

REVIEW REPORT FROM ON THE PHD THESIS

“Integrated assessment of regulating ecosystem services in urban areas”

Reviewer: Fernando Santos Martín

Universidad Rey Juan Carlos (URJC), Madrid, Spain

PhD candidate: Vanya Emilova Stoycheva

National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences

Scientific area: 4.4 Earth Sciences; Scientific programme: Physical Geography and Landscape Ecology

Scientific supervisor: Prof. Stoyan Nedkov, PhD

Scientific advisor: Prof. Davide Geneletti, PhD

Thesis version reviewed: 17 June 2026

1. General information about the candidate and the procedure

The thesis addresses a timely and important research problem: how regulating ecosystem services (RES) in urban areas can be assessed in an integrated manner while accounting for the strong dependence of ecosystem-service assessment on the availability, quality and spatial resolution of data. The central research question is how to develop a methodological approach for the integrated assessment of urban regulating ecosystem services. The work is focused primarily on Sofia, Bulgaria, which is used as a case study through which the proposed methodological developments are tested.

The dissertation is organised around four main research tasks: (1) identifying priority regulating ecosystem services and the methods used to assess, model and map them; (2) evaluating the applicability of models and datasets for urban RES assessment; (3) developing an approach for assessing ecosystem-service supply, demand and balance; and (4) developing an integrated, multi-tier approach that can accommodate different levels of data availability. The thesis combines a synthesis of the scientific literature with empirical GIS-based modelling and analysis.

The submitted thesis is publication-based. It contains five publication-related chapters. Three papers are already published: Stoycheva and Geneletti (2023), Stoycheva and Nedkov (2024), and Petkova, Prodanova and Stoycheva (2022). A fourth publication, on cooling regulation and PM10 filtration, is identified as under review, while the fifth publication/chapter describing the final integrated approach is still in preparation. The thesis also contains a synthesis chapter, references, appendices, author-contribution statements, a publication list and a list of presentations.

The publication record demonstrates sustained research activity in the subject area. The candidate declares substantial intellectual and practical contributions to the first three papers directly associated with the thesis, including conceptualisation, methodology, data curation, analysis, validation, visualisation and writing. In the multi-authored papers, the candidate's contribution statements are sufficiently detailed to allow her role in the research to be assessed.

2. General review of the thesis (structure and content)

The thesis has a clear overall methodological logic. The introductory chapter establishes the motivation and research question, while Chapter 2 provides the methodological background and connects the individual

research tasks with the subsequent publication chapters. Chapters 3–7 then address successive components of the research programme, and Chapter 8 synthesises the findings, discusses limitations and uncertainties, identifies future research directions and formulates the theoretical and methodological contributions.

The conceptual focus on regulating ecosystem services is well justified. The thesis recognises that urban RES are particularly relevant because urban populations generate substantial demand for services such as air-quality regulation, temperature regulation and flood regulation, while urban development can simultaneously reduce or fragment the ecological structures that provide these services. The use of the CICES classification and the explicit connection with ecosystem-service assessment frameworks gives the work an appropriate conceptual foundation.

A major strength is that the thesis does not treat ecosystem-service modelling as independent of the underlying data. Instead, data availability, spatial resolution, data quality and uncertainty are treated as central methodological constraints. This is particularly visible in the transition from the review of methods, through the comparison of flood-regulation models, to the supply-demand-balance assessment of cooling regulation and PM10 filtration, and finally to the proposed multi-tier framework.

Chapter 3 provides a systematic foundation for the empirical work. The review comprises 58 papers selected through a defined search and screening process and analyses spatial data, assessment methods, regulating services and links to urban planning. The review identifies atmospheric composition regulation, temperature and humidity regulation, and hydrological-cycle/water-flow regulation as the most frequently studied groups of RES. It also identifies gaps in the connection between ecosystem-service assessment and urban planning. This chapter therefore serves a clear function in the overall dissertation rather than being an isolated literature review.

Chapter 4 is an important methodological component because it explicitly tests the sensitivity of flood-regulation assessment to both model choice and input-data quality. Two models, InVEST UFRM and IMECOGIP WRRM, are applied to Sofia using different datasets and rainfall scenarios. The work updates ecosystem-type, Urban Atlas and soil information before repeating the modelling. The results show that model outputs can differ substantially depending on both the modelling framework and the input data. This provides empirical support for one of the central premises of the dissertation: methodological choices and data quality need to be considered jointly when interpreting spatial ecosystem-service assessments.

Chapter 5 represents the most developed application of the integrated supply-demand-balance concept. It examines cooling regulation and PM10 filtration in Sofia using EnhancES/IMECOGIP, combines biophysical supply modelling with a demand assessment based on risk and hazard indicators, and applies spatial analyses to identify hotspots, cold spots, clusters and outliers. The study reports a highly negative combined balance for the two services, with PM10 filtration contributing substantially to the negative balance because of high demand and relatively limited supply. The analysis also demonstrates that the role of a land-cover class cannot be interpreted independently of its geographical location.

Chapter 6 is intended to provide the final methodological synthesis. The proposed multi-tier approach distinguishes three levels according to data availability: Tier 1 based primarily on non-centralised information and expert assessment; Tier 2 based on statistical or biophysical information that can be spatially refined; and Tier 3 based on detailed spatial data and modelling. Six priority regulating ecosystem services are allocated across these tiers according to the available evidence. This is a useful attempt to make the assessment framework operational under realistic data constraints.

Chapter 7 addresses an important but often underappreciated issue: the quality and interoperability of national ecosystem spatial datasets. The analysis of the Bulgarian ecosystem database identifies inconsistencies in classifications, coding and spatial topology, including substantial gaps and overlaps between ecosystem layers. The conclusion that the existing layers cannot simply be merged into a single

coherent GIS layer is highly relevant for subsequent ecosystem-service assessment, because errors or inconsistencies in the underlying ecosystem map can propagate into service estimates.

Chapter 8 provides the necessary synthesis. It explicitly acknowledges model uncertainty and data limitations, including incomplete PM10 monitoring coverage, missing rainfall and temperature information, geolocation problems and limitations in land-use/land-cover datasets. The thesis also identifies appropriate directions for further research, including scenario analysis, alternative ecosystem-service models and application to other geographical contexts.

Overall, the structure is coherent and the individual chapters contribute to a common methodological argument. The thesis is particularly strong where it moves from conceptual discussion to empirical demonstration. At the same time, the integrative synthesis could be strengthened further by making the generalisable principles of the proposed framework more explicit and by distinguishing more clearly between what has been demonstrated empirically in Sofia and what is proposed as transferable to other urban contexts.

3. Scientific contributions

The candidate identifies theoretical and methodological contributions, and I broadly accept these contributions, with some qualifications concerning their scope and degree of generalisation.

First, the thesis contributes to the literature on urban ecosystem services by bringing together supply, demand and balance within a common assessment framework. Much of the applied ecosystem-service literature focuses primarily on supply or capacity. The thesis makes a useful methodological step by explicitly incorporating demand and by considering the spatial balance between supply and demand. The demand framework developed in Chapter 5, which combines population vulnerability and exposure with service-specific hazard indicators, is a substantive contribution of the dissertation.

Second, the thesis demonstrates that the assessment of urban regulating ecosystem services is strongly conditioned by data availability and data quality. The comparison of two flood-regulation models using alternative input datasets is particularly useful in this respect. The results do not simply provide another application of existing models; they demonstrate that the interpretation of modelled service supply can change with the choice and refinement of the underlying spatial datasets.

Third, the multi-tier assessment framework is a potentially useful methodological contribution. Its main value is pragmatic: it recognises that a complete Tier-3 modelling approach cannot always be implemented for all ecosystem services, locations or planning contexts. By linking the assessment method to the level and quality of available information, the framework provides a way to avoid treating data-poor and data-rich assessments as methodologically equivalent.

