

Response to Contributing Commenters' comments to manuscript ESSD- 2025-264

“Spatial Patterns of Sandy Beaches in China and Risk Analysis of Human Infrastructure Squeeze Based on Multi-Source Data and Ensemble Learning”

Dear Contributing Commenter:

Thank you very much for your thoughtful and detailed review. Your suggestions have provided us with important and constructive insights, which have significantly improved the manuscript. We have carefully considered all of your comments and have made substantial revisions to the manuscript based on your feedback. We have done our best to enhance the manuscript and hope that the revised version will meet your approval. A point-by-point response to the outstanding comments is attached to this manuscript. The major revisions are summarized as follows:

Response to Comments by Contributing Commenter 1:

- 1. This study has made valuable contributions to coastal resource research by addressing long-term challenges in beach identification and human impact assessment. Its most obvious advantage lies in the innovative integration of multi-source remote sensing data and integrated learning, which effectively overcomes the limitations of traditional single data or single model methods. By combining Sentinel-1/2 images, terrain data, and nighttime light data, and extracting four-dimensional features, this study constructed a stacked ensemble model that integrates RF, SVM, CART, and GBDT. The consistent high accuracy from 2016 to 2023, as well as comparisons with three reference datasets, confirm the robustness of this method, particularly in reducing misclassification of bare land and urban areas, which is a common issue in existing research. The resulting 10 meter resolution beach dataset and regional pattern analysis have filled the gap in long-term beach monitoring nationwide, providing a reliable data foundation for coastal ecological management. This study also provides practical insights into the risk of human infrastructure crowding. By establishing a 100 meter buffer zone and analyzing impermeable surface data from 1990 to 2023, the increase in risk areas and regional differences were quantified. Linking risk trends with economic factors further reveals the coupling relationship between coastal urbanization and beach degradation, providing targeted guidance for policy-making, such as prioritizing protection in high-risk areas such as Shandong and Guangdