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Daylighting the Role of Soil Ecosystem Services (SoESs) for Climate Change Adaptation

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Abstract

Soil plays a critical role in providing various Ecosystem Services (ESs) that are beneficial to humanity. Services such as clean air, water, and food production are directly or indirectly provided through soils. The soil ecosystem is considered as the most important Carbon (C) sink in terrestrial systems, and human activities, particularly land use, impact ESs and increase carbon emissions into the atmosphere. Mapping ESs and assessing the risks associated with climate-related hydro-meteorological hazards and soil degradation can contribute to making spatial decisions for planning more climate-resilient. Indeed, strategies based on soil ecosystem services provide valuable insight for enhancing the resilience of spatial decision-making in adapting to climate change. The aim of this article is to illuminate the significance of SoES in the spatial planning decision-making for better integration and adaptation into climate change adaptation policies as a decision support tool. In this regard, ESs related to climate change were highlighted and mapped, and their suitability for settlement development decisions and relation with ESs' integrity were assessed through weighted multi-criteria analysis, while discussing the contributions of this process to climate change adaptation. Incorporating Social-Ecological Systems (SoESs) factors into suitability analysis is crucial for comprehensive urban planning, particularly in the context of climate change adaptation and environmental protection. In this study, two settlement suitability analyses were conducted. The first analysis considered various factors, such as land use, soil classification, DEM (Digital Elevation Model), and slope. The second analysis utilized weighted climate-related SoES indicators, including soil depth, soil carbon sequestration capacity, soil loss, flood risk, temperature, and precipitation. The results revealed that the SoES-based suitability analysis was more stringent in identifying suitable areas for urban development and offered a more holistic perspective for urban planners.

Keywords

Spatial Planning, Suitability Analysis, Environment, Ecological Footprints, Resillience

1. Introduction

Climate change is one of the most sensitive issues of our time, and the development of adaptation strategies to mitigate its impacts is a significant priority. Indeed, as stated by Baggethun and Barton (2013), atmospheric carbon dioxide (CO_2) levels are currently showing the highest values in the past 800,000 years, and these values continue to increase at a rapid pace. Technological advancements have nurtured an urban community understanding that increasingly separates itself from ESs, while the demands for natural capital and ESs in our urbanized planet continue to increase. Protecting and restoring ESs in urban areas not only reduces cities' ecological footprints and ecological debts, but also enhances their resilience, health, and quality of life in the face of climate change (Baggethun & Barton, 2013; Borrelli et al., 2020; Eekhout & Vente, 2022).

Studies in the last two decades have been highlighting the strong and mutual relationship between climate change and SoES (Jónsson & Davíðsdóttir, 2016; Lal, 2004; Kardol et al., 2020; Chen, 2002). When soils are unsustainably managed, they become a significant source of CO_2 emissions, impacting the concentration of CO_2 in the atmosphere. Agricultural and farming activities directly associated with soil, as well as emissions from land use and land cover change, contribute to approximately 25% of global greenhouse gas emissions and around 10% in Europe (Schils et al., 2008; Jónsson & Davíðsdóttir, 2016).

Tezer and colleagues (2018) proposed an ES-based multicriteria decision-making process as a means to achieve a more sustainable approach for spatial decision-making, facilitating improved land development and land management practices, while also considering the unsuitability of land for ecosystem service provision. In their study, they examined habitat fragility, soil capability, slope permeability, and geology. Building upon the work of Tezer and colleagues, this study further explores the evaluation of land suitability for settlement by investigating the interplay between soil carbon sequestration, soil classification, soil depth, and climate-related hazards, such as floods and soil loss. This evaluation is conducted through the utilization of the weighted multiple data overlay method.

The main objective of this research is to daylight the relationship between climate change and SoES and examine how these services can be integrated into spatial planning decision-making to better adapt to climate change through land management. Therefore, this study aims to elucidate the relationship between climate change and SoES and how these services can be integrated into spatial planning to facilitate adaptation to climate change. In this context, the study will analyze the role of SoES in regards to climate change by using rational methods and integrating this relationship into spatial decision-making as an analytical tool. A case representing the assessment of proposed approach will be presented by illuminating the steps of the approach and the findings will be evaluated in the rest of the paper.

2. How SoES Contribute to Climate Change

Studies conducted by institutions such as the IPCC (Intergovernmental Panel on Climate Change), UNEP (United Nations Environment Programme), and WMO (World Meteorological Organization) have revealed the effects and consequences of climate change, providing evidence that climate change has had adverse impacts on the world (IPCC, 2015; UNEP, 2022; WMO, 2022). Spatial planning, through adaptation and mitigation policies, enables the resilience and flexibility of the natural and built environment against climate change. Spatial planning is recognized by UNISDR (United Nations International Strategy for Disaster Risk Reduction) as a field that has great potential to contribute to establishing settlements and cities with lower disaster risks (URL-1, 2023).

Albert et al. (2017) describe the main inputs for spatial planning related to ES mapping and assessment, which can be integrated into a spatial planning process based on SoES. The proposed inputs are as follows: 1) Analysis of SoES and identification of potential SoES, 2) comparison of existing and potential SoES indicators, 3) assessment of the capacity to provide multiple services for each identified SoES, 4) identification of hotspots of SoES areas with a high potential of providing such services and bringing solutions for conservation or restoration, 5) evaluation of the impacts of planning solutions on SoES, 6) visualization of changes in SoES resulting from different land use alternatives, 7) identification of mismatches between supply and demand areas of SoES, 8) communication of the benefits and limitations of planning proposals to enhance stakeholder and decision-maker engagement, 9) local data collection and exchange of information on ecosystems to increase citizen participation in planning and decision-making processes (Albert et al., 2017).

Considering the services they provide, integrating knowledge on the hazards and risks associated with SoES into spatial planning is necessary at both national and local levels. Fossey et al. (2020) specifically assessed planning processes in terms of the integration of SoES into spatial planning. In their study, Fossey and colleagues followed the fundamental spatial planning processes identified by Grieving and Fleischhauer. According to Fossey et al. (2020), the processes of SoES-based spatial planning are as follows (**Figure 1**): 1) Analysis of SoES and identification of potential SoES, 2) Comparison of existing and potential SoES indicator values, 3) Assessment of the capacity to provide multiple services for each identified SoES, 4) Creation of maps that allow visualization of these results through GIS data processing.

During the process of making spatial planning decisions for the conservation of SoES, it is crucial to assess the capacity of providing multiple services of each

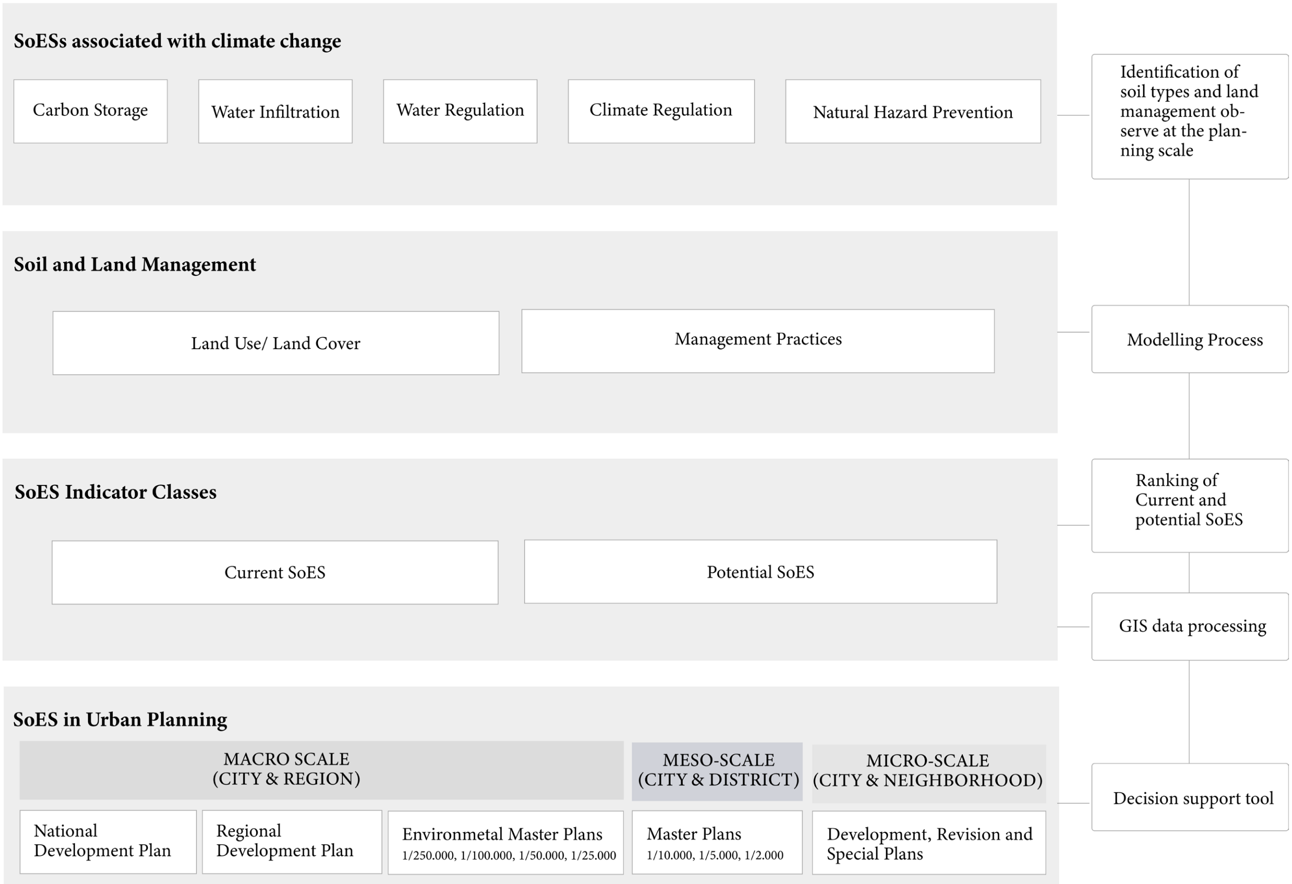


Figure 1. An example of application of the operational model to consider SoES decision support information in territorial planning (adapted by Fossey et al., 2020 and Delibas et al., 2018).

identified SoES (Fossey et al., 2020). In this context, the effects of climate-related SoES (such as soil carbon sequestration, impact on the water cycle, and connection to hydro-morphological hazards) should also be taken into account within the scope of spatial adaptation to climate change. Hence, spatial plans which are considered as future-oriented activities should adopt a holistic approach aiming to conserve SoES and achieve climate change adaptation, making cities more resilient against future risks. Delibas et al. (2018) express the multifaceted and complex connections between SoES, spatial planning, and climate change, emphasizes their importance for urban sustainability, and they highlight three connections among these three concepts. The former connection addressed by the authors emphasizes the positive and negative effects of climate change on soil, revealing the potential of soil carbon storage capacity as a preventive measure against adverse impacts. The former connection addressed by the authors emphasizes the positive and negative effects of climate change on soil, revealing the potential of soil carbon storage capacity as a preventive measure against adverse impacts. The latter connection focuses on interventions in soil quality and sustainable land use and their impact on spatial planning.

The final connection considers the interactions between climate change and spatial planning. In this regard, strategies such as soil conservation, sustainable land use planning, afforestation, and increasing permeable surfaces are important for balancing negative impacts and enhancing positive ones (Delibas et al., 2018). These connections provide a strong input in discussion of the position of SoES in spatial adaptation to climate change.

The literature examining the relationships between soil erosion, land use change, and climate change (Bojocco et al., 2018; Dissanayake et al., 2019; Paul et al., 2020) considers the RUSLE (Revised Universal Soil Loss Equation) as an important tool in making spatial planning decisions. RUSLE analysis evaluates factors such as precipitation, vegetation cover, soil structure, slope, and plant cover to determine soil erosion risk. Mitigating soil erosion is a crucial strategy in the fight against climate change as erosion leads to organic carbon loss and greenhouse gas emissions from the soil. Therefore, spatial planning decisions should focus on preserving vegetation cover and enhancing organic carbon storage capacity to minimize soil erosion risk. When considering land use change, soil erosion, climate change, and spatial planning together, it becomes evident that this context has a significant impact on the environmental and economic sustainability of a region. Spatial planning emerges as an important tool for planning and implementing measures against land use change, soil erosion, and climate change.

3. Materials and Methods

In the first stage of the research, an examination was conducted on how Ecosystem Services (ESs) and climate change have been addressed in the academic studies carried out, and bibliometric analysis was conducted using the peer-reviewed citation database in SCOPUS (URL-2, 2023) and VosViewer tool (URL-3, 2023). The number of publications in SCOPUS, which are open sources and include SoES in the title of the article, is 138. In the search made on the concepts of climate change and SoES through the abstract, title and keywords of the publications, 1256 open sources were found. These studies find a total of 8246 keywords. In addition to basic key concepts such as soil, ecosystem, climate change, soil carbon, carbon sequestration, forest, land use and land use change, climate change and ToES studies are the most clustered key concepts.

The literature assessing the relationship between climate change and SoES was reviewed, and prominent SoESs in the context of climate change adaptation were identified. The studies by Weber (2007) and Lal (2004) focus on the role of soil as a carbon sink in SoES and climate change. However, Dominati et al. (2010), Orwin et al. (2015) and Nedkov and Burkhard (2022) emphasize SoESs that form the basis of carbon and water storage, climate regulation, flood mitigation, and soil loss reduction. Based on these sources, carbon sequestration, soil classes, soil depth, flood risk, and soil loss maps were generated in relation to the climate change-SoES relationship in the content of our study. **Figure 2** shows the data analysis figure. In this context, soil, LULC, climate and topography data and