Fourth, the work contributes to the operationalisation of urban ecosystem-service assessment through the integration of several spatial data sources and typologies. The cross-walking between national ecosystem classifications, Urban Atlas and other land-use/land-cover information, together with the updating and validation of spatial inputs, is technically demanding and relevant to applied ecosystem-service mapping.

Fifth, the thesis provides a useful empirical contribution for Sofia. The combined analysis of cooling regulation and PM10 filtration identifies spatial patterns of service supply, demand and balance and demonstrates how green infrastructure can have different implications depending on its size, location and relationship to areas of high demand. The results provide a basis for subsequent planning-oriented analysis, although their direct transferability beyond Sofia remains to be demonstrated.

The publication record supports the scientific contribution claimed by the candidate. Two of the core methodological studies are already published in peer-reviewed journals, while the most recent integrated

supply-demand-balance study is under review. The final integrative publication is still in preparation, which is a limitation of the current publication portfolio but does not, in my assessment, undermine the scientific coherence of the dissertation itself.

4. Criticisms, comments and questions for the defence

The following points are intended primarily to clarify the scientific scope of the contribution and to provide topics for discussion during the defence. They do not invalidate the overall methodological contribution of the thesis.

4.1. Definition of “integrated assessment”.

The thesis uses the term integrated assessment in several contexts: integration of supply and demand, integration of several ecosystem services, integration of different datasets, and integration across different data tiers. It would be useful for the candidate to provide a concise definition of what makes the proposed framework an integrated assessment rather than a combination of individual assessments. Which component is essential to the integration?

4.2. Transferability beyond Sofia.

Most of the empirical development and testing is based on Sofia. The thesis argues that parts of the approach can be applied to other spatial units and case studies. What are the minimum data and methodological conditions required to transfer the framework to another city? Which components are genuinely transferable and which require recalibration for local ecological, climatic and socio-economic conditions?

4.3. Interpretation of ecosystem-service demand.

The proposed demand assessment combines vulnerability, exposure and service-specific hazard indicators. This is a potentially important contribution, but the conceptual relationship between “need”, “demand”, “risk” and “hazard” deserves clarification. How does the candidate distinguish ecosystem-service demand from the population's exposure to an environmental problem, and how should the proposed demand indicators be validated?

4.4. Aggregation and combined ES balance.

The thesis combines cooling regulation and PM10 filtration to identify areas with a negative combined balance. How were the different service values made comparable before aggregation? What assumptions are implicit in the weighting or combination procedure, and how sensitive are the identified hotspots and trade-offs to alternative normalisation or weighting choices?

4.5. Model uncertainty versus data uncertainty.

The thesis correctly identifies both modelling and data limitations. However, it would be valuable to distinguish more systematically between uncertainty caused by the model structure, parameterisation, input-data quality and spatial resolution. If resources were available for one additional uncertainty analysis, which source would the candidate consider most influential and why?

4.6. Choice of models.

In Chapter 4, differences between InVEST UFRM and IMECOGIP WRRM are documented. In Chapter 5, EnhancES/IMECOGIP is used for the supply assessment. What criteria should determine model selection in a planning application? Under what circumstances would the candidate recommend using multiple models rather than selecting one model?

4.7. Validation of modelled ecosystem services.

The thesis provides several forms of comparison and plausibility checking, but direct validation of all service estimates is difficult. What additional empirical observations would be most useful for validating the cooling-regulation and PM10-filtration estimates, and how would the candidate design such a validation study?

4.8. Scale dependence.

The results are spatially explicit and depend on the resolution and classification of the input datasets. How does the candidate expect the supply-demand-balance results to change when moving from the city scale to neighbourhood or regional scales? Is there a risk that the identification of hotspots is partly a scale-dependent phenomenon?

4.9. Role of ecosystem condition.

The thesis focuses on ecosystem services and discusses ecosystem condition, but condition is not developed as a fully independent analytical dimension throughout the empirical framework. Could the candidate explain how ecosystem condition should be incorporated explicitly into the proposed multi-tier framework, and whether two ecosystems with similar land-cover classes but different ecological condition would receive different service-capacity estimates?

4.10. Status of the final integrative contribution.

Chapter 6 is described as a publication in preparation. During the defence, it would be useful for the candidate to explain which elements of the final integrated framework are already empirically demonstrated in the thesis and which remain methodological proposals requiring further validation.

A further general comment concerns terminology and presentation. The thesis is technically detailed and contains a substantial amount of methodological information, but some sections could more clearly distinguish methodological innovation from the application of established tools. For the scientific contribution to be most visible, the candidate should emphasise during the defence what is new in the conceptual architecture of the assessment framework, rather than focusing primarily on the technical execution of GIS and model workflows.

5. Conclusion and overall opinion

The dissertation presents a coherent body of research addressing an important methodological problem in urban ecosystem-service science: how to assess regulating ecosystem services in a way that integrates supply and demand while explicitly accounting for differences in data availability, quality and spatial resolution.

The work combines a literature-based assessment, methodological comparison of ecosystem-service models, empirical GIS analysis, development of a supply-demand-balance framework, and a multi-tier approach for dealing with heterogeneous data conditions. The case study of Sofia is used consistently

across the empirical components, which provides continuity between the individual studies. The thesis also demonstrates awareness of methodological uncertainty and does not present the modelled results as independent of the limitations of the underlying data.

In my assessment, the scientific contributions claimed by the candidate are supported by the work presented. In particular, I consider the integration of supply and demand, the operationalisation of a risk- and hazard-based demand assessment, the explicit treatment of data availability through a multi-tier framework, and the analysis of model and input-data sensitivity to constitute meaningful contributions to the methodological development of urban ecosystem-service assessment.

There are, nevertheless, several issues that should be addressed during the defence. The most important concern the conceptual definition of integration, the validation and interpretation of ecosystem-service demand, the comparability and aggregation of different ecosystem services, the transferability of the framework beyond Sofia, and the distinction between demonstrated results and proposed methodological extensions. These are appropriate topics for scientific discussion and clarification rather than fundamental objections to the dissertation.

The thesis contains sufficient original scientific work, methodological development and empirical analysis to constitute a substantive doctoral contribution in the field of Physical Geography and Landscape Ecology. The publication record further demonstrates the candidate's ability to conduct and communicate research in the field. The fact that one manuscript remains under review and another is still in preparation should be recognised, but the core scientific work required for the dissertation is present in the submitted thesis.

Subject to the candidate providing satisfactory answers to the questions raised above during the defence, **I consider the thesis to meet the expected scientific standard for the doctoral degree. I therefore give a positive opinion on the dissertation and state that I will vote in favour of awarding the doctoral degree to Vanya Emilova Stoycheva.**

Fernando Santos Martín

Universidad Rey Juan Carlos (URJC), Madrid, Spain

Signature:

Date: 29 September 2026

References to the submitted thesis

Stoycheva, V. (2026, thesis version dated 17 June 2026). Integrated assessment of regulating ecosystem services in urban areas. PhD Thesis, National Institute of Geophysics, Geodesy and Geography – Bulgarian Academy of Sciences, Sofia, Bulgaria.

Stoycheva, V., & Geneletti, D. (2023). A review of regulating ecosystem services in the context of urban planning. *Journal of the Bulgarian Geographical Society*, 48, 27–42.

Stoycheva, V., & Nedkov, S. (2024). The performance of two urban flood regulation models using different input data. *One Ecosystem*, 9, e134022.

Stoycheva, V., & Nedkov, S. (2026). Cooling regulation and PM10 filtration: An approach for integrated supply-demand-balance assessment. Manuscript under review.

Petkova, G., Prodanova, H., & Stoycheva, V. (2022). Analysis of the national ecosystem database of Bulgaria: (Mis)matches with the MAES framework. *Journal of the Bulgarian Geographical Society*, 47, 73–82.