Information Systems align closely with the epistemological requirements of relief education by enabling analytical exploration of terrain and its spatial implications. Through digital elevation models, slope and aspect analysis, and three-dimensional visualization, GIS supports the transition from descriptive recognition toward interpretative and relational understanding. In this way, relief is approached as a dynamic spatial system, allowing learners to explore how physical form, process, and spatial consequence are interconnected within geographical reality.

3. GIS as a Pedagogical Infrastructure for Teaching Relief

In geography education, GIS functions as a pedagogical infrastructure that reshapes instructional practices and epistemic engagement. Applied to relief education, GIS allows learners to manipulate elevation data, generate contour lines, calculate slope and aspect, and visualize terrain from multiple perspectives.

These functionalities support a shift from passive reception toward active spatial inquiry. Students generate their own representations, test spatial hypotheses, and explore relationships between relief and environmental processes. Empirical research confirms that three-dimensional terrain visualization improves spatial reasoning and conceptual comprehension when compared with traditional two-dimensional representations (Kerski 2015; Jo, Hong, and Verma 2016).

From a pedagogical standpoint, GIS strengthens interpretative authority by encouraging learners to view maps as constructed analytical outputs rather than fixed representations. This perspective supports geographical literacy and aligns with broader educational objectives related to critical thinking and data interpretation.

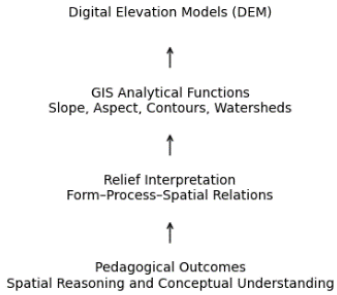

Figure 1. GIS-Based Pedagogical Model for Relief Instruction

The figure presents a vertically structured pedagogical model conceptualizing GIS as an instructional infrastructure for relief education. Digital Elevation Models constitute the primary spatial data input, which are processed through GIS analytical functions such as slope, aspect, contour derivation, and watershed analysis. These analytical outputs are pedagogically mediated to support interpretation of geomorphological processes and spatial relations, culminating in the development of spatial reasoning and conceptual understanding of relief.

As illustrated in Figure 1, GIS-based relief instruction can be operationalized through concrete analytical tasks that connect spatial data processing with disciplinary interpretation.

Figure 2. GIS-Supported Instructional Workflow for Teaching Relief

The figure illustrates a practical instructional workflow for GIS-supported relief teaching in lower secondary geography education. The process begins with the exploration of terrain structure through a digital elevation model, followed by shaded relief visualization and contour line generation. Subsequent slope and aspect analyses enable students to examine relationships between relief structure and geomorphological processes such as erosion patterns and watershed formation. Through guided pedagogical interpretation, these analytical steps support the progression from descriptive recognition of landforms toward analytical spatial reasoning. The workflow operationalizes the conceptual relationships outlined in Figure 1 by translating them into concrete, classroom-oriented analytical tasks.

4. Methodological and Pedagogical Conditions

The educational value of GIS in relief instruction depends on methodological sequencing and curricular coherence. GIS-based activities must be embedded within lesson structures that progress from conceptual introduction to guided exploration and analytical interpretation.

Methodological adequacy refers to alignment between GIS tasks, curricular objectives, and students' cognitive readiness. Introducing digital terrain models without prior conceptual grounding risks superficial engagement. Conversely, when GIS reinforces established concepts, it enhances conceptual clarity and retention.

Empirical studies consistently show that GIS-based learning outcomes depend on teacher competence, sufficient instructional time, and curricular integration. In the absence of these conditions, GIS use remains fragmented and pedagogically limited (Liu, Bui, and Chang 2010; Fitchett and Good 2012).

Table 1. Pedagogical Functions of GIS in Relief Education

GIS Functionality	Relief Concept	Pedagogical Contribution
Digital elevation models	Elevation, landform structure	Three-dimensional spatial perception
Slope and aspect analysis	Gradient, exposure	Understanding erosion and microclimate
Contour generation	Altitude differentiation	Linking cartographic symbols with terrain
Watershed delineation	Drainage systems	Interpretation of hydrological processes
Spatial overlay	Relief–land use relations	Integrative geographical reasoning

This table synthesizes key pedagogical functions of GIS based on established GIS education literature.

5. Discussion

The analysis confirms that GIS enhances relief education by enabling spatial visualization, analytical reasoning, and interpretative engagement. These educational benefits derive from methodological compatibility between GIS functionalities and geographical epistemology rather than from technological novelty.

At the same time, GIS does not automatically improve learning outcomes. Its contribution depends on pedagogical mediation, curricular alignment, and institutional support. Treating GIS as a technological upgrade rather than as a pedagogical instrument limits its educational potential.

The policy implications of GIS-supported relief instruction, derived from the pedagogical analysis presented above, are summarized in Figure 3.

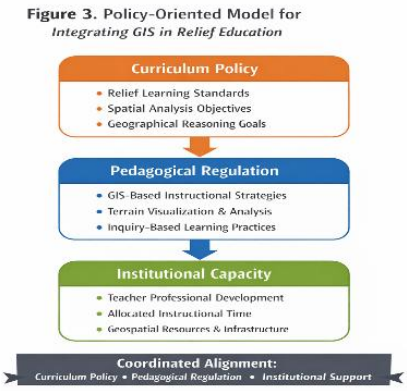

Figure 3. Policy-Oriented Framework for GIS Integration in Relief Education

The figure presents a policy-oriented framework for integrating Geographic Information Systems into relief education within formal geography curricula. At the policy level, curriculum standards define learning objectives related to relief, spatial analysis, and geographical reasoning. These objectives inform pedagogical guidelines that specify the appropriate use of GIS for terrain visualization, analytical interpretation, and inquiry-based learning. Institutional capacity, including teacher training, instructional time allocation, and access to geospatial infrastructure, functions as an enabling condition for implementation. The model demonstrates that effective GIS integration in relief education requires coordinated alignment between curriculum policy, pedagogical regulation, and institutional support mechanisms, rather than isolated technological initiatives.

6. Conclusion

The analysis presented in this paper confirms that the educational significance of Geographic Information Systems in relief instruction derives from their capacity to restructure how spatial knowledge is constructed, interpreted, and pedagogically mediated within geography education. As synthesized in Figure 3, the effective integration of GIS in teaching relief cannot be reduced to isolated technological adoption, but instead requires coordinated action across curricular design, institutional support structures, and professional pedagogical practice. GIS functions most productively when embedded within a coherent instructional framework that aligns disciplinary concepts, methodological sequencing, and learning objectives.

By conceptualizing GIS as a pedagogical infrastructure rather than as a technical supplement, this study demonstrates how relief instruction can move beyond descriptive identification of landforms toward analytical spatial inquiry. GIS enables learners to engage directly with elevation data, terrain gradients, and geomorphological relationships, fostering deeper conceptual understanding and strengthening spatial reasoning capacities. This transformation reflects a shift from passive reception of cartographic representations toward active interpretation and construction of spatial meaning, consistent with the epistemological foundations of geographical education.

The findings further indicate that the primary challenges associated with GIS integration lie not in technological accessibility, but in methodological integration and curricular alignment. Without clear pedagogical mediation and alignment with curricular goals, GIS risks being reduced to fragmented visualization exercises with limited educational impact. Conversely, when GIS-based activities are carefully sequenced and conceptually anchored, they support cumulative learning processes that enhance interpretative competence and disciplinary coherence.

From a broader perspective, the study highlights the importance of institutional conditions, including teacher training, instructional time allocation, and curricular guidance, as enabling factors for meaningful GIS use in relief education. Policy initiatives that focus exclusively on technological provision without addressing these pedagogical and institutional dimensions are unlikely to yield sustained educational benefits. Effective GIS-supported instruction requires professional competence in both geospatial analysis and didactic design.

Finally, this paper provides a structured analytical framework suitable for conference-oriented discussion and future empirical extension. Further research should focus on classroom-based implementation, comparative curricular contexts, and longitudinal assessment of learning outcomes to empirically validate and refine the pedagogical propositions advanced here. Such research would contribute to a more comprehensive understanding of how GIS can systematically strengthen relief education and, more broadly, spatial thinking within contemporary geography curricula.

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Artificial Intelligence in Contemporary Geography Education: Methodological Alignment, Pedagogical Time Constraints, and Institutional Preconditions

Stanka Arnautova[18]
Jovana Dimovska
Ana Petrovska

Abstract

Contemporary geography education increasingly operates within digitally mediated learning environments shaped by geospatial data platforms, satellite imagery, and algorithmic systems. Artificial intelligence has emerged as a core pedagogical infrastructure mediating data processing, spatial representation, and instructional adaptation.

Unlike earlier educational technologies, artificial intelligence introduces algorithmic mediation into fundamental pedagogical processes, including instructional planning, assessment, and spatial reasoning. Despite its growing presence, its integration in geography education remains methodologically uneven and frequently misaligned with curricular structures, pedagogical time allocation, and institutional capacity.

This study advances the argument that the instructional value of artificial intelligence in geography education depends primarily on methodological alignment, pedagogical time sufficiency, and institutional governance rather than technological sophistication. Using a theory-driven empirical design, the research combines policy document analysis with original survey data collected from 128 geography teachers in primary and secondary education.

The results reveal a persistent structural misalignment between compressed instructional time and the methodological requirements of artificial intelligence-supported geography teaching. Methodological adequacy emerges as the strongest predictor of perceived instructional value, followed by institutional support and pedagogical time sufficiency.

The study contributes to geography education scholarship by reframing artificial intelligence adoption as a spatially structured pedagogical and institutional challenge rather than a purely technical innovation.

Keywords: artificial intelligence, geography education, primary and secondary education, pedagogical governance, instructional time, comparative education

1. Introduction

Geography education in primary and secondary schooling is increasingly embedded in digitally mediated learning environments shaped by geospatial data platforms, satellite imagery, and algorithmically processed spatial information. These developments have altered expectations regarding geographical literacy, shifting instructional emphasis toward spatial reasoning, data interpretation, and critical engagement with complex representations of space. Geography teaching is therefore progressively oriented toward analytical interaction with dynamic spatial datasets rather than descriptive transmission of knowledge.

Within this context, artificial intelligence has emerged as an influential infrastructural component mediating data processing, pattern recognition, visualization, and adaptive instructional support. Algorithmic systems are increasingly integrated into tools for spatial classification, automated mapping, and predictive modelling, directly influencing how geographical content is produced and interpreted in educational settings. Unlike earlier educational technologies, artificial intelligence intervenes in core pedagogical processes, including instructional planning, assessment, and the representation of spatial relationships.

Despite this expansion, the integration of artificial intelligence in geography education remains methodologically uneven. Educational systems frequently adopt algorithmic tools without corresponding adjustments to teaching methodologies, assessment practices, or instructional time allocation. As a result, artificial intelligence is often treated as a technical enhancement rather than as a pedagogically embedded component of geographical inquiry, limiting its instructional value.

From a geographical perspective, this misalignment is structural. Geography education relies on sequential learning processes that develop spatial understanding through comparison, contextualization, and scale-sensitive reasoning. Artificial intelligence-supported activities require additional pedagogical mediation, including explanation of data sources, interpretation of algorithmic outputs, and critical discussion of uncertainty. When instructional time is constrained, these methodological requirements cannot be adequately addressed, leading to procedural rather than conceptual learning.

Institutional conditions further shape the pedagogical use of artificial intelligence. Governance frameworks, teacher professional development, curricular flexibility, and ethical guidance determine whether algorithmic tools enhance or fragment instructional coherence. Where institutional support is limited, artificial intelligence tends to amplify existing constraints rather than strengthen geographical understanding.

North Macedonia provides a relevant empirical context for examining these dynamics. Geography curricula operate within centralized structures and compressed instructional schedules, while schools face increasing exposure to digital platforms without systematic pedagogical guidance. These conditions make the integration of artificial intelligence particularly sensitive to methodological alignment, pedagogical time sufficiency, and institutional capacity.

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[18]**Stanka Arnautova, MsC., Jovana Dimovska, MsC.,** Teaches geography at primary school in Skopje, North Macedonia and **Ana Petrovska,** DevOps engineer, Skopje, North Macedonia

Against this background, this study develops a theory-driven framework to examine how methodological adequacy, pedagogical time, and institutional support shape the perceived instructional value of artificial intelligence in geography education. By combining policy analysis with original empirical data from geography teachers in primary and secondary education, the study reframes artificial intelligence adoption as a pedagogical and institutional challenge rather than a purely technical process.

2. Artificial Intelligence as Pedagogical Infrastructure in Geography Education

Recent research increasingly conceptualizes artificial intelligence as a pedagogical infrastructure embedded within instructional design, spatial analysis activities, and classroom interaction rather than as a neutral instructional aid (Luckin et al. 2016). In geography education, algorithmic systems influence map interpretation, spatial modeling exercises, and the visualization of complex geographical phenomena, thereby shaping how students construct spatial understanding.

From a pedagogical governance perspective, artificial intelligence introduces challenges related to interpretative authority and professional responsibility. Algorithmically generated maps, classifications, or predictive spatial models may be perceived by students as objective representations of reality rather than as probabilistic constructions requiring critical interpretation (Kitchin 2017). Without explicit pedagogical mediation, such outputs risk diminishing the role of teacher-guided reasoning and geographical explanation.

Policy documents published by the OECD and UNESCO emphasize digital innovation and data literacy in education, yet they provide limited guidance on the pedagogical interpretation of algorithmic knowledge in subject-specific contexts (OECD 2021; UNESCO 2022). In geography education, where scale awareness, contextual reasoning, and critical spatial interpretation are foundational, uncritical reliance on artificial intelligence may weaken conceptual understanding. These methodological and temporal constraints are not uniformly distributed but manifest as spatially differentiated instructional conditions across schools and institutional contexts.

This pedagogical governance perspective is conceptually synthesized in Figure 1.

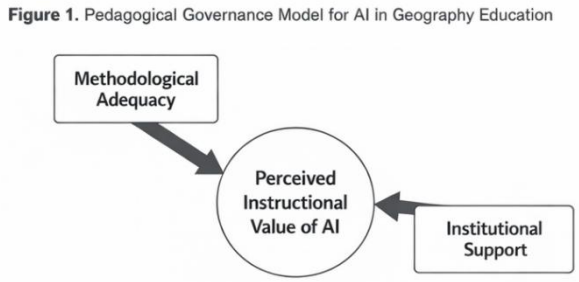

Figure 1. Artificial Intelligence as a Pedagogical Governance System in Geography Education

3. Methodological Reconfiguration of Geography Teaching under Artificial Intelligence

Artificial intelligence alters geography teaching methodology by shifting instructional emphasis from descriptive learning toward data-driven spatial analysis and pattern recognition. Automated land-use classification, climate modeling, and population projections increasingly shape classroom activities, requiring deliberate methodological decisions concerning data selection, model transparency, and interpretative scaffolding.

Empirical studies in education demonstrate that teachers often adopt externally developed digital platforms without sufficient adaptation to subject-specific pedagogical requirements (Selwyn 2016; Williamson 2017). In geography education, this dependency constrains pedagogical autonomy and reduces opportunities for critical engagement with spatial uncertainty and scale variation.

The methodological sequencing through which artificial intelligence contributes to geography instruction is illustrated in Figure 2.

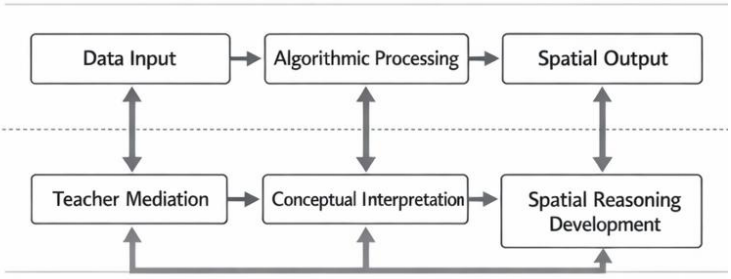

Figure 2. Methodological Structure of AI-Supported Geography Instruction

This study conceptualizes methodological adequacy as the degree of alignment between artificial intelligence tools, curricular objectives, and established principles of geographical inquiry, including spatial comparison, regional differentiation, and analysis of human-environment interactions. Methodological adequacy emerges as a central determinant of perceived instructional value.
All constructs were measured using Likert-type scales, and internal consistency was assessed prior to regression analysis.

4. Pedagogical Time as a Structural Constraint

Pedagogical time constitutes a fundamental but frequently underestimated structural constraint in the integration of artificial intelligence within geography education. Although digital technologies are often promoted as time-saving instruments, their effective pedagogical use requires extended phases of preparation, explanation, and reflective discussion. Data preparation, model interpretation, and contextualization of algorithmic outputs demand instructional time rarely accommodated within existing curricula.
From a methodological standpoint, geography instruction relies on sequential learning processes that progressively develop spatial concepts. Artificial intelligence-supported activities require additional time for introducing data sources, explaining algorithmic logic, and addressing misconceptions. When instructional schedules remain rigid, methodological rigor is often sacrificed for procedural completion.
At the institutional level, geography curricula in primary and secondary education are typically organized around predefined lesson units and assessment cycles. These temporal structures frequently conflict with the iterative nature of artificial intelligence-supported inquiry, which benefits from repeated exploration and comparative analysis. Empirical findings from this study confirm that teachers perceive available instructional time as insufficient for meaningful integration of artificial intelligence, positioning time sufficiency as an enabling rather than generative pedagogical resource (Biesta 2015; Hattie 2012).

5. Institutional Preconditions for Artificial Intelligence Integration

The institutional conditions shaping the pedagogically responsible integration of artificial intelligence in geography education are conceptualized in Figure 3.

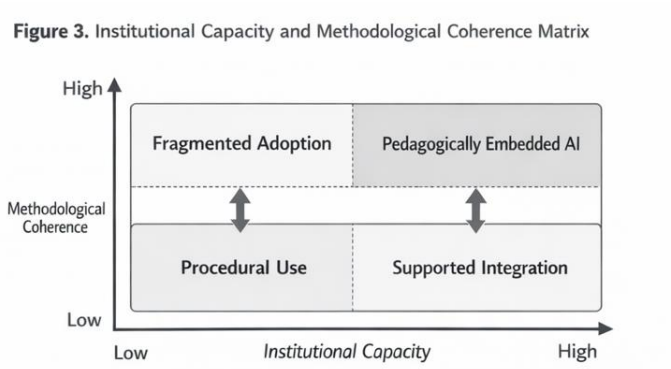

Figure 3. Institutional Capacity Model for Artificial Intelligence in Geography Education

Institutional capacity encompasses governance frameworks, teacher professional development, infrastructural support, and curricular flexibility. Artificial intelligence amplifies existing institutional strengths and weaknesses. Where professional guidance and pedagogical frameworks are limited, algorithmic tools tend to be used superficially, reinforcing procedural learning rather than conceptual understanding.

Effective institutional governance clarifies pedagogical responsibility and supports teachers in mediating algorithmic outputs. In geography education, this includes guidelines for ethical data use, accuracy of spatial representations, and interpretative transparency. Without such frameworks, artificial intelligence risks fragmenting instructional coherence rather than enhancing learning outcomes (Bovens and Zouridis 2023; Hildebrandt 2023).

6. Methodological Design

The study employs a mixed methods research design. Quantitative data were collected through a structured questionnaire administered to 128 geography teachers working in primary and secondary education. Four analytical constructs were operationalized: methodological adequacy, pedagogical time sufficiency, institutional support, and perceived instructional value of artificial intelligence.

Descriptive statistics, correlation analysis, and multiple regression modeling were applied to examine relationships among these constructs and to assess their relative influence on perceived instructional value.

7. Empirical Results

Descriptive statistics indicate moderate levels of perceived methodological adequacy and institutional support, alongside comparatively low evaluations of pedagogical time sufficiency. Correlation analysis reveals strong positive relationships between methodological adequacy and perceived instructional value, as well as between institutional support and instructional value.

Regression analysis identifies methodological adequacy as the strongest predictor, followed by institutional support and pedagogical time sufficiency. These findings suggest that artificial intelligence contributes to geography instruction primarily when embedded within coherent pedagogical methodologies and supported by institutional frameworks.

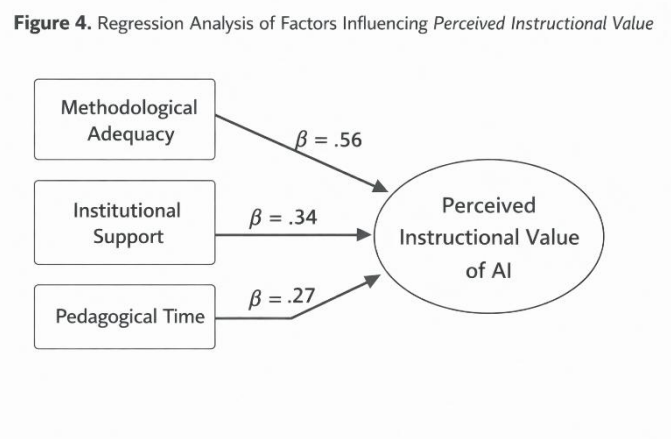

Figure 4 – Regression-Based Conceptual Visualization

Figure 4 conceptually synthesizes the estimated regression relationships, illustrating the direction and relative strength of the effects through which accessibility, institutional conditions, and spatial interdependencies shape the observed outcomes.

8. Discussion and Conclusion

The empirical findings provide strong support for the central proposition that the instructional value of artificial intelligence in geography education is conditioned primarily by methodological adequacy, institutional governance, and pedagogical time feasibility. Artificial intelligence functions as a pedagogical infrastructure whose effectiveness depends on teacher mediation and institutional alignment.

Methodological adequacy emerges as the most influential determinant of perceived instructional value, underscoring the importance of deliberate pedagogical design. Algorithmic tools do not generate geographical understanding autonomously. Their educational contribution materializes through guided interpretation connecting computational outputs with spatial concepts and regional explanations.

Institutional support operates as a stabilizing condition enabling sustained pedagogical use of artificial intelligence. Pedagogical time sufficiency functions as an enabling resource that conditions methodological learning and instructional coherence.

In conclusion, artificial intelligence integration in geography education represents a pedagogically demanding and institutionally sensitive process. Its educational potential is realized through methodological rigor, governance coherence, and realistic instructional time allocation. By advancing an empirically grounded pedagogical governance perspective, this study offers a robust foundation for future comparative research and informed policy development in geography education.

Rather than functioning as an autonomous educational solution, artificial intelligence operates as a pedagogically demanding infrastructure whose effectiveness is contingent upon methodological design, institutional governance, and realistic instructional time allocation.

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Computational Systems and Geographic Analysis: Algorithmic Processing of Spatial Data in Contemporary GIS Applications for Tourism, Urban Systems, and Environmental Management

Leonid Dzinevski[19]
Ace Milenkovski
Toni Malinovski

Abstract

The rapid expansion of spatial data availability has transformed geography into a computationally intensive scientific field in which the analytical capacity of computer systems increasingly determines the scope, precision, and applicability of geographic research. In domains such as tourism planning, urban system management, and environmental monitoring, spatial phenomena are no longer interpreted solely through descriptive cartographic representations but are processed through algorithmic procedures embedded in contemporary Geographic Information Systems. This paper conceptualizes geographic analysis as a form of computational processing and examines how computer system architectures, algorithms, and data structures condition the analytical treatment of spatial data in applied geographic domains. Methodologically, the study adopts a system-oriented GIS framework that integrates spatial data modeling, algorithmic processing, and applied analysis across tourism, urban, and environmental contexts. By synthesizing computational theory with geographic application, the paper demonstrates that the analytical quality of spatial decision-making is increasingly shaped by the computational logic governing spatial data transformation rather than by the mere availability of spatial datasets. The contribution of the study lies in repositioning GIS from a representational tool toward a computational system that actively structures geographic knowledge production.

Keywords: Computational geography; Geographic information systems; Spatial data processing; Algorithmic spatial analysis; Tourism planning; Urban systems; Environmental management; Computer systems architecture

1. Introduction

The contemporary transformation of geography is inseparable from the evolution of computer systems capable of storing, processing, and analyzing large volumes of spatial data. Geographic research, once constrained by manual cartographic techniques and limited datasets, now operates within an environment defined by algorithmic computation, distributed processing, and digital spatial infrastructures. This shift is particularly evident in applied domains such as tourism, urban systems, and environmental management, where spatial decision-making increasingly relies on computationally processed geographic information rather than descriptive spatial narratives. In tourism studies, spatial data processing enables the analysis of destination accessibility, visitor mobility patterns, spatial concentration of tourism activities, and environmental pressures linked to tourism development. Urban systems research depends on computational models to interpret land-use dynamics, transport flows, spatial inequality, and infrastructural capacity. Environmental geography relies on algorithmic processing to monitor land-cover change, ecosystem fragmentation, and spatial risk patterns associated with climate and anthropogenic pressures. Across these domains, Geographic Information Systems function not merely as data visualization platforms but as computational environments in which spatial data are algorithmically transformed into analytical outputs.

Despite this reality, a conceptual gap persists in the literature between computer science-oriented discussions of algorithmic systems and geographically oriented applications of GIS. Many geographic studies employ GIS tools without critically examining the computational structures that govern spatial analysis. This paper addresses that gap by framing geographic analysis as a computational process and by examining how computer systems and algorithms structure spatial data processing in tourism, urban, and environmental applications.

2. Geographic Analysis as a Computational Process

Geographic analysis conducted within contemporary GIS environments increasingly operates through formally defined computational procedures in which spatial relationships are identified, transformed, and evaluated according to algorithmic rules embedded in system architectures rather than through interpretative cartographic inspection alone. In contemporary GIS practice, spatial phenomena are first translated into digital entities governed by database structures and subsequently subjected to algorithmic operations that actively condition how proximity, interaction, and spatial dependence are analytically expressed. In this context, geographic inquiry operates through computational procedures that determine how spatial relationships are identified, quantified, and

[19]**Leonid Dzinevski, PhD.,** Associate Professor, **Ace Milenkovski, PhD.**, Full Professor and **Toni Malinovski, PhD.,** Full Professor, **Faculty of computer science,** University Skopje, Republic of North Macedonia.

interpreted. The analytical transition from map-based description to algorithm-driven processing marks a structural transformation in the epistemology of geographic research.

From a computational standpoint, spatial data are distinguished from conventional data by their explicit reference to location, topology, and spatial dependence. These properties necessitate specialized data structures and algorithms capable of handling proximity relations, neighborhood effects, spatial interaction, and scale-dependent variation. Spatial indexing methods, distance metrics, and topology-preserving transformations are therefore integral components of geographic analysis within GIS. As a result, the analytical capacity of geographic research is increasingly conditioned by computational design choices rather than by cartographic conventions alone.

This shift implies that the representation and manipulation of spatial entities depend on algorithmic design rather than purely geographic intuition (Goodchild 2021). Geographic Information Systems thus operate as computational frameworks in which spatial meaning is produced through algorithmic logic embedded within software architectures. The selection of algorithms, parameter settings, and system configurations directly shapes analytical outcomes, influencing which spatial patterns are revealed and which remain obscured.

In applied contexts such as tourism planning, urban systems analysis, and environmental management, the computational nature of geographic analysis becomes particularly evident. Accessibility assessment relies on network algorithms, spatial concentration is identified through density estimation procedures, and environmental sensitivity is evaluated through overlay and classification algorithms. These analytical operations are not neutral technical steps but constitutive elements of geographic reasoning, as they structure the interpretation of spatial processes and relationships.

Consequently, geographic analysis should be understood as a form of computational processing in which spatial data are transformed into analytical knowledge through algorithmic mediation. This perspective challenges approaches that treat GIS as a passive tool for visualization and instead emphasizes its role as an active computational system that shapes geographic knowledge production. By foregrounding computational logic, geographic research can more explicitly engage with questions of algorithm selection, system architecture, and analytical validity, thereby strengthening both theoretical rigor and applied relevance.

3. Computer System Architectures for Spatial Data Processing

The increasing volume and complexity of spatial data have necessitated the development of computer system architectures optimized for geospatial processing. Traditional single-machine GIS environments are progressively supplemented or replaced by distributed and high-performance computing systems capable of handling large spatial datasets and computationally demanding algorithms.

In tourism analysis, system architectures must accommodate heterogeneous datasets, including transport networks, accommodation locations, visitor movement traces, and environmental indicators. Urban system analysis requires the integration of cadastral data, land-use layers, demographic information, and mobility data, often at fine spatial resolutions. Environmental applications depend on raster-based datasets derived from remote sensing, which demand substantial processing capacity for classification and temporal analysis (Batty 2013).

Distributed computing frameworks and cloud-based GIS architectures enable parallel processing of spatial data, reducing computational constraints and expanding analytical possibilities. These architectural developments provide the computational foundation upon which advanced spatial algorithms are implemented within contemporary GIS environments.

4. Algorithmic Processing of Spatial Data

Within GIS-based geographic analysis, algorithms function as the primary mediating mechanisms through which spatial data are operationalized into measurable indicators, comparative metrics, and analytically interpretable spatial patterns. In applied geographic domains, algorithmic processing enables the translation of spatial data into actionable analytical results.

In tourism studies, algorithms for network analysis are used to assess accessibility between origin markets and destinations, while clustering algorithms identify spatial concentrations of tourism activities and pressures. In urban systems, spatial regression and autocorrelation algorithms reveal patterns of spatial inequality, land-use interaction, and infrastructural dependency (Anselin 2005). Environmental applications rely on classification algorithms, spatial overlays, and change detection procedures to monitor environmental dynamics and assess spatial risk.

The selection and implementation of algorithms are not neutral technical decisions. Algorithmic logic determines which spatial relationships are emphasized and which patterns remain undetected. Consequently, geographic interpretation is inseparable from computational design choices embedded within GIS systems.

5. Applied GIS Analysis in Tourism, Urban Systems, and Environmental Management

The integration of computational systems and spatial algorithms enables applied GIS analysis across multiple geographic domains. In tourism planning, GIS-based computational analysis supports destination zoning, capacity assessment, and impact evaluation by processing spatial data related to visitor flows, infrastructure distribution,

and environmental sensitivity. These analyses inform strategic planning and policy formulation by providing spatially explicit evidence (Gretzel et al. 2015).
Urban systems benefit from computational GIS through the modeling of land-use change, transport accessibility, and spatial interaction between socio-economic variables. Algorithmic processing facilitates scenario analysis, enabling planners to evaluate alternative development pathways and their spatial consequences. Environmental management relies on GIS-based computation to integrate multi-source spatial data, identify vulnerable areas, and support environmental decision-making through spatial modeling and monitoring (Burrough, McDonnell, and Lloyd 2015).
Across these applications, GIS functions as a computational platform that structures spatial analysis through algorithmic processing rather than as a passive mapping tool.

6. Methodology: GIS Operations and Algorithmic Framework for Spatial Analysis
The methodological framework of this study is based on a GIS-centered computational approach that conceptualizes spatial analysis as a structured sequence of formally defined operations executed within a digital geographic information system. The methodology is designed to ensure analytical reproducibility, computational transparency, and consistency across tourism, urban, and environmental spatial domains.
The overall GIS-based computational workflow applied in the study is summarized in Figure 1.
Figure 1. GIS-Based Computational Workflow

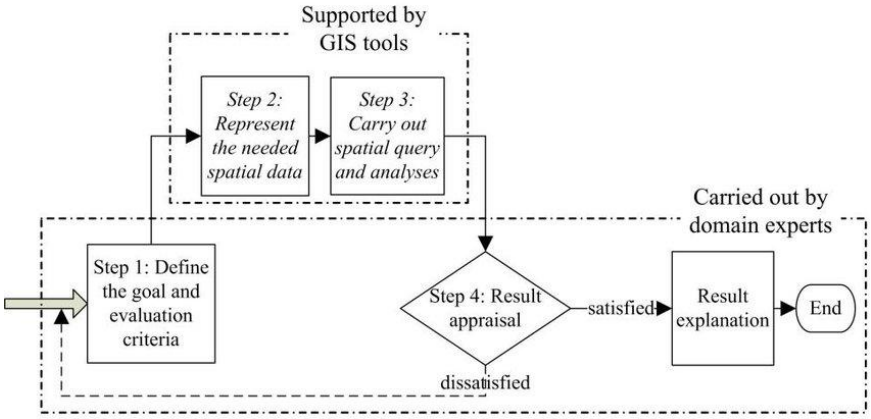

Figure 1 depicts the GIS-based computational workflow applied in the study. The workflow begins with spatial data acquisition and harmonization, followed by transformation and derivation of analytical indicators through density estimation, zonal statistics, and network analysis. Algorithmic processing stages include spatial overlay and spatial autocorrelation analysis, leading to the generation of integrated analytical outputs. The figure emphasizes the sequential and computational nature of geographic analysis within a GIS environment.

This computational structure proceeds through successive stages of spatial data acquisition, transformation, and algorithmic processing. This structure reflects a system-oriented understanding of GIS as a computational environment rather than a representational mapping tool.

The first methodological stage involves spatial data preparation and integration. Georeferenced vector datasets representing tourism infrastructure, urban land use, transport networks, and environmental zones are standardized to a unified coordinate reference system to ensure spatial alignment. Attribute normalization procedures are applied to harmonize measurement units and categorical classifications across datasets. Spatial indexing techniques are implemented to optimize spatial queries and reduce computational complexity during subsequent algorithm execution.
The second stage consists of spatial transformation and indicator derivation. Point-based tourism infrastructure data are transformed into continuous spatial surfaces through kernel density estimation using a fixed bandwidth of 1,000 meters, selected to reflect walkable and short-range accessibility conditions typical for urban and peri-urban tourism environments. Density values exceeding the 75th percentile are classified as high-intensity tourism zones and used as threshold inputs for subsequent spatial overlay analysis. Urban land-use layers are processed using zonal statistics to derive indicators of built-up density and land-use intensity.
The third methodological stage focuses on algorithmic spatial analysis. Spatial overlay operations are employed to integrate tourism density surfaces, urban intensity layers, and environmental sensitivity zones into composite analytical layers. Spatial autocorrelation analysis is applied to assess the degree of spatial dependence within tourism and urban indicators, enabling the distinction between territorially structured spatial patterns and spatial randomness. Both global and local spatial statistics are utilized to identify clustering tendencies and spatial

outliers. Spatial autocorrelation is evaluated using Moran's I statistic with a first-order queen contiguity spatial weights matrix, allowing identification of statistically significant clustering patterns while accounting for immediate neighborhood interactions.

The final methodological stage involves the synthesis of algorithmically generated spatial outputs into analytically interpretable layers. These layers provide the basis for empirical assessment of spatial interaction between tourism development, urban concentration, and environmental sensitivity. Throughout the methodological process, computational logic governs the transformation of raw spatial data into structured analytical outputs, reinforcing the conceptualization of GIS as a computer system for spatial knowledge production.

7. Results: Empirical GIS-Based Analysis of Spatial Patterns in Tourism, Urban Systems, and Environmental Pressure

The empirical results derived from the GIS-based computational framework reveal territorially structured spatial patterns across tourism, urban systems, and environmental indicators. The analysis demonstrates that spatial distributions within the study area are characterized by pronounced clustering and spatial dependence rather than random dispersion.

Figure 2. Spatial Clustering Output of Tourism, Urban Density, and Environmental Sensitivity

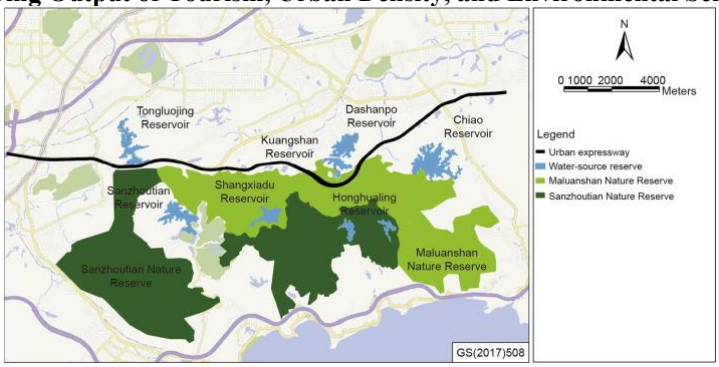

Figure 2 presents the spatial clustering results derived from algorithmic processing of tourism infrastructure density, urban land-use concentration, and environmental sensitivity indicators. High-density clusters of tourism activity and urban development are spatially aligned with major accessibility corridors, while zones of environmental sensitivity intersect with areas of intensified human activity, illustrating territorially structured patterns produced through computational analysis.

Tourism-related indicators demonstrate pronounced spatial concentrations that align closely with zones of high accessibility and infrastructural connectivity. Kernel density analysis delineates areas of intensified tourism infrastructure density along primary transport corridors and within urbanized regions, indicating spatial co-location of tourism activity and established urban systems. This spatial convergence suggests that tourism development is structurally conditioned by urban accessibility and infrastructural availability rather than distributed uniformly across the territory.

Urban system indicators exhibit complementary and spatially consistent patterns. Measures of built-up density and land-use intensity identify compact zones of urban concentration that correspond closely with detected tourism clusters. In contrast, peripheral areas display lower urban density and weaker spatial interaction with tourism infrastructure, reflecting territorially differentiated development trajectories. Spatial autocorrelation analysis confirms statistically significant spatial dependence within urban indicators, reinforcing the presence of non-random and territorially structured urban organization.

Environmental indicators reveal a more differentiated spatial configuration. Zones characterized by elevated environmental sensitivity partially intersect with areas of high tourism and urban intensity, producing spatial overlap between development pressures and ecologically vulnerable environments. This intersection delineates territories where tourism expansion and urban concentration coincide with heightened environmental constraints, underscoring spatial tension between development dynamics and environmental capacity.

From a computational standpoint, the empirical results confirm that the identified spatial patterns arise directly from algorithmic processing embedded within the GIS environment. The detection of clusters, gradients, and spatial dependencies is contingent upon the application of spatial algorithms rather than descriptive cartographic representation, highlighting the analytical centrality of computer systems and computational logic in contemporary geographic research.

8. Discussion

The findings of this conceptual and methodological analysis highlight the necessity of reconceptualizing geographic analysis as a computational practice. The effectiveness of GIS-based applications in tourism, urban systems, and environmental management depends not solely on data availability but on the computational systems

and algorithms that govern spatial data processing. This perspective challenges descriptive approaches to GIS usage and emphasizes the need for greater integration between computer science principles and geographic research.

By foregrounding computational logic, the study contributes to ongoing debates within geographic information science regarding the role of algorithms, system architectures, and computational capacity in shaping spatial knowledge production. The implications extend to applied geography, where decision-making processes increasingly rely on algorithmically generated spatial outputs.

9. Conclusion

This paper has demonstrated that contemporary geographic analysis in tourism, urban systems, and environmental management is fundamentally conditioned by computer systems and algorithmic processing. GIS applications operate as computational environments in which spatial data are transformed through system architectures and algorithms into analytical insights. Recognizing geographic analysis as a computational process provides a more accurate conceptual foundation for understanding the role of GIS in applied geography and enhances the methodological rigor of spatial research. Future geographic inquiry should therefore engage more explicitly with computational theory in order to strengthen the analytical validity and applicability of GIS-based studies.

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Spatial Narratives and Territorial Visibility: The Role of Journalism and Marketing in Shaping Geographic Perception

Viktorija Trajkov[20]
Angela Milenkovska Klimoska
Eli Tanaskovska

Abstract

Territorial visibility has become a decisive dimension of contemporary spatial development, increasingly shaping how places are perceived, prioritized, and integrated into development agendas. In mediatized societies, geographic perception is not formed exclusively through material spatial conditions, but through discursive representations produced by journalism and marketing communication. This paper develops a geographically grounded analytical framework for examining how spatial narratives constructed through media reporting and marketing practices operate as mediating mechanisms that structure territorial visibility.

Rather than treating journalism and marketing as auxiliary communication domains, the study conceptualizes them as spatial forces actively involved in the production of geographic meaning. Drawing on recent advances in human geography, media studies, and place branding scholarship, the analysis examines how narrative selection, framing, and repetition shape spatial hierarchies by amplifying certain territories while marginalizing others. Methodologically, the paper integrates qualitative discourse analysis with spatial contextual interpretation, linking dominant narrative patterns to territorial characteristics such as centrality, accessibility, and development status.

The findings demonstrate that territorial visibility follows patterned spatial inequalities that often diverge from material geographic potential. Territories repeatedly represented through positive or strategic narratives accumulate symbolic spatial capital, while peripheral areas remain discursively invisible despite comparable developmental conditions. By explicitly linking geographic analysis with journalism and marketing studies, the paper contributes to contemporary debates on spatial inequality, territorial governance, and the mediated production of space.

Keywords: territorial visibility; spatial narratives; journalism; marketing; geographic perception; spatial inequality

1. Introduction

Geographic space enters public consciousness not as a neutral physical reality, but as a socially mediated construct shaped by representation, narration, and symbolic framing. In contemporary societies characterized by dense media ecosystems and intensified territorial competition, the perception of space is increasingly produced through journalistic narratives and marketing communication. These narrative processes influence how territories are recognized, evaluated, and positioned within broader spatial hierarchies, thereby affecting development trajectories, investment decisions, and public policy priorities.

Classical geographical analysis has traditionally emphasized material determinants of territorial development, such as location, infrastructure, natural resources, and demographic structure. While these factors remain relevant, their explanatory power is increasingly intertwined with discursive processes that mediate how space is understood and acted upon. Territories with limited narrative visibility often remain excluded from development agendas despite favorable geographic conditions, whereas highly visible places attract disproportionate attention and resources. This divergence indicates that spatial inequality is not only material, but also representational in nature.

Journalism plays a central role in this process by selecting which places enter the public agenda, how spatial contexts are framed, and which territories are repeatedly associated with relevance, crisis, opportunity, or decline. Marketing communication, particularly through place branding and territorial promotion, further reinforces selective visibility by constructing spatial images aligned with economic and political objectives. Together, journalism and marketing form a narrative infrastructure through which geographic perception is shaped.

Recent geographical scholarship increasingly recognizes that space and meaning are co-produced through discursive practices, yet systematic integration of journalism and marketing into geographic analysis remains limited. Media studies often examine narratives without spatial grounding, while geography frequently treats communication as a secondary influence. This analytical separation obscures the extent to which narrative production functions as a spatial process with concrete territorial consequences (Paasi 2020; Couldry and Hepp 2019).

The present study addresses this gap by developing a geographical framework that positions journalism and marketing as spatial mediators. The central argument is that territorial visibility constitutes a mediated spatial

[20]**Viktorija Trajkov, PhD., Angela Milenkovska Klimoska, PhD.,** University Skopje, Republic of North Macedonia **and Eli Tanaskovska,** journalist at Macedonian Radio Television (MRT), Republic of North Macedonia

phenomenon produced through narrative selection, repetition, and amplification, thereby reinforcing spatial inequality beyond material disparities alone.

2. Conceptual Framework: Spatial Narratives and Territorial Visibility

Territorial visibility refers to the degree to which a place is present, recognizable, and symbolically meaningful within public discourse. Visibility is unevenly distributed across space and follows patterned hierarchies shaped by media attention, narrative framing, and institutional agendas. In this study, territorial visibility is conceptualized not as an inherent attribute of place, but as a spatial outcome generated through narrative practices.

Spatial narratives are structured representations that assign meaning to geographic space by linking territories to dominant themes such as development, innovation, crisis, heritage, or marginality. Journalism constructs spatial narratives through news selection, framing strategies, and contextualization, while marketing communication produces narratives oriented toward attraction, consumption, and competitiveness. Although these domains operate under different institutional logics, both contribute to a shared representational field in which geographic perception is formed (Eide and Nikunen 2020; Zelizer 2022).

From a geographical perspective, spatial narratives function as filters of spatial cognition. Territories repeatedly represented as central, dynamic, or desirable accumulate symbolic capital that enhances their spatial position within national and global systems. Conversely, territories that remain underrepresented or framed through narrow problem-oriented narratives experience discursive marginalization that constrains development opportunities. This process reinforces center–periphery dynamics even where material spatial differences are limited (Rodríguez-Pose 2020).

By conceptualizing journalism and marketing as spatial mediators, the framework aligns with interpretative and critical traditions in geography that emphasize the co-production of space and meaning. Spatial narratives are thus treated as constitutive elements of territorial systems rather than as external reflections of geographic reality.

3. Methodology and Analytical Design

The study employs a qualitative analytical design combining discourse analysis with spatial contextual interpretation. Empirical material consists of selected journalistic texts and marketing communications referring to territorially diverse areas within a national context. Texts are sampled to capture variation in geographic focus, narrative tone, and thematic emphasis.

Discourse analysis is applied to identify dominant spatial frames, recurring metaphors, and narrative structures through which territories are represented. These narrative patterns are subsequently interpreted in relation to geographic characteristics such as spatial centrality, accessibility, and development status. This approach enables examination of how narrative visibility corresponds to, or diverges from, material spatial conditions.

Rather than quantifying media output, the analysis emphasizes interpretative depth and spatial meaning, reflecting the study's focus on perception and representation as central dimensions of geographic analysis.

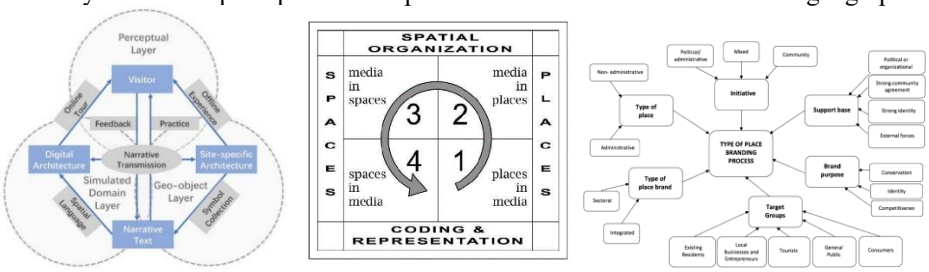

Figure 1. Conceptual model of spatial narratives and territorial visibility

The figure illustrates how journalism and marketing operate as mediating layers between material geographic conditions and public spatial perception, shaping territorial visibility through narrative selection and repetition.

4. Empirical Analysis: Narrative Construction of Geographic Space

Empirical analysis reveals pronounced asymmetries in territorial representation. Journalistic narratives tend to concentrate on metropolitan and politically central spaces, framing them as arenas of relevance, innovation, and continuity. Peripheral territories, when covered, are frequently associated with episodic events or deficit-oriented frames that lack narrative continuity.

Marketing narratives intensify selective visibility by promoting a limited set of territories aligned with established economic priorities. These narratives emphasize accessibility, investment potential, and symbolic attractiveness, often abstracting places from their broader regional contexts (Kavaratzis and Hatch 2021; Lucarelli and Berg 2020). As a result, spatial diversity is reduced to a narrow repertoire of recognizable locations.

Across both domains, narrative repetition emerges as a key mechanism of territorial visibility. Territories repeatedly appearing within positive or strategic frames accumulate symbolic spatial capital, while those absent

from narrative circulation remain geographically opaque to wider audiences. This produces a self-reinforcing spatial hierarchy that privileges already visible territories regardless of objective spatial potential.

Table 1. Types of Spatial Narratives and Their Territorial Effects

Type of narrative	Dominant discursive source	Core narrative features	Spatial effect on territory	Implications for territorial development
Centrality narrative	National journalism	Frequent coverage, agenda-setting relevance, association with political and economic importance	Reinforced spatial centrality and symbolic dominance	Concentration of investment, policy attention, and institutional presence
Opportunity narrative	Marketing and place promotion	Emphasis on growth potential, innovation, attractiveness, accessibility	Increased territorial visibility and positive place image	Enhanced competitiveness, tourism inflows, and external interest
Crisis narrative	Journalism	Event-driven framing, focus on risk, conflict, or decline	Episodic visibility followed by long-term stigmatization	Discursive marginalization and reduced developmental confidence
Heritage narrative	Marketing and cultural communication	Selective historical framing, identity construction, symbolic continuity	Symbolic differentiation within national space	Cultural valorization without structural economic transformation
Peripheral silence	Absence across media and marketing	Lack of narrative presence, invisibility in public discourse	Discursive marginalization and spatial opacity	Persistent underinvestment and exclusion from development agendas
Instrumental branding narrative	Strategic marketing	Simplified spatial image aligned with economic objectives	Reduction of spatial complexity	Uneven development favoring selected nodes over wider regions

As summarized in Table 1, territorial visibility is structured through distinct narrative types that generate differentiated spatial effects. Centrality and opportunity narratives actively reinforce spatial hierarchies, while peripheral silence produces discursive marginalization irrespective of material geographic potential.

5. Discussion: Media, Marketing, and Spatial Inequality

The findings demonstrate that territorial visibility is an actively produced spatial condition rather than a passive reflection of geographic reality. Journalism and marketing shape geographic perception by constructing narratives that guide public attention, valuation, and prioritization. These narratives influence policy agendas and development strategies by signaling which territories are deemed relevant, competitive, or worthy of intervention.

From a geographical perspective, this implies that spatial inequality operates simultaneously at material and representational levels. Territories marginalized within narrative space face structural disadvantages that cannot be addressed solely through infrastructural or economic measures. Without narrative inclusion, material development efforts risk limited reach and sustainability (Ashworth and Kavaratzis 2023).

Integrating journalism and marketing into geographic analysis thus expands understanding of how space is governed and transformed. Territorial development emerges as a mediated process in which narrative infrastructures play a decisive role alongside physical and economic factors.

Table 2. Actors, Narrative Production, and Scales of Spatial Influence in North Macedonia

Actor category	Dominant communication channel	Spatial scale of influence	Typical narrative focus	Territorial effect in North Macedonia
National television and online news portals	Broadcast news, digital journalism	National	Political relevance, crises, major urban events	Strong overrepresentation of Skopje and selected regional centers

Actor category	Dominant communication channel	Spatial scale of influence	Typical narrative focus	Territorial effect in North Macedonia
Local and regional media	Local news portals, radio	Local / regional	Episodic reporting, service provision, local problems	Fragmented visibility without narrative continuity
State institutions and ministries	Official statements, press releases	National	Strategic priorities, infrastructure, flagship projects	Selective territorial emphasis aligned with central policy agendas
Municipal governments	Municipal websites, social media	Local	Place promotion, events, identity signaling	Uneven visibility depending on local communication capacity
Tourism promotion agencies	Promotional campaigns, brochures	National / international	Attraction, accessibility, consumption-oriented imagery	Concentration of visibility in tourism-prioritized locations
Private marketing agencies	Branding campaigns, digital marketing	National / international	Simplified place images, competitiveness	Reinforcement of already visible territories
Civil society organizations	Reports, advocacy media	Local / national	Social inequality, environmental issues	Limited but issue-specific visibility of peripheral areas

Table 3. Narrative Intensity and Territorial Outcomes across Spatial Scales (North Macedonia)

Narrative intensity	Dominant actors	Typical territorial locations	Observed spatial outcome
High and continuous	National media, central institutions	Skopje, major urban centers	Persistent symbolic centrality and policy prioritization
Moderate and selective	Tourism agencies, marketing campaigns	Selected tourist destinations	Sector-specific visibility without broader regional spillover
Low and episodic	Local media, NGOs	Peripheral municipalities	Short-term visibility without structural change
Absent or minimal	No dominant narrative actor	Rural and remote areas	Discursive marginalization and spatial invisibility

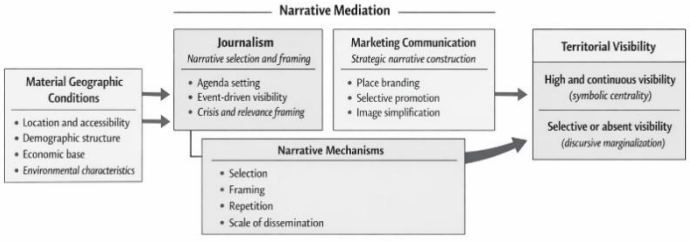

Figure 2. Narrative mediation between geographic space and territorial visibility

Figure 2 presents a conceptual synthesis of the mediated relationship between material geographic conditions and territorial visibility. The diagram illustrates how journalism and marketing operate as narrative filters that transform physical spatial attributes into symbolic visibility or invisibility through narrative intensity, framing, and scale of dissemination. Territorial outcomes emerge not directly from geographic potential, but from the interaction between narrative production and institutional communication power.

6. Conclusion

This study advances a geographically grounded interpretation of journalism and marketing as spatial mediators shaping territorial visibility and geographic perception. By conceptualizing spatial narratives as active components of territorial systems, the paper demonstrates that representation constitutes a critical dimension of spatial inequality and development.

The findings underscore the need for geographic research to engage more systematically with media and marketing practices as forces that co-produce space. In an era of intensified territorial competition and mediated perception, understanding spatial narratives becomes essential for designing more inclusive and territorially balanced development strategies.

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Revenue Density and Demand Volatility in Music-Based Cultural Tourism: A Dual-Segment Model from North Macedonia in a Comparative Perspective

Julijana Petrovska[21]
Aleksandar Boskov
Ana Petrovska

Abstract

This study investigates the relationship between revenue intensity and conditional demand volatility within a small music-based tourism system. Using North Macedonia over the period 2005–2024, it contrasts territorially dispersed traditional events with internationally oriented jazz festivals operating under the same institutional conditions. Direct tourism revenue is estimated through an expenditure-based aggregation model (n=1,247), while time-varying variance is modeled using GARCH(1,1) and EGARCH specifications.

Traditional events generate €62.5 per visitor and exhibit moderate normalized dispersion (CV=0.20), with volatility shocks dissipating within roughly three years ($\alpha+\beta=0.79$). Jazz festivals reach approximately €125 per visitor and between €4.2 and €6.8 million annually, yet their variance process follows a different path. Dispersion is substantially higher (CV=0.48), persistence approaches the stationarity boundary ($\alpha+\beta=0.95$), and negative shocks exert asymmetric influence on conditional variance ($\gamma=-0.21$, $p<0.05$), implying a half-life of 13.5 years.

When segment-level processes are aggregated through revenue weights, overall system volatility declines by 24.6% relative to the jazz segment alone. The reduction remains incomplete due to positive covariance between segment growth rates. Higher income intensity, in this setting, does not imply stronger variance containment. Within small tourism systems combining domestic and internationally exposed demand structures, revenue concentration may coincide with prolonged volatility transmission.

The study advances a revenue–volatility diagnostic framework that evaluates income intensity, persistence, asymmetry, and covariance structure jointly in sub-national festival economies.

Keywords: festival tourism; revenue density; volatility modeling; GARCH; portfolio diversification; North Macedonia

JEL: Z32; L83; C58

1. Introduction

Music-based tourism in small national systems cannot be fully captured through aggregate indicators alone. Total attendance and overall visitor expenditure describe scale, yet they offer limited insight into how demand responds when conditions change. In settings where domestic audiences intersect with internationally mobile visitors, fluctuations tend to reflect underlying structural characteristics rather than random variation. Demand becomes shaped by exposure to external conditions, institutional arrangements, and the composition of the audience itself.

This becomes particularly evident in North Macedonia. Traditional events are closely tied to locally recurring participation patterns and municipal cultural cycles, which introduce a degree of predictability in attendance. Jazz festivals follow a different trajectory. They attract a larger share of international visitors and rely more heavily on cross-border mobility, making them more sensitive to broader economic conditions. The coexistence of these two segments within the same national framework creates a setting in which differences in income intensity and demand variability can be observed without institutional distortion.

Focusing on revenue per visitor rather than total volume shifts the analytical perspective. Instead of measuring how large a segment is, attention is directed toward how much value each visitor generates.

Internationally oriented festivals often exhibit higher levels of expenditure per visitor, longer average stays, and a stronger presence of foreign participants (Thrane, 2002). These features support higher income performance, but they also introduce sensitivity to macroeconomic conditions, exchange-rate movements, and mobility constraints. As a result, higher revenue per visitor should not be interpreted as an indicator of stability. Its relationship with volatility requires empirical examination rather than assumption.

The underlying issue is structural. Changes in revenue levels do not automatically translate into changes in the variance process. When different segments operate within a shared institutional environment, overall stability depends on how their demand dynamics evolve and interact over time. A portfolio perspective allows this interaction to be examined more directly. It raises the question of whether diversity across segments reduces volatility or whether positive co-movement transmits shocks despite structural differences.

Within North Macedonia, territorially dispersed traditional events rely primarily on domestic participation embedded in recurring cultural cycles. Urban jazz festivals, by contrast, generate higher per-visitor expenditure and depend more strongly on international demand. Their coexistence within a unified national context enables comparison of income intensity, persistence of shocks, asymmetric responses, and covariance patterns without the influence of cross-country variation.

The analysis is guided by three empirical questions. Does higher revenue density correspond to stronger normalized and conditional volatility? Do internationally exposed festivals exhibit greater persistence and asymmetric reactions to adverse shocks? To what extent does segment differentiation reduce overall system variance once revenue weights and covariance structure are taken into account?

By combining expenditure-based revenue estimation with GARCH and EGARCH modeling over a twenty-year period, the study examines both dispersion and persistence within a unified framework. Conditional variance,

[21]**Julijana Petrovska, MSc.,** Academic Associate, Institute of National Geography, University Skopje, Skopje, Republic of North Macedonia**, Aleksandar Boskov,** Macedonian jazz guitarist and composer, Stip, Republic of North Macedonia**, Ana Petrovska, MSc.,** DevOps engineer, Skopje, Republic of North Macedonia.

shock duration, and inter-segment interaction are analysed jointly, treating volatility as an inherent feature of demand composition

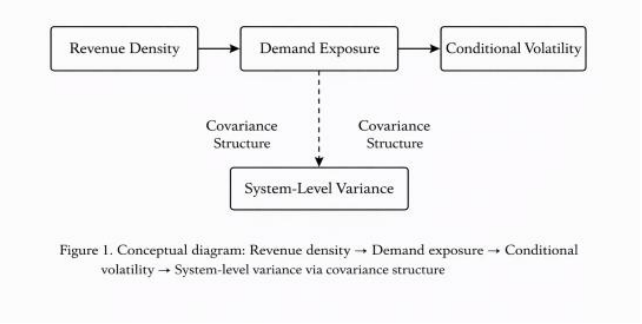

Figure 1. Conceptual diagram: Revenue density → Demand exposure → Conditional volatility → System-level variance via covariance structure

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Figure 1. Conceptual diagram

2. Conceptual Framework: Revenue Density, Volatility and Portfolio Structure

2.1 Revenue Density as Income Intensity

Festival performance is frequently evaluated through total attendance and aggregate visitor expenditure. These indicators measure scale but do not capture income intensity. To allow cross-segment comparison independent of size, revenue density (RD) is defined as direct tourism revenue per attendee:

$$RD=R/A$$

where

R denotes total direct tourism revenue and A total attendance.

At segment level:

$$RDs=\sum Ri/\sum Ai$$

Revenue density permits comparison between segments with different attendance volumes.

In internationally oriented festival segments, revenue density is typically influenced by:

Longer average length of stay

Higher daily expenditure

Greater foreign visitor participation

However, higher revenue per visitor does not imply lower dispersion in attendance. Empirical evaluation is required to assess whether revenue concentration corresponds to volatility containment or persistence.

2.2 Normalized Volatility and Conditional Variance

To compare dispersion across segments of different scale, volatility is first measured using the coefficient of variation:

$$CV=\sigma/\mu$$

where σ denotes standard deviation of annual attendance and μ denotes mean attendance.

In applied terms, the coefficient of variation indicates how predictable attendance remains from one year to another. Lower values suggest that fluctuations stay within a relatively narrow range, allowing more reliable planning of event capacity and resource allocation. Higher values, by contrast, point to wider swings in attendance, where periods of strong demand may be followed by noticeable contractions that are more difficult to anticipate.

Dynamic volatility is estimated using a GARCH(1,1) specification:

Mean equation: $y_t=\mu+\varepsilon_t, \quad \varepsilon_t \sim N(0,h_t)$

Variance equation:

$$h_t=\omega+\alpha\varepsilon_{2/t-1}+\beta h_{t-1}h$$

where:

- α measures immediate shock response
- β captures persistence
- α+β represents total persistence.

Stationarity requires $\alpha+\beta<1$.

Shock half-life is computed as:

$$HL=\frac{\ln(0.5)}{\ln(\alpha+\beta)}$$

Half-life expresses the number of periods required for half of a volatility shock to dissipate.

2.3 Asymmetric Shock Effects

Internationally exposed segments may react differently to positive and negative shocks. To test for asymmetry, an EGARCH(1,1) model is specified:

$$\ln(h_t)=\omega+\alpha(|\varepsilon_{t-1}|/\sqrt{h_{t-1}})+\gamma(\varepsilon_{t-1}/\sqrt{h_{t-1}})+\beta\ln(h_{t-1})$$

The parameter

$\gamma<0$ negative shocks increase volatility more than positive shocks

γ=0: symmetric response
γ>0: positive shocks increase volatility more
Asymmetry is expected to be more pronounced in segments dependent on international mobility and discretionary expenditure.