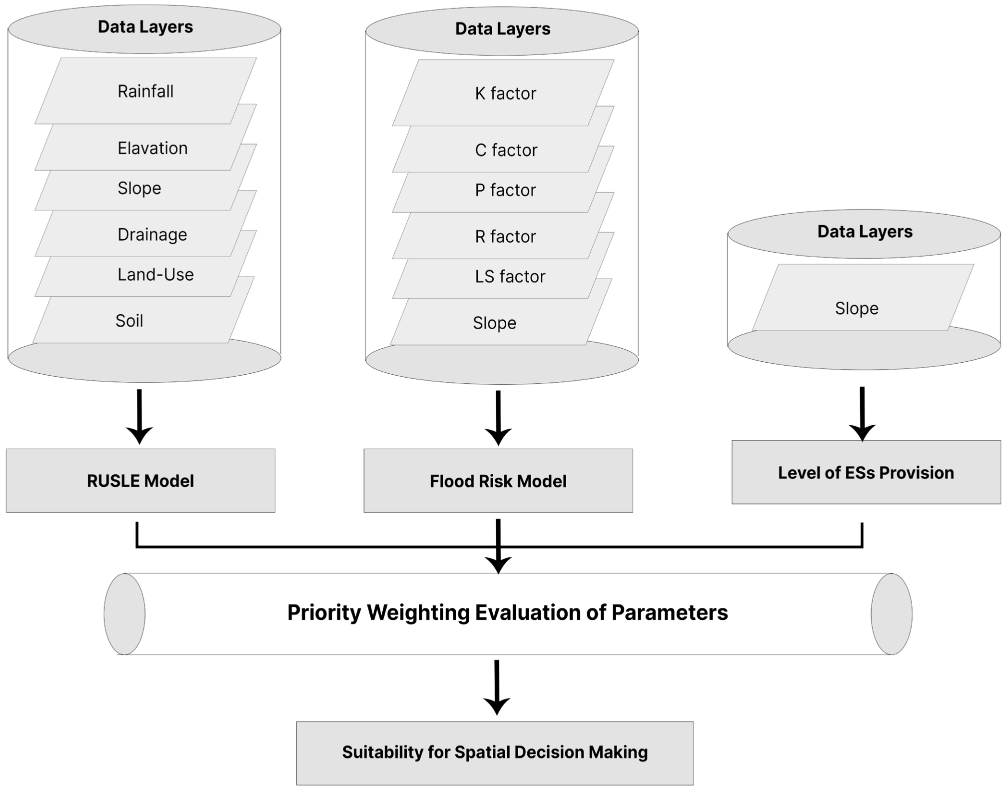


Figure 2. Overview of the data analysis method.

RUSLE soil loss model, flood risk model were made and these data were evaluated for suitability analysis. The aforementioned analyses were produced using ArcGIS 10.3.1 software. The Revised Universal Soil Loss Equation (RUSLE) model, which Tanyaş et al. (2015) indicated as the most commonly used soil erosion model worldwide, was applied as the soil loss model.

After creating a database for SoESs, a suitability analysis, providing a rational evaluation particularly from an ecological functionality perspective, was conducted by weighting the data, as suggested by Tezer et al. (2018). Regarding the weighting of selected parameters for suitability analysis in site selection, the studies of Hassan et al. (2020) were referenced, where they utilized GIS for suitability analysis in their chosen study area, focusing on soil and thus SoES. Additionally, the scoring methodology employed by Kopperoinen et al. (2014) for land use planning based on ES and the evaluation of natural environmental components in the suitability analysis conducted by Özşahin (2016) were considered (Karakuş & Cerit, 2017). The weighting of the factors used in this study is presented in **Appendix**.

Watersheds stand out with their significant contribution of diverse ES provisions (Tezer et al., 2018); therefore, the Nilüfer River Basin, including the urban centers of Bursa, undergoing a rapid urban transformation process, was chosen as the application area (**Figure 3**). The subsequent sections explain the mentioned analyses through the lens of the selected study area.

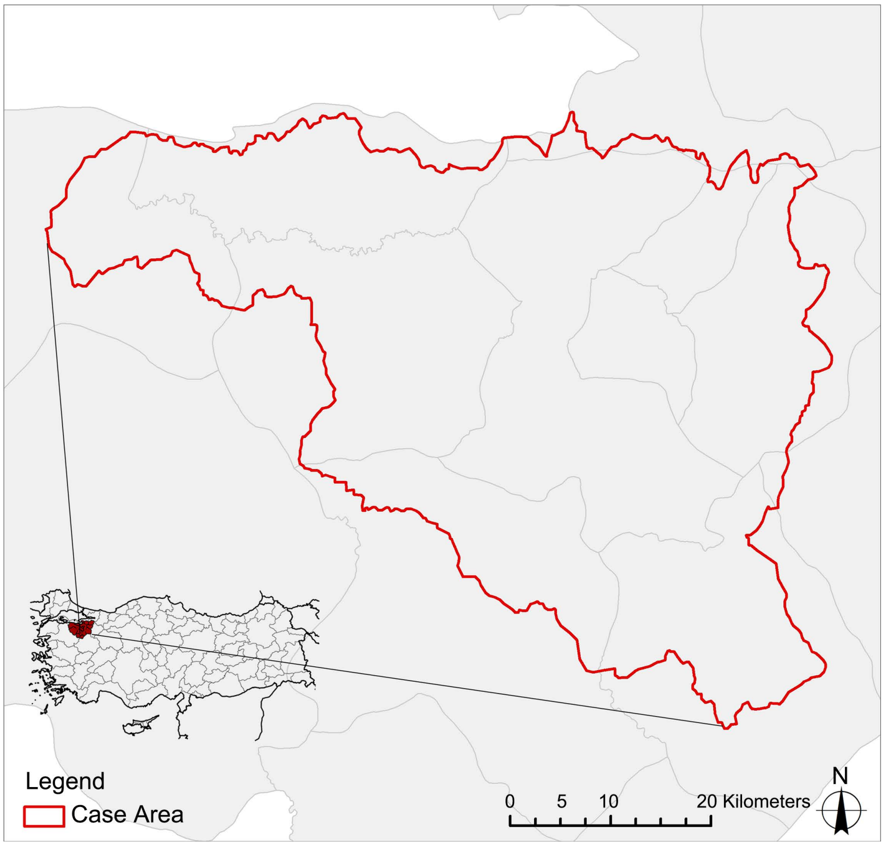


Figure 3. The case area is Nilüfer Basin located in Bursa, Türkiye.

3.1. Soil Classes, Soil Depth, and Carbon Sequestration Capacity in the Nilüfer River Basin

When examining the land use capabilities in the Nilüfer Basin, it is observed that 65% of the area consists of Class 7 soils. Lands classified as Classes 5, 6, 7, and 8 are suitable for pasture, forests, and natural habitats, but they cannot be used for intensive agriculture. The second largest soil group, covering 20% of the basin area, is Class 6 soils. Classes 1 and 2 soils, representing fertile soils, account for 5% and 14% of the area, respectively (Figure 4). Within the study area, there is a soil group classified as Class D, which represents areas beneath the bedrock, covering approximately 10,081 km^2. This group indicates soils with a depth of D, accounting for 44% of the study area. The A soil horizon group, characterized by high organic matter content, constitutes 15% of the study area (Figure 5). The areas with the highest carbon retention rates in the Nilüfer Basin are depicted in Figure 6, represented by dark blue color, corresponding to areas capable of retaining carbon at a capacity of 49 - 60 kg/m^3.

3.2. Flood Risk Analysis

The IPCC's 6th Assessment Report emphasizes an increase in floods due to climate change-induced weather and precipitation anomalies (IPCC, 2022). Furthermore, the report's 2nd section on Terrestrial and Freshwater Ecosystems

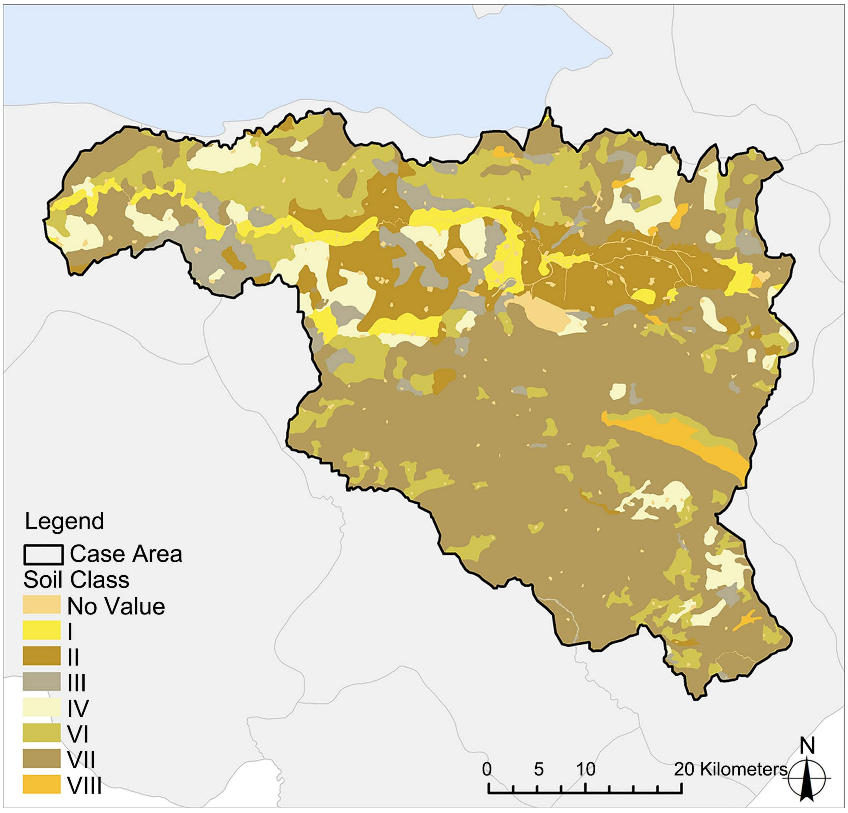


Figure 4. Soil classification map.

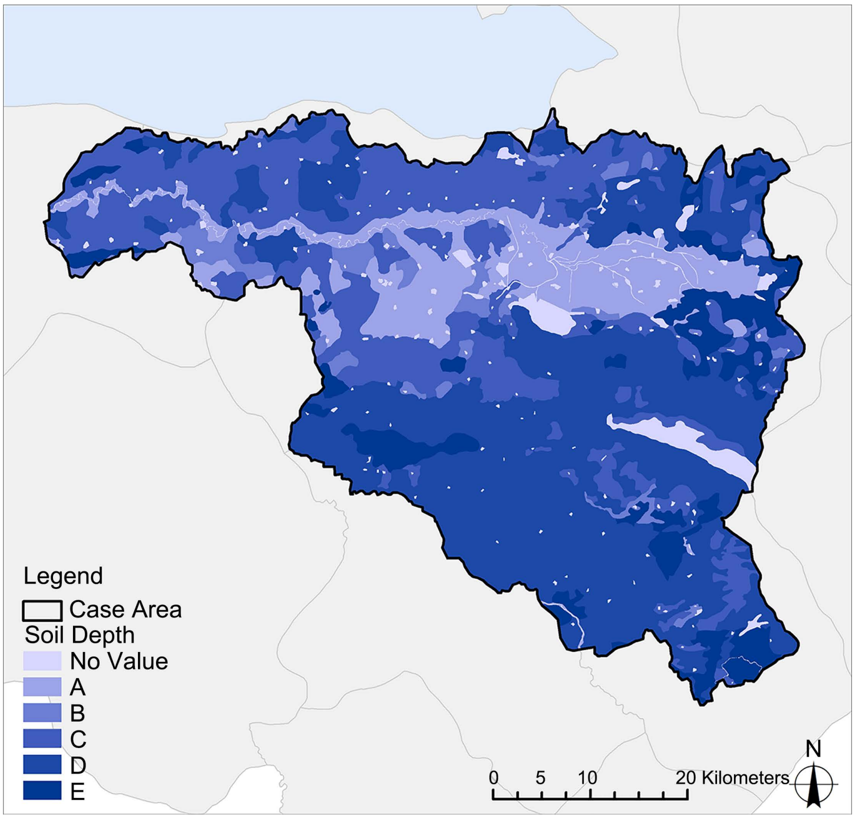


Figure 5. Soil depth map.

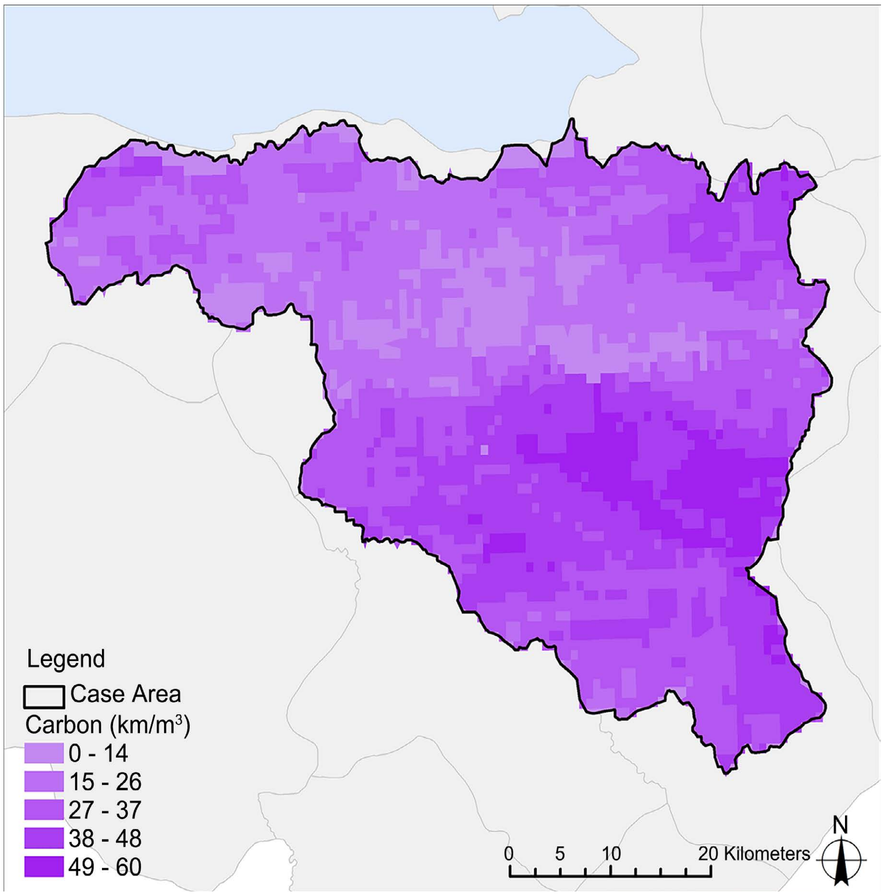


Figure 6. Soil C map.

and Services highlights the sustainability of utilizing ecosystem services to reduce flood risks. In this study, a flood risk map was evaluated using the weighted overlay analysis approach in ArcGIS software, incorporating different datasets. The parameters were weighted to obtain spatial results. During the weighting process, the study titled "Flood Risk Mapping Using GIS and Multi-Criteria Analysis: A Major Case Study in the Toronto Region" by Rincón et al. (2018) was referenced. The analysis revealed that the areas with the highest flood risk within the Nilüfer Basin are concentrated in the eastern part of the basin and along the slopes of Uludağ (**Figure 7**).

3.3. Evaluation of Soil Loss Using RUSLE Analysis

Soil loss, resulting from the reduction of soil cover and erosion, leads to habitat loss, water pollution, carbon emissions, and increased greenhouse gas emissions (Yang et al., 2003; Berberoğlu et al., 2020). In this study, the Revised Universal Soil Loss Equation (RUSLE), which is considered one of the most effective soil loss models by Tanyaş et al. (2015), was employed to analyze soil loss within the case study area.

To assess soil loss by RUSLE, several factor maps were prepared, including the K (soil erodibility), R (rainfall erosivity), P (slope length and steepness), C (crop

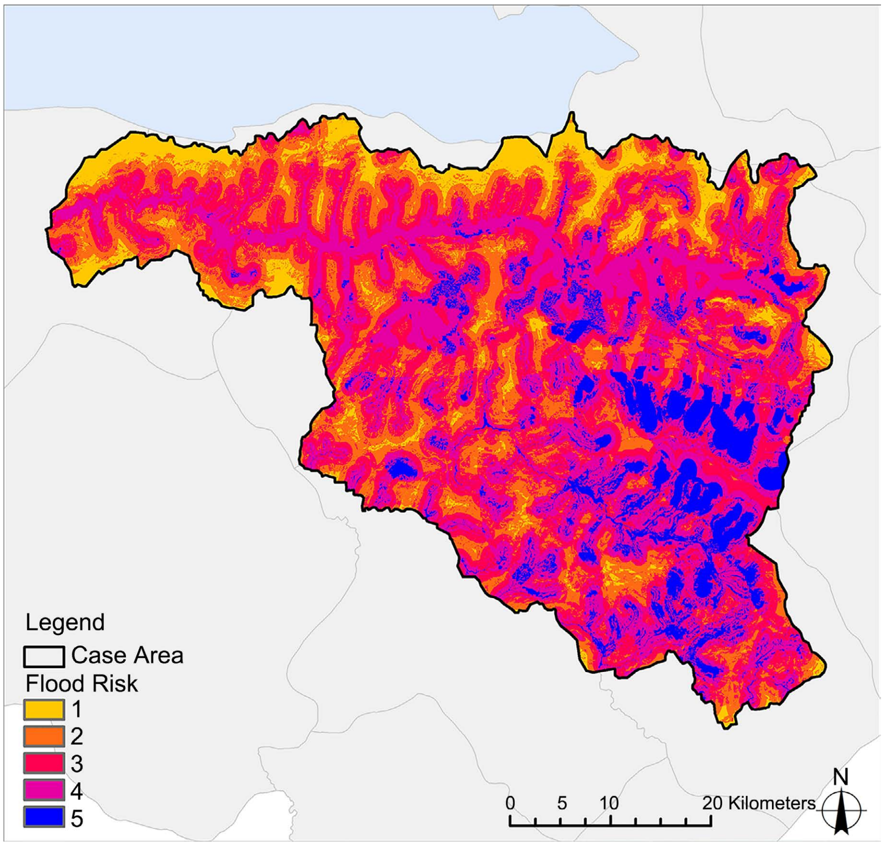


Figure 7. Flood risk map.

and management factor), and LS (slope length and steepness factor) factors. The K factor represents the sensitivity of the soil to erosion, considering its structural properties, water absorption capacity, and soil type. A higher K factor indicates higher susceptibility of the soil to erosion. Based on the analysis of the K factor, it has been revealed that the southern part of the basin is more prone to soil erosion (**Figure 8**).

RUSLE model can be formulated as follows:

$$A = R \times K \times LS \times C \times P . \quad (1)$$

where,

A = Average annual soil loss;

R = Rainfall intensity and density factor;

K = Soil erodibility factor;

LS = Slope length and steepness factor;

C = Vegetation cover and management factor;

P = Support practice factor.

3.4. Analysis of Settlement Suitability in the Nilüfer Basin, Bursa

Suitability analysis for site selection was conducted by combining geographic data and utilizing the "weighted overlay" analysis in the ArcGIS program. This method involves overlaying and weighting different geographic data layers to

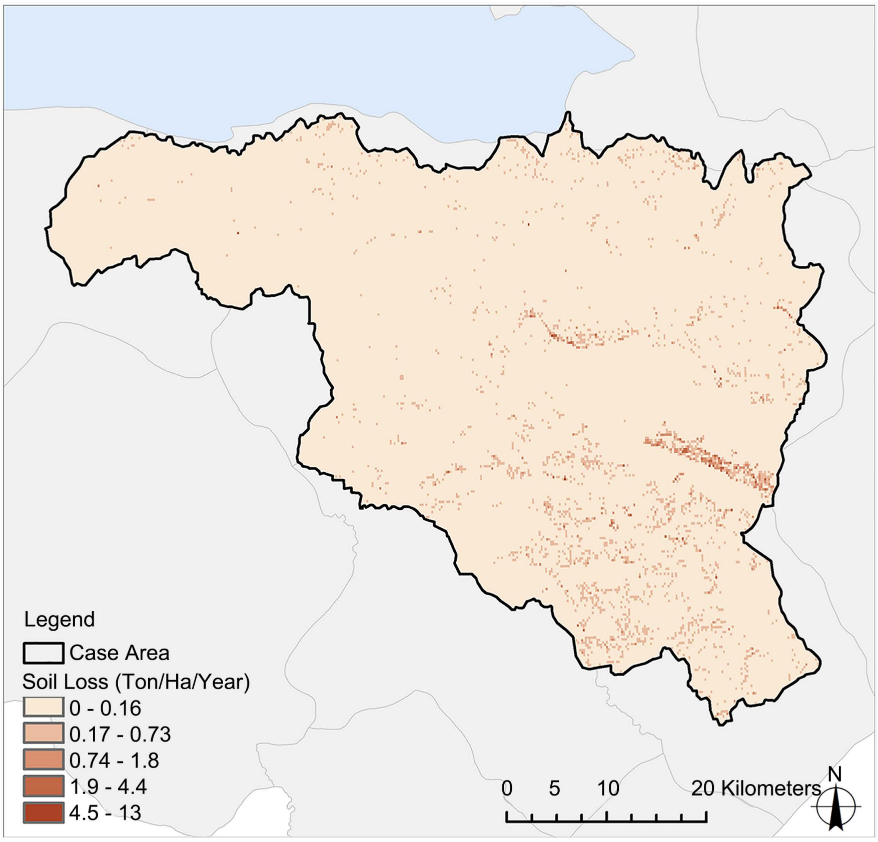
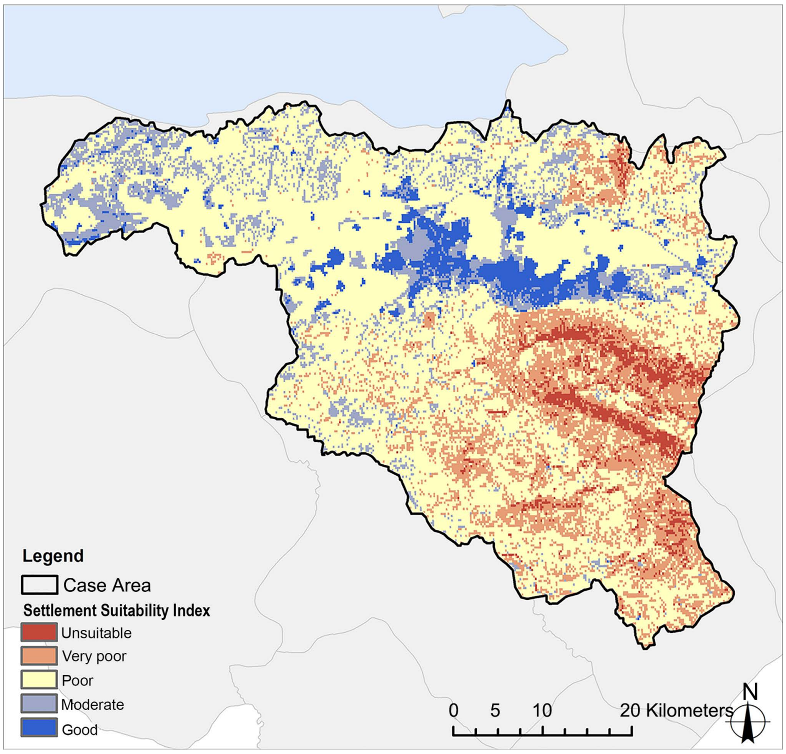


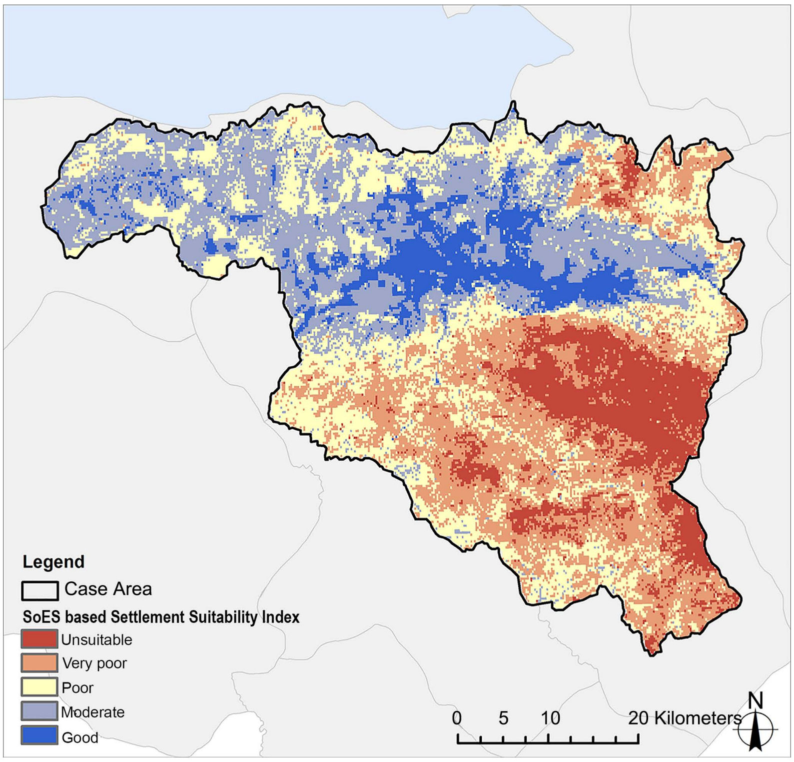
Figure 8. Soil loss map.

generate a spatial result that represents the convergence of multiple criteria or layers (Kopperoinen et al., 2014). Regarding the weighting of selected parameters for suitability analysis, references were made to the studies conducted by Hassan et al. (2020) and Kopperoinen et al. (2014) for their analysis of suitability using GIS in a study conducted in Pakistan, which focused on soil and thus SoES. The scoring methodology employed by Özşahin (2016) in the suitability analysis for land use and the assessment of natural environmental components, as well as the study by Tezer et al. (2018) on the importance and scope of defining "Watershed Conservation Areas" based on ecosystem services in the Düzce-Melen Basin, were also utilized (Maqsoom et al., 2020; Kopperoinen et al., 2014). The weighting of factors used in this study is provided in **Appendix**.

For the development of spatial planning decisions that are compatible with SoES and climate change, a suitability analysis using the scoring presented in **Appendix** was followed. The analysis using the weighted overlay method categorized the suitability for settlement in the Nilüfer River Basin into 5 levels: unsuitable, very poor, poor, moderate, good. The areas unsuitable for settlement, indicated in red and, cover 44,918 hectares, representing 17.75% of the basin. These unsuitable areas are mainly clustered in the southeast and the slopes of Uludağ within the study area. When overlaid with CORINE data, the unsuitable areas are found to be forest and shrubland areas. The areas represented by very poor, indicating sensitive ecosystem services and considered unsuitable for



(a)



(b)

Figure 9. (a) The suitability analysis has assigned weights to key criteria including land use, slope, Digital Elevation Model (DEM), and soil classes. (b) The suitability analysis based on SoES has incorporated weighted climate-related SoES, such as soil depth, soil carbon sequestration capacity, soil loss and flood risk, temperature, and precipitation.

settlement, form the next level. Looking at the land use distribution in these areas, it is predominantly characterized by forests, shrublands, and heterogeneous agricultural areas. These areas need to preserve their ecological characteristics and were identified as less suitable in the suitability analysis. They are represented as orange on the map and cover 67,142 hectares within the study area. The areas identified as most suitable for settlement follow the current urban footprint of Bursa. The current land uses in these areas are predominantly agricultural.

In the suitability analysis conducted using an equal scoring system with equal weighting of land use, soil classes, slope, and elevation data, an area of 24,567 hectares is classified as unsuitable for settlement (unsuitable and very poor) within the study area (**Figure 9(a)**). This area represents 54% smaller than the result obtained from the analysis considering SoES. In this scenario, the areas identified as most suitable for settlement do not overlap with the areas classified as unsuitable in the SoES approach but spread towards the second-priority areas. However, it can be observed that the suitability analysis conducted with the inclusion of SoES weighting provides a more compact model for site selection in settlement areas. This suggests that when SoES is included in the weighting of the suitability analysis, the boundaries of suitable and unsuitable areas for settlement are more clearly defined.