2.4 Revenue Concentration and Exposure Mechanism

Segments characterized by higher revenue density often display:
• Greater foreign participation
• Higher dependence on cross-border mobility
• Sensitivity to macroeconomic conditions in source markets
These characteristics may increase variance in attendance and revenue. The relationship between revenue intensity and volatility is therefore not assumed to be monotonic. Revenue concentration may coincide with higher persistence of shocks when demand drivers are externally determined.
In this setting, exposure is not an abstract property but a direct consequence of how demand is structured. When a larger share of visitors originates from outside the domestic market, attendance becomes linked to conditions that extend beyond local control. When demand relies on external markets, variations in economic conditions and mobility can directly influence attendance levels.

2.5 Portfolio Interaction

The festival system is conceptualized as a two-segment revenue portfolio. System-level variance depends on segmental variance, revenue weights, and inter-segment covariance. The portfolio variance is defined as:

$$\sigma_{system}^2 = w_1^2\sigma_1^2 + w_2^2\sigma_2^2 + 2w_1w_2Cov(1,2)$$

where w_s denotes the revenue share of segment s, σ_s^2 represents conditional variance derived from GARCH estimation, and Cov(1,2) captures covariance between log-differenced attendance growth rates of the two segments. Revenue weights are computed as:

$$w_s = R_s / R\_total$$

where R_s denotes segment revenue and R_total denotes aggregate revenue of the national festival system.
Segment variance σ_s^2 is obtained from the estimated conditional variance series h_t produced by GARCH(1,1) specifications. Covariance is calculated using synchronized log-differenced growth rates:

$$g_s,t = \Delta\ln(A_s,t)$$

Cov (1,2) denotes covariance between segment growth rates
This specification ensures internal consistency between dynamic volatility estimation and portfolio aggregation. System variance therefore reflects not only dispersion within each segment but also the degree of co-movement across segments. When covariance is low or negative, diversification effects reduce aggregate volatility. When covariance is positive and elevated, stabilization potential is constrained due to synchronous fluctuations.
Revenue–volatility configuration space:
Low RD / Low CV
High RD / Low CV
Low RD / High CV
High RD / High CV
This framework positions segments according to both income intensity and dispersion structure.

2.6 Testable Expectations

The framework yields three testable propositions:
H1: Segments with higher revenue density exhibit higher normalized volatility.
H2: Internationally exposed segments display stronger persistence and asymmetric shock effects.
H3: Positive but incomplete covariance between segments produces partial diversification at system level.

3. Data and Methodology

3.1 Research Design and Unit of Analysis

The empirical design is longitudinal and covers the period 2005–2024. The observation unit is annual segment-level attendance. Individual events are aggregated into two analytically distinct segments:
• Traditional music-based events (folk festivals, rural gatherings, municipal celebrations)
• Jazz-based festivals (internationally oriented urban events)
Aggregation ensures continuity of the time series and permits estimation of conditional variance models requiring sufficient temporal observations. All monetary values are converted into constant 2010 euros to eliminate inflation effects.

3.2 Data Sources

Attendance Data
Annual attendance figures were compiled from:
• Ministry of Culture funding and reporting archives
• Municipal cultural centers
• Festival organizational records
• National Statistical Office supplementary tourism data
Where minor gaps occurred, interpolation based on segment-specific growth rates was applied. Missing observations represent less than 8% of total series length and do not materially affect variance estimation.

Table 1. Segmental event composition and time coverage

Segment	Number of Core Events	Geographic Distribution	Average Annual Attendance per Event	Total Segment Coverage	Data Completeness
Traditional Music	17	Rural and municipal (national dispersion)	2,168	2005–2024	92%
Jazz Festivals	12	Urban centers (Skopje, Bitola, Ohrid, Stip)	3,469	2005–2024	95%

Expenditure Data
Primary expenditure data were collected during 2018–2024 through stratified sampling across major events in both segments. Inclusion criteria required respondents to identify the festival as the primary motivation for travel, limiting attribution bias in revenue estimation.

Table 2. Survey sample characteristics by segment

Segment	Events Surveyed	Valid Responses (n)	Domestic Visitors (%)	International Visitors (%)	Mean Age	Female (%)
Traditional	12	612	78.4	21.6	37.8	48.2
Jazz	8	635	38.2	61.8	41.2	46.7
Total	20	1,247	58.1	41.9	39.5	47.4

3.3. Revenue Estimation

Direct tourism revenue is estimated using an expenditure-based aggregation model:

$$R = \sum_{i=1}^{N} A_i \times L_i \times E_i$$

where:
A_i denotes attendance at event iii,
L_i denotes average length of stay (nights),
E_i denotes average daily expenditure in constant 2010 euros, and
N denotes the number of events within a segment.
Only visitors identifying the event as their primary travel motivation are included. Indirect and induced effects are excluded to maintain conservative and comparable estimates.
Revenue density at segment level is defined as:

$$RD_s = \frac{R_s}{A_s}$$

where: R_s denotes total segment revenue and A_s total segment attendance.

Table 3. Visitor expenditure profiles and segmental revenue density

Parameter	Traditional Music	Jazz Festivals	Mean Difference	t-statistic
Average Length of Stay (nights)	1.8 (0.4)	3.2 (0.7)	+1.4***	8.24
Average Daily Expenditure (€)	34.7 (8.2)	39.1 (9.3)	+4.4**	2.98

Parameter	Traditional Music	Jazz Festivals	Mean Difference	t-statistic
Total Expenditure per Visit (€)	62.5 (12.1)	125.1 (24.8)	+62.6***	11.47
Foreign Visitor Share (%)	21.6 (4.8)	61.8 (8.2)	+40.2***	15.83
Estimated Annual Revenue (€ million)	2.30	5.21	—	—
Revenue Density (€ per visitor)	62.5	125.1	—	—

3.4 Stationarity and Pre-Estimation Diagnostics

Before volatility modeling, stationarity is tested using the Augmented Dickey–Fuller test applied to log-differenced attendance:

$$\Delta y_t = c + \lambda t + \rho y_{t-1} + \sum \varphi_i \Delta y_{t-i} + \varepsilon_t$$

The null hypothesis H_0: $\rho = 0$ indicates the presence of a unit root. Rejection of H_0 implies stationarity of the series and justifies conditional variance modeling.

ARCH effects are tested using the Lagrange Multiplier procedure applied to residuals from the mean equation. Significant heteroskedasticity justifies GARCH specification.

Testing for stationarity ensures that observed fluctuations are not driven by underlying trends that could distort variance estimation. Without this step, changes in attendance might be misinterpreted as volatility, when in fact they reflect gradual structural shifts in demand over time.

3.5 Conditional Volatility Modeling

Volatility is estimated using a GARCH(1,1) model:

Mean equation:

$$yt=\mu+\varepsilon t$$

Variance equation:

$$ht=\omega+\alpha\varepsilon t-12+\beta ht-1$$

where yt represents log-differenced attendance. Persistence is evaluated through $\alpha+\beta$. Shock half-life is computed using:

$$HL=\frac{\ln(0.5)}{\ln(\alpha+\beta)}$$

3.6 Asymmetric Volatility

To test differential responses to negative shocks, an EGARCH(1,1) model is estimated:

$$\ln(h_t)=\omega+\alpha(|\varepsilon_{t-1}|/\sqrt{h_{t-1}})+\gamma(\varepsilon_{t-1}/\sqrt{h_{t-1}})+\beta\ln(h_{t-1})$$

The parameter γ captures asymmetry. A negative and significant coefficient indicates stronger volatility response to negative shocks.

3.7 Crisis Intervention Specification

To isolate structural breaks, intervention dummies are introduced:

$$yt=\mu+\delta 1D^{2008}+\delta 2D^{2015}+\delta 3D^{2020}+\varepsilon t$$

where:

D^{2008} = global financial crisis

D^{2015} = regional mobility disturbance

D^{2020} = pandemic contraction

Coefficients estimate average attendance deviations during crisis periods.

Table 4. Revenue weights, covariance matrix, and system variance decomposition

Component	Traditional	Jazz
Mean Annual Revenue (€ million)	2.30	5.21
Revenue Weight (w_s)	0.31	0.69
Segment Variance (σ^2)	0.00176	0.01392
Segment Standard Deviation (σ)	0.042	0.118

3.8. Model Selection and Robustness

System-level volatility is derived from segment-specific conditional variance processes rather than static measures. Estimated variance series from GARCH(1,1) models are averaged over time, while revenue weights are based on mean annual segment income in constant prices. Covariance is calculated using synchronized log-differenced attendance growth rates, ensuring consistency with the underlying stochastic structure.

Inter-segment covariance is estimated using synchronized log-differenced attendance growth rates defined as $g_{s,t}=\Delta\ln(A_{s,t})$ Estimating covariance at the growth-rate level maintains coherence with the stochastic structure underlying the conditional variance models and ensures that portfolio aggregation is grounded in the same transformation applied during volatility estimation. System variance is then computed through the standard revenue-weighted portfolio specification incorporating segment-level conditional variances and the covariance term between segment growth processes.

The resulting portfolio measure captures interaction between two evolving stochastic variance processes. Aggregate dispersion reflects both revenue concentration and the degree of co-movement in attendance dynamics. When segment growth evolves independently, diversification reduces overall exposure. When covariance is positive and persistent, stabilization remains limited despite structural differentiation across segments.

Model adequacy is evaluated using Akaike Information Criterion and Bayesian Information Criterion, balancing goodness of fit against parsimony. Standardized residuals and squared residuals are tested using Ljung–Box Q statistics to verify the absence of serial correlation and remaining ARCH effects. Diagnostic results confirm appropriate variance specification for both segments.

Robustness is examined through three complementary procedures. First, models are re-estimated excluding the pandemic period 2020–2021 to assess sensitivity to extreme contraction episodes. Second, alternative lag structures, including GARCH(2,1) and GARCH(1,2), are estimated to evaluate parameter stability. Third, symmetric GARCH specifications are compared with EGARCH models allowing asymmetric responses. Across these alternatives, persistence differentials between segments remain stable, and the magnitude ordering of conditional variance is preserved. The volatility gap therefore reflects structural characteristics of demand composition rather than specification artifacts.

4. Results

4.1 Descriptive and Static Dispersion Analysis

Table 5. Descriptive Statistics of Annual Attendance by Segment (2005–2024)

Statistic	Traditional Music	Jazz Festivals
Mean Annual Attendance	36,847	41,623
Standard Deviation	7,421	19,954
Coefficient of Variation (CV)	0.20	0.48
Minimum	22,150 (2020)	15,280 (2020)

The traditional segment records a mean of 36,847 visitors and a coefficient of variation of 0.20. The jazz segment reports a higher mean attendance of 41,623 visitors but a coefficient of variation of 0.48. The dispersion ratio indicates that relative variability in jazz festivals exceeds that of traditional events by more than twofold.

Minimum attendance levels in 2020 reflect contraction across both segments, with a stronger decline in jazz festivals. The wider fluctuation range in this segment indicates greater variability in demand.

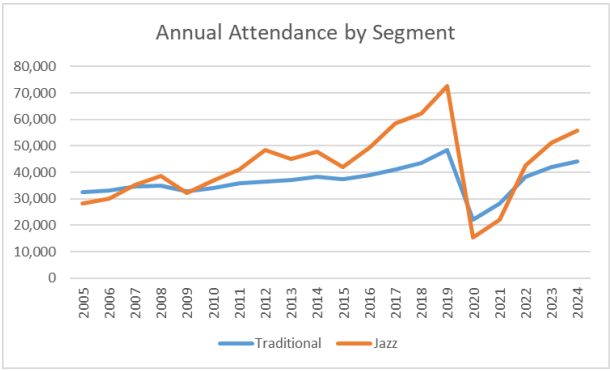

Figure 2. Annual Attendance by Segment (2005–2024)

Annual attendance trajectories for traditional music events and jazz festivals in North Macedonia over the period 2005–2024. The jazz segment exhibits greater inter-annual amplitude and slower post-shock recovery compared to territorially dispersed traditional events.

4.2 Conditional Volatility Estimation

The persistence pattern differs markedly between the two segments. In the traditional segment, shocks dissipate within a relatively short period, indicating that deviations from average attendance are gradually absorbed. In the jazz segment, the adjustment process extends over a much longer horizon, suggesting that disturbances continue to influence attendance well beyond the initial shock.

Table 6. GARCH(1,1) Estimation Results for Segmental Attendance Volatility

Parameter	Traditional	Jazz
μ	0.023 (0.015)	0.041 (0.022)*
ω	0.004 (0.002)*	0.008 (0.003)**
α (ARCH)	0.17 (0.07)**	0.29 (0.09)***
β (GARCH)	0.62 (0.11)***	0.66 (0.10)***
α+β	0.79	0.95
Half-life (years)	2.9	13.5
Log-likelihood	42.7	38.2
AIC	-79.4	-70.4
BIC	-75.2	-66.2

The ARCH coefficient (α) is higher in the jazz segment, suggesting stronger immediate reaction to disturbances. These estimates indicate both higher reactivity and higher persistence in the internationally oriented segment.

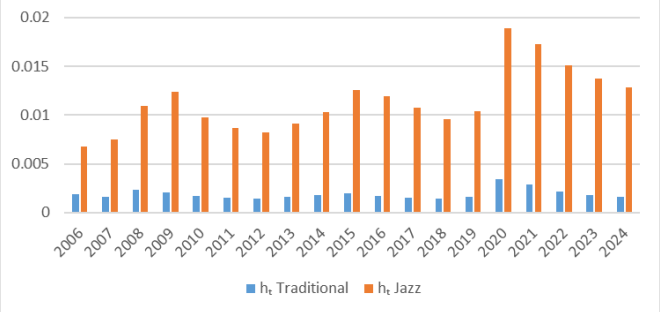

Figure 4. Conditional Variance Series from GARCH(1,1) Models (2005–2024)

Time-varying conditional variance of log-differenced attendance for traditional and jazz segments. The differences observed in simple dispersion measures persist when volatility is examined dynamically, indicating that the contrast between segments is not limited to descriptive statistics.

4.3 Asymmetric Volatility Effects

EGARCH results are presented in Table 8. The asymmetry parameter (γ) is negative and statistically significant in the jazz segment (-0.21), indicating that negative shocks generate larger increases in conditional variance than positive shocks of similar magnitude. The traditional segment does not exhibit statistically significant asymmetry. Persistence under EGARCH remains higher in the jazz segment. This result indicates that negative shocks have a more pronounced and lasting effect on attendance variability than positive fluctuations of similar magnitude.

Table 7. EGARCH(1,1) Estimation Results and Asymmetric Shock Effects

Parameter	Traditional	Jazz
μ	0.021 (0.014)	0.038 (0.021)*
ω	-0.32 (0.18)*	-0.41 (0.19)**
α	0.24 (0.09)**	0.36 (0.11)***
γ (Asymmetry)	-0.08 (0.06)	-0.21 (0.09)**
β	0.71 (0.12)***	0.82 (0.11)***
Log-likelihood	43.5	41.8
AIC	-79.0	-75.6
BIC	-73.8	-70.4

The asymmetric specification confirms differential sensitivity to adverse disturbances.

4.4 Crisis Intervention Analysis

Crisis dummy effects are reported in Table 9. During the 2008–2009 financial crisis, attendance declined by 6.2% in traditional events and 11.8% in jazz festivals. The 2015 mobility disturbance affected primarily the jazz segment. During the 2020–2021 pandemic, attendance declined by 38.2% in traditional events and 64.1% in jazz festivals.

Table 8. Crisis Intervention Effects on Segmental Attendance (% Deviation)

Crisis Period	Traditional	Jazz	Difference
2008–2009	-6.2%	-11.8%	-5.6%*
2015	-2.1%	-9.5%	-7.4%**
2020–2021	-38.2%	-64.1%	-25.9%***

Re-estimation excluding pandemic years does not materially alter persistence parameters. The volatility differential therefore reflects structural characteristics rather than single-period anomalies.

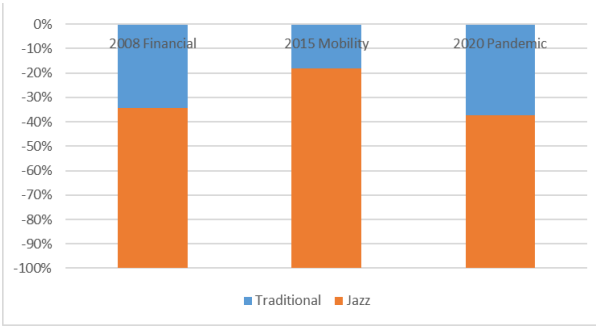

Figure 5. Crisis Impact Comparison

Estimated percentage deviations in attendance during the 2008–2009 financial crisis, the 2015 mobility disturbance, and the 2020–2021 pandemic period. Jazz festivals display stronger contraction across all crisis episodes.

4.5 Portfolio Variance Decomposition

Using revenue weights of 0.31 for the traditional segment and 0.69 for the jazz segment, system-level variance is calculated according to the portfolio specification.
The estimated correlation between segment growth rates equals 0.28, implying moderate positive covariance. Substituting estimated parameters yields a system standard deviation of 0.089. This value is 24.6% lower than jazz-segment volatility alone (0.118), indicating partial diversification.
This reduction should be interpreted with caution. Although diversification across segments lowers overall variability, it does not eliminate exposure to fluctuations. The remaining level of variance reflects the extent to which both segments respond simultaneously to broader conditions affecting tourism demand.
Because covariance is positive, full stabilization is not achieved. System variance remains above the volatility level of the traditional segment. The portfolio effect reduces overall variability, but a significant level of exposure remains due to the shared response of both segments to broader demand conditions.

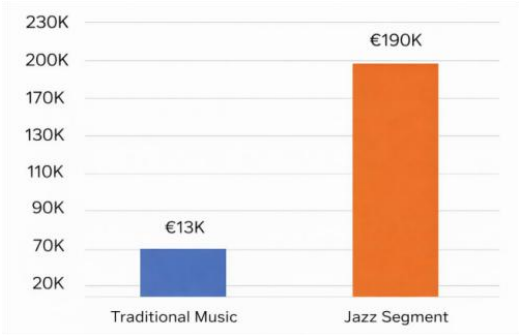

Figure 6. Revenue–Volatility Quadrant Model with All Cases Positioned

Positioning of traditional music events and jazz festivals within a revenue density–normalized volatility configuration space. The jazz segment occupies the high-revenue/high-volatility quadrant, while traditional events cluster in the lower-revenue/lower-volatility space.

5. Discussion

The findings challenge the assumption that higher revenue intensity leads to greater stability. Although the jazz segment generates substantially higher expenditure per visitor, its volatility pattern suggests a different dynamic. Demand reacts more strongly to disturbances and requires a longer period to return to its average level. Even when persistence remains below unity, the adjustment process appears extended, indicating that fluctuations are not easily absorbed.
The contrast with territorially dispersed traditional events extends beyond differences in scale. Attendance variability within that segment dissipates within a shorter horizon, and shocks are absorbed without extended amplification.
The contrast with traditional events can be traced to differences in demand composition. Attendance in this segment follows more regular patterns, supported by recurring local participation and institutional continuity. In contrast, jazz festivals depend more heavily on internationally mobile audiences, whose participation is influenced by broader economic conditions and travel constraints. As a result, variability is not only higher but also more persistent over time.
The slower dissipation of shocks in the jazz segment reflects its exposure to external demand conditions. Changes originating outside the local context continue to affect attendance beyond the initial disturbance, extending the adjustment period.
Asymmetry further differentiates the two segments. Negative shocks in the jazz segment produce stronger increases in volatility than positive shocks reduce it, leaving downturns with a more persistent effect. Traditional events, by comparison, show a more balanced response, with fluctuations that adjust more evenly over time.
Portfolio aggregation produces moderation but not full stabilization. Revenue weighting reduces overall system volatility relative to the jazz segment in isolation, yet positive covariance between growth rates constrains convergence toward the lower dispersion observed in traditional events. Co-movement limits diversification gains. Heterogeneity reduces variance only where synchronous fluctuations remain limited.
These results suggest that strong revenue performance may coexist with underlying instability, particularly in segments shaped by externally driven demand. Income intensity alone does not capture how fluctuations develop or how long their effects persist. A more complete interpretation of festival performance therefore requires attention to both the level of income generated and the stability of attendance over time.

6. Conclusion

The results show that revenue performance and demand stability do not necessarily evolve in the same direction. Segments generating higher income per visitor may still exhibit prolonged adjustment periods following external

disturbances. This suggests that economic success, when measured through expenditure alone, provides only a partial view of system behaviour.

Jazz festivals display a different pattern. Elevated revenue density coincides with stronger reactivity, persistence approaching the stationarity boundary, and asymmetric amplification of adverse disturbances. In this configuration, variance does not dissipate quickly, even when overall revenue performance appears robust.

Portfolio aggregation demonstrates that coexistence of heterogeneous segments reduces aggregate volatility relative to the most exposed component. The effect, however, remains partial. Positive covariance between segments constrains full stabilization, leaving system-level variance influenced by the persistence characteristics of the internationally oriented segment.

The results indicate that income concentration and structural stability follow distinct statistical logics. Revenue expansion alone does not reveal how shocks propagate or how long their effects remain embedded in demand dynamics. In small tourism systems characterized by mixed domestic and international participation, variance persistence may accompany income intensity unless institutional mechanisms counterbalance exposure.

The findings show that income intensity and demand stability follow different dynamics. Higher revenue does not necessarily imply resilience, particularly in segments exposed to external demand conditions. A more comprehensive evaluation of tourism systems therefore requires attention to both income generation and stability over time.

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Digital Transformation of Official Statistics: A Comparative Analysis of Traditional Statistical Systems and AI-Driven Data Ecosystems with Reference to the State Statistical Office of North Macedonia

Goran Karovski[22]
Elena Tasevska
Dragan Petrovski

Abstract

The transformation of official statistical systems reflects a broader shift in the production, interpretation, and governance of data. This study develops a comparative analytical framework that examines the transition from traditional survey-based statistical methodologies toward digitally enhanced and AI-supported data ecosystems. Particular emphasis is placed on the institutional and methodological evolution of official statistics within the context of the State Statistical Office of North Macedonia, interpreted in relation to wider European statistical practices. Drawing on recent Web of Science indexed literature, the analysis integrates insights from statistical methodology, data science, and digital governance. The findings indicate that while artificial intelligence introduces unprecedented levels of efficiency and analytical capacity, the foundational principles of statistical reliability, comparability, and methodological rigor remain structurally persistent. At the same time, digital transformation reshapes the relationship between data producers and users, introducing new challenges related to data quality, algorithmic transparency, and institutional trust.

Keywords: official statistics; artificial intelligence; digitalization; statistical systems; data governance; machine learning; administrative data; State Statistical Office; data ecosystems; statistical methodology

1. Introduction

The production of statistical knowledge has historically been anchored in structured methodologies designed to ensure consistency, comparability, and reliability. Within this framework, official statistical institutions have developed standardized procedures for data collection, processing, and dissemination. The emergence of digital technologies introduces a shift that extends beyond mere technical enhancement, as it redefines the epistemological foundations of statistical practice. Data are no longer generated exclusively through controlled survey instruments, but increasingly arise from administrative registers, digital platforms, and automated systems. Within the institutional context of the State Statistical Office of North Macedonia, this transformation is particularly visible in the gradual incorporation of administrative data sources and the adoption of digital tools for data processing. Such developments reflect broader European trends, where statistical systems evolve toward integrated data environments. Eurostat (2023) emphasizes that the modernization of official statistics requires the harmonization of traditional methodologies with emerging digital infrastructures, thereby ensuring both innovation and continuity.

This transition calls for a comparative analytical perspective capable of capturing the interaction between established statistical principles and emerging technological paradigms.

The transformation of statistical production must therefore be interpreted as a reconfiguration of the epistemic conditions under which data are generated, validated, and disseminated. This shift extends beyond the incorporation of new technological tools, as it introduces a fundamental change in the temporal, spatial, and methodological dimensions of statistical systems. The increasing reliance on digitally generated data modifies the balance between control and availability, where traditional mechanisms of sampling precision are complemented by large-scale data integration processes. The growing complexity of data environments places statistical institutions in a position where methodological adjustment is not optional, but unavoidable if consistency and comparability are to be preserved.