3.5. Evaluation of Land Use in the Nilüfer Basin in Relation to SoESs

According to the analysis conducted in the Nilüfer Basin, in the area designated as unsuitable for settlement, the majority of the land was classified as forest area in the 25,000-scale Comprehensive Development Plan (CDP) projected for 2023, which was prepared in 2013 (Bursa Municipality, 2013). When intersecting the 2018 CORINE data with the suitability analysis, it was found that 58% of the unsuitable areas are forest areas. The second largest land use category within the unsuitable areas is the compatible shrubland and herbaceous land use class, which aligns with the plan. The settlement areas within the unsuitable areas include rural settlements covering approximately 92 hectares. When examining how these areas were addressed in the CDP, the southern part of the very poorly suitable for settlement areas was designated as forest and agricultural areas, aligning with the most suitable land uses for these areas. The northern part of the area has been influenced by the growth of Bursa city center and is designated as a settlement area.

4. Conclusion and Recommendations

The relationship between soil and climate change occurs through carbon storage/sequestration, the water cycle, and soil degradation processes. The characteristics of SoESs that can be integrated into spatial plans and associated with climate change can be summarized as follows:

1) Soil and Carbon Storage/Sequestration: Soils are important carbon reservoirs that regulate carbon dioxide levels in the atmosphere.

2) Soil and Water: Soils are crucial for storing rainfall, filtering water, and replenishing water resources.

3) Soil Degradation: Soil degradation is a process that reduces soil fertility, organic matter content, and water-holding capacity.

4) Soil and Natural Hazards: Soils are also important for providing protection and mitigation against natural hazards.

In the Bursa Nilüfer Basin, an analysis of SoESs and factors related to climate change, such as the RUSLE soil loss model, flood risk, temperature, rainfall, soil classes, and soil depth data, was conducted. Based on these analyses, a four-class (1 not suitable at all, 2 not suitable, 3 moderate, 4 suitable) suitability analysis was performed, considering weighting factors. The suitability analysis was overlaid with the land use data obtained from the 2018 CORINE dataset and the land use decisions from the approved 2013 Comprehensive Development Plan (CDP). According to the results, the area identified as unsuitable for settlement in the Nilüfer Basin was found to be consistent with the characteristics and objectives of the region and was appropriately evaluated. In the 2023 projected 25,000-scale CDP plan prepared in 2013, the majority of this area was designated as forest in the category of protected areas. The 2018 land use data also supported this, with 68% of the unsuitable areas being forested. Although the current spatial arrangement aligns with the findings of the analysis, other SoESs associated with climate change, such as carbon sequestration and hydrological and microclimate regulation, are not addressed in the legislation in Türkiye within the context of climate change adaptation.

Spatial integration is an important component of planning policies aimed at mitigating the impacts of climate change and building resilience. By incorporating SoESs related to climate change into spatial planning, settlements can become more flexible, adaptive, and sustainable. Risk assessment, integrated planning, nature-based solutions, infrastructure flexibility, and community engagement principles are key to effective spatial integration. The methods for addressing the impacts of climate change are increasingly important, and prioritizing spatial adaptation measures has become inevitable to ensure the well-being and longevity of settlements and communities. In conclusion, when evaluated in the spatial planning process, SoESs play a significant role in combating climate change. Considering the relationships between soil and climate change, the C storage capacity of soil, soil erosion, rainfall, water filtration, and the role of soil in reducing the impacts of disasters can be integrated into the spatial planning process through SoES analytical assessment approaches. This integration can contribute to more effective and sustainable management of soil resources.

The study suggests using advanced technologies, fostering interdisciplinary collaboration, and exploring different urban development scenarios to improve the accuracy and relevance of the research. In future research, enhancing this study's effectiveness could involve integrating climate change scenarios and urban development trends into the suitability analysis for settlement areas within the context of soil ecosystems and climate change spatial adaptation.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Albert, C., Geneletti, D., & Kopperoinen, L. (2017). From Regional Environmental Planning to Implementation: Paths and Challenges of Integrating Ecosystem Services. *Ecosystem Services, 18,* 118-129. https://doi.org/10.1016/j.ecoser.2016.02.031

Baggethun, E., & Barton, D. (2013). Classifying and Valuing Ecosystem Services for Urban Planning. *Ecological Economics*, *86,* 235-245. https://doi.org/10.1016/j.ecolecon.2012.08.019

Berberoğlu, S., Çilek, A., & Kirkby, M. (2020). Spatial and Temporal Evaluation of Soil Erosion in Turkey under Climate Change Scenarios Using the Pan-European Soil Erosion Risk Assessment (Pesera) Model. *Environmental Monitoring and Assessment, 192,* Article No. 491. https://doi.org/10.1007/s10661-020-08429-5

Bojocco, S., Smiraglia, D., Raparelli, E., & Salvati, L. (2018). Exploring the Role of Land Degradation on Agricultural Land Use Change Dynamics. *Science of the Total Environment, 631,* 1373-1381. https://doi.org/10.1016/j.scitotenv.2018.04.412

Borrelli, P., Robinson, D., Panagos, P., Lugato, E., Yang, J., Alewell, C., & Alewell, C. (2020). Land Use and Climate Change Impacts on Global Soil Erosion by Water. *Proceedings of the National Academy of America, 117,* 21994-22001. https://doi.org/10.1073/pnas.2001403117

Bursa Municipality (2013). *Bursa Çevre Düzeni Plani.* https://meps.bursa.bel.tr/projeler/bursacdp/

Chen, J. (2002). Soil Degradation: A Global Problem Endangering Sustainable Development. *Journal of Geographical Sciences, 12,* 243-252. https://doi.org/10.1007/BF02837480

Delibas, M., Tezer, A., & Bacchini, T. (2018). Soil Ecosystem Services (SoES) in Urban Planning. A Review on Urban Soil. In *54th ISOCARP Congress* (pp. 679-691). ISOCARP.

Dissanayake, D., Morimoto, T., Ranagalage, M., & Murayamma, Y. (2019). Land-Use/Land-Cover Changes and Their Impact on Surface Urban Heat Islands: Case Study of Kandy City, Sri Lanka. *Urban Heat Islands, 7,* Article 99. https://doi.org/10.3390/cli7080099

Dominati, E., Patterson, M., & Mackay, A. (2010). A Framework for Classifying and Quantifying the Natural Capital and Ecosystem Services of Soils. *Ecological Economics, 69,* 1858-1868. https://doi.org/10.1016/j.ecolecon.2010.05.002

Eekhout, J., & Vente, J. (2022). Global Impact of Climate Change on Soil Erosion and Potential for Adaptation through Soil Conservation. *Earth Science Review, 226,* Article ID: 103921. https://doi.org/10.1016/j.earscirev.2022.103921

Fossey, M., Angers, D., Bustany, C., Cudenne, C., Durand, P., Gascuel-Odoux, C., & Christelle, B. (2020). A Framework to Consider Soil Ecosystem Services in Territorial Planning. *Frontiers in Environmental Science, 8,* Article 28. https://doi.org/10.3389/fenvs.2020.00028

Hassan, I., Javed, M., Asif, M., Luqman, M., Ahmad J., Ahmad, A., Akhtar, S., & Hussain, B. (2020). Weighted Overlay Based Land Suitability Analysis of Agriculture Land in Azad Jammu and Kashmir Using GIS. *Pakistan Journal of Agricultural Research, 57,* 1509-1519.