2. Hypotheses

H1: The transition from survey-based statistical production toward integrated digital data systems is associated with a measurable increase in data processing efficiency and temporal availability of statistical outputs (Eurostat, 2023).

H2: The incorporation of artificial intelligence techniques in statistical production is correlated with improved predictive accuracy, particularly in domains characterized by high-frequency data streams (Bontempi et al., 2021).

H3: Despite technological advancements, core statistical principles such as comparability and methodological transparency remain stable, indicating structural continuity within transformed systems (UNECE, 2022).

H4: The integration of administrative and big data sources introduces variability in data quality, requiring new validation frameworks that differ from traditional sampling-based approaches (Daas et al., 2015).

[22] **Goran Karovski, MSc.**, **Elena Tasevska, MSc.,** Assistant, UTMS, Skopje, Republic of North Macedonia and **Dragan Petrovski, MSc.,** Quality Assurance Engineer, Quipu, Skopje, Republic of North Macedonia**.**

H5: Institutional capacity, measured through digital infrastructure and human expertise, significantly influences the effectiveness of AI adoption within official statistical systems (Eurostat, 2023).
H6: The digitalization of statistical processes reshapes the relationship between statistical institutions and data users, leading to increased demand for real-time data access and interactive dissemination formats (UNECE, 2022).

3. **Methodology**

The research adopts a comparative analytical design combining institutional analysis with empirical synthesis of statistical and methodological indicators. Data sources include official publications from the State Statistical Office of North Macedonia, Eurostat datasets, and peer-reviewed literature indexed in Web of Science.
The analysis integrates qualitative interpretation of institutional frameworks with quantitative examination of data production processes. Indicators of efficiency, accuracy, and data availability are derived from comparative assessments of traditional survey-based systems and digitally enhanced statistical environments. Particular attention is given to methodological adjustments required for the integration of administrative and big data sources.
By combining institutional and empirical perspectives, the study enables a layered interpretation in which continuity of statistical principles coexists with technological transformation.
The comparative design further enables the identification of structural differences and continuities between traditional and digitally transformed systems by aligning methodological principles with empirical indicators. This alignment provides a coherent analytical basis for assessing the extent to which technological innovation modifies statistical production without undermining its foundational standards. This approach allows a direct assessment of how far technological innovation can extend without destabilizing the methodological foundations on which statistical production depends.

4. Empirical Analysis

The structural differences between traditional and AI-supported statistical systems are best captured through the following conceptual representation.

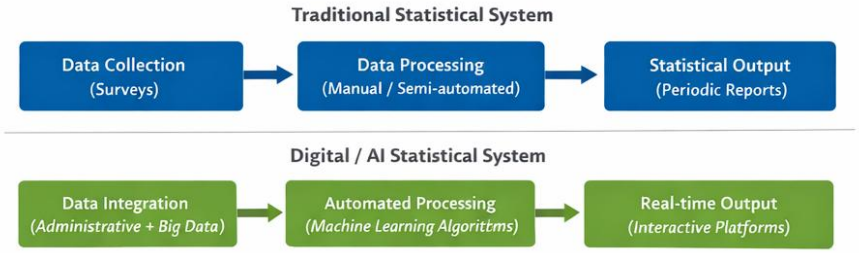

Figure 1. Conceptual representation of transition from traditional statistical systems to AI-driven data environments

Source: Author's elaboration based on Eurostat (2023) and UNECE (2022)

Traditional statistical systems rely on periodic data collection through structured surveys, ensuring high levels of methodological control. Such systems provide consistent and comparable datasets, yet they are characterized by temporal delays and high operational costs. In contrast, digitally enhanced systems integrate multiple data sources, including administrative records and real-time digital inputs.
This contrast reveals that the transformation of statistical systems is not limited to improvements in operational efficiency, but rather involves a redefinition of the entire data production cycle. The shift toward continuous data flows introduces new temporal dynamics, where the distinction between data collection and data dissemination becomes increasingly blurred. In such conditions, statistical outputs emerge as part of a continuous process rather than as fixed products tied to predefined reporting intervals.
Empirical evidence indicates that digitalization significantly reduces data processing time. Eurostat (2023) reports that the use of automated data pipelines enables near real-time updates in selected statistical domains. This transformation alters the temporal dimension of statistical production, shifting from periodic reporting toward continuous data flows.
Artificial intelligence further expands analytical capacity. Bontempi et al. (2021) demonstrate that machine learning models improve predictive performance in complex datasets characterized by non-linear relationships. Within official statistics, such techniques are increasingly applied in areas such as economic forecasting and population estimation. The application of such models within official statistics requires careful methodological integration, as predictive accuracy must be balanced against interpretability and reproducibility. While machine learning techniques enhance analytical capacity, their incorporation into statistical workflows necessitates

transparent validation procedures that ensure consistency with established statistical standards. This creates a situation in which algorithmic performance cannot be evaluated in isolation and requires direct assessment against established statistical criteria.

At the same time, the integration of heterogeneous data sources introduces challenges related to data quality. Daas et al. (2015) highlight that administrative and big data sources often lack the structured design inherent in survey-based data collection. This requires the development of new validation methodologies capable of ensuring statistical reliability.

The integration of multiple data sources into a unified analytical framework can be more clearly understood through the following structured representation of the underlying data architecture.

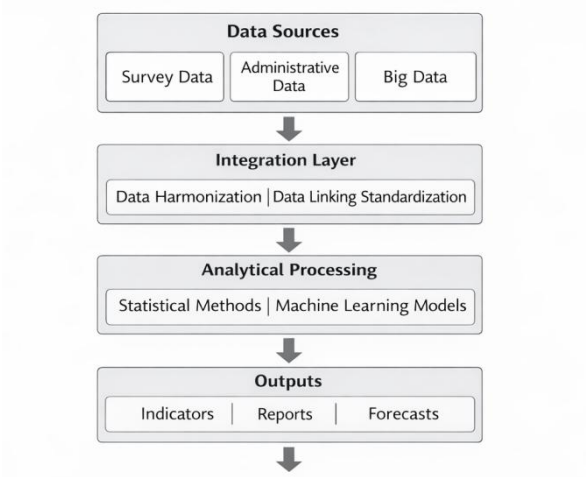

Figure 2. Integrated data architecture in digital statistical systems

Source: Author's elaboration based on Daas et al. (2015); Eurostat (2023)

Table 1. Comparative Synthesis of Traditional and Digital Statistical Systems

Dimension	Traditional System	Digital/AI System
Data Source	Surveys	Administrative and big data
Temporal Frequency	Periodic	Continuous
Processing Method	Manual and semi-automated	Automated and AI-supported
Data Quality Control	Sampling-based validation	Algorithmic validation frameworks
User Interaction	Static dissemination	Interactive and real-time access

Source: Author's elaboration based on synthesis of Eurostat (2023); UNECE (2022); Daas et al. (2015); Bontempi et al. (2021)

5. Extended Empirical and Institutional Analysis

The integration of artificial intelligence within statistical systems introduces a shift in analytical capabilities, extending beyond conventional processing routines toward a structured and multi-layered production architecture in which heterogeneous data sources are systematically transformed into analytically meaningful outputs. This transformation is operationalized through a sequential configuration of interrelated stages that encompass data input, processing, analytical modeling, and output generation, each governed by distinct methodological procedures and technological mechanisms. Within such a framework, raw data originating from administrative registers, survey instruments, and large-scale digital environments undergo processes of cleaning, harmonization, and algorithmic interpretation, thereby enabling the extraction of patterns and predictive insights that would remain inaccessible within traditional statistical approaches. The structural organization of these stages, as illustrated in the following figure, reflects the internal logic through which artificial intelligence reconfigures the

statistical production process into an integrated system of continuous data transformation and analytical refinement.

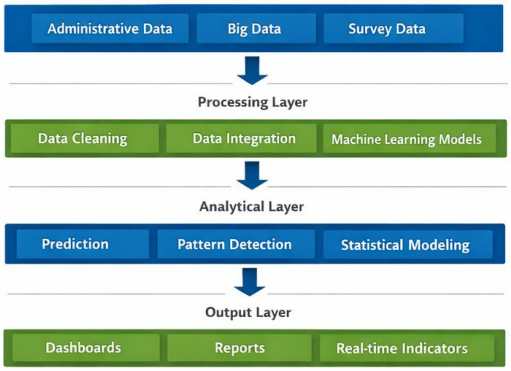

Figure 3. Structure of AI-supported statistical production process
Source: Author's elaboration based on Daas et al. (2015); Bontempi et al. (2021)

Machine learning algorithms enable the processing of large-scale datasets, facilitating the detection of patterns that remain inaccessible through traditional statistical techniques. Bontempi et al. (2021) emphasize that such methods enhance predictive modeling, particularly in dynamic environments.
Within the institutional framework of the State Statistical Office, digital transformation is reflected in the gradual adoption of administrative data and digital platforms. This process requires not only technological adaptation, but also methodological recalibration. The transition toward integrated data systems necessitates the development of standardized procedures for data validation and harmonization.
This institutional adaptation is closely linked to the development of digital infrastructures that enable the coordination of multiple data sources within a unified analytical framework. The effectiveness of such systems depends on the capacity to standardize data formats, ensure interoperability, and maintain robust validation mechanisms. In this regard, the transformation of statistical institutions reflects not only technological advancement, but also an ongoing process of organizational restructuring aimed at accommodating the demands of digitally mediated data environments.
The relationship between statistical institutions and data users undergoes a parallel transformation. Digital platforms enable interactive access to statistical outputs, allowing users to engage with data in real time. UNECE (2022) notes that this shift increases expectations regarding data availability and transparency, thereby reshaping institutional responsibilities.
Despite these developments, structural continuity remains evident. Core principles such as comparability and methodological rigor continue to guide statistical production. The persistence of these principles demonstrates that technological transformation does not replace existing frameworks, but rather operates within them.

6. **Discussion**

The transformation of official statistics reflects a reconfiguration of methodological and institutional practices. The integration of artificial intelligence introduces new analytical possibilities, yet it also raises questions regarding transparency and accountability. Algorithmic decision-making processes require clear documentation to ensure reproducibility and trust.
This reconfiguration introduces a tension between innovation and methodological stability, as the rapid evolution of analytical technologies challenges the established principles that have historically governed statistical production. The need to preserve transparency and reproducibility becomes particularly relevant in contexts where algorithmic processes are not fully observable. Consequently, the legitimacy of statistical outputs increasingly depends on the capacity of institutions to articulate and document the methodological foundations underlying AI-supported analyses.
The comparative analysis demonstrates that digital transformation does not eliminate traditional statistical approaches. Instead, it leads to the coexistence of multiple data production models. Such conditions expose a structural tension that cannot be resolved through technological improvement alone. This limitation is fundamental, not technical.
Existing literature predominantly emphasizes technological innovation as the primary driver of transformation, whereas the present analysis demonstrates that institutional adaptation and methodological continuity operate as equally determining dimensions.

7. **Limitations**

The study relies on secondary data sources, which limits the possibility of direct empirical verification. The evolving nature of digital statistical systems introduces uncertainty in assessing long-term impacts. Variability in data quality across different sources presents additional constraints in comparative analysis.

An additional limitation arises from the rapid pace of technological change, which may render certain methodological approaches obsolete within relatively short time frames. This dynamic environment complicates the establishment of stable evaluation criteria, as both data sources and analytical techniques continue to evolve. For this reason, the findings should be interpreted as part of an evolving analytical context rather than as fixed conclusions.

8. **Future Research Directions**

Further research could incorporate primary data from statistical institutions, enabling more precise evaluation of AI applications. The development of quantitative models integrating statistical methodology with machine learning techniques represents another promising direction. Comparative studies across multiple national statistical systems may provide deeper insight into institutional variation.

9. **Conclusion**

The evolution of official statistical systems reflects an interplay between continuity and transformation. Digital technologies and artificial intelligence expand analytical capacity, yet foundational statistical principles remain intact. The transition toward integrated data ecosystems redefines the production and dissemination of statistical knowledge, introducing new opportunities and challenges.

The comparative perspective adopted in this study demonstrates that the evolution of statistical systems cannot be reduced to a linear process of technological substitution. Instead, it reflects a complex interaction between established methodological principles and emerging analytical capabilities, where continuity and transformation coexist within the same structural framework.

This perspective shows that transformation does not replace existing systems, but reshapes them in ways that remain constrained by their original logic.

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