IPCC (2015). *AR5 Synthesis Report: Climate Change 2014.* https://www.ipcc.ch/report/ar5/

IPCC (2022). *Sixth Assessment Report.* https://www.ipcc.ch/assessment-report/ar6/

Jónsson, Ö., & Davíðsdóttir, B. (2016). Classification and Valuation of Soil Ecosystem Services. *Agricultural Systems, 145,* 24-38. https://doi.org/10.1016/j.agsy.2016.02.010

Karakuş, C., & Cerit, O. (2017). Oğrafi Bilgi Sistemi Kullanılarak Sivas Kenti ve Yakın Çevresi İçin Yerleşim Açısından En Uygun Alanların Belirlenmesi. *Fen Bilimleri Dergisi, 38,* 131-145. https://doi.org/10.17776/csj.44475

Kardol, P., Campany, C., Souzo, L., RIichard, J. N., Ake, W., & Class, A. T. (2020). Climate Change Effects on Plant Biomass Alter Dominance Patterns and Community Evenness in an Experimental Old-Field Ecosystem. *Global Change Biology, 16,* 2676-2687. https://doi.org/10.1111/j.1365-2486.2010.02162.x

Kopperoinen, L., Itkonen, P., & Niemelä, J. (2014). Using Expert Knowledge in Combining Green Infrastructure and Ecosystem Services in Land Use Planning: An Insight into a New Place-Based Methodology. *Landscape Ecology, 29,* 1361-1375. https://doi.org/10.1007/s10980-014-0014-2

Lal, R. (2004). Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. *Science, 304,* 1623-1627. https://doi.org/10.1126/science.1097396

Maqsoom, A., Aslam, B., Hassan, U., Kazmi, Z. A., Sodangi, M., Tufail, R. F., & Farooq, D. (2020). Geospatial Assessment of Soil Erosion Intensity and Sediment Yield Using the Revised Universal Soil Loss Equation (RUSLE) Model. *Geospatial Advances in Landscape Ecology, 9,* Article 356. https://doi.org/10.3390/ijgi9060356

Nedkov, S., & Burkhard, B. (2022). Flood Regulating Ecosystem Services—Mapping Supply and Demand, in the Etropole Municipality, Bulgaria. *Ecological Indicators, 21,* 67-79. https://doi.org/10.1016/j.ecolind.2011.06.022

Orwin, K., Stevenson, B., Smaill, S., Kirshbaum, M., Dickie, I., Clothier, B., & Gentile, R. (2015). Effects of Climate Change on the Delivery of Soil-Mediated Ecosystem Services within the Primary Sector in Temperate Ecosystems: A Review and New Zealand Case Study. *Global Change Biology, 21,* 2844-2860. https://doi.org/10.1111/gcb.12949

Özşahin, E. (2016). The Spatial Distribution of Soil Loss in Alakir Creek Basin (Antalya) and Factors Influential on It. *Journal of Tekirdag Agricultural Faculty, 13,* 123-134. https://dergipark.org.tr/en/pub/jotaf/issue/19063/201763

Paul, C., Kuhn, K., Steinhoff-Knopp, B., Weißhuhn, P., & Helming, K. (2020). Towards a Standardization of Soil-Related Ecosystem Service Assessments. *Soil Science, 72,* 1543-1558. https://doi.org/10.1111/ejss.13022

Rincón, D., Khan, U., & Armenakis, C. (2018). Flood Risk Mapping Using GIS and Multi-Criteria Analysis: A Greater Toronto Area Case Study. *Hydrology of Urban Catchments, 8,* Article 275. https://doi.org/10.3390/geosciences8080275

Schils, R., Kuikman, P., Liski, J., Van Oijen, M., Smith, P., Webb, J., & Hiederer (2008). *Review of Existing Information on the Interrelations between Soil and Climate Chang.* European Commission.

Tanyaş, H., Kolat, Ç., & Süzen, M. (2015). A New Approach to Estimate Cover-Management Factor of RUSLE and Validation of RUSLE Model in the Watershed of Kartalkaya Dam. *Journal of Hydrology, 528,* 584-598. https://doi.org/10.1016/j.jhydrol.2015.06.048

Tezer, A., Uzun, O., Terzi, F., Okay, N., Köylü, P., Aydın, B., & Türkay, Z. (2018). *Importance and Scope of Defining "Basin Protection Areas" Based on Ecosystem Services: Düzce-Melen Basin.* Turkish Healthy Cities Association.

UNEP (2022). *Emissions Gap Report 2022.* https://www.unep.org/resources/emissions-gap-report-2022

Url-1 (2023). *UNDRR*. https://www.unisdr.org

Url-2 (2023). *SCOPUS*. https://www.scopus.com

Url-3 (2023). *VOSviewer*. https://vosviewer.com

Weber, J.-L. (2007). Accounting for Soil in the SEEA. In *12th Meeting of the London Group on Environmental Accounting* (5 p.). European Environment Agency. https://mdgs.un.org/unsd/envaccounting/londongroup/meeting12/LG12_9a.pdf

WMO (2022). *State of Global Climate 2022.* https://library.wmo.int/idurl/4/66214

Yang, D., Kanae, S., Oki, T., Koike, T., & Musiake, K. (2003). Global Potential Soil Erosion with Reference to Land Use and Climate Changes. *Hydrological Process, 17,* 2913-2928. https://doi.org/10.1002/hyp.1441

Appendix

Factors	Variables/Subunits	Weights	
Soil Classification	VIII.	4	0.10
	VII.	3	
	VI.	2	
	IV.	1	
	V.	0	
	III.	0	
	II.	0	
	I.	0	
	No value	0	
Slope	0% - 2%	4	0.10
	2% - 6%	4	
	6% - 12%	3	
	12% - 20%	2	
	20% - 30%	1	
	>30%	0	
Soil Loss	None or low	4	0.15
	Medium	3	
	High	2	
	Very high	1	
	No value	0	
Elevation	1250 m - 1300 m	4	0.15
	1300 m - 1350 m	3	
	1350 m - 1400 m	2	
	1400 m - 1550 m	1	
	1550 m - 1700 m	0	
Soil Carbon	50 - 60	1	0.10
	38 - 49	2	
	27 - 37	3	
	16 - 26	4	
	0 - 15	5	
Soil Depth	A	5	0.10
	B	4	
	C	3	
	D	2	
	E	1	

Continued

Heat	2.1 - 6	1	0.10
	6.1 - 8	2	
	8.1 - 10	3	
	10.1 - 13	4	
	13 - 14	5	
Precipation	770 - 830	5	0.10
	840 - 930	4	
	940 - 1100	3	
	1200 - 1400	2	
	1500 - 2000	1	
LULC	Open areas with little or no vegetation	3	0.10
	Sea water	1	
	Industrial	4	
	Heterogeneous agricultural lands	1	
	Permanent agricultural lands	1	
	Terrestrial waters	1	
	Mine	3	
	Maki Grass	2	
	Grassland	1	
	Forest	1	
	Agricultural lands	1	
	Vegetated areas not used in agriculture	3	
	Settlement	5	
Flood Risk	None or low	4	0.10
	Medium	3	
	High	2	
	Very high	1	
	No value	0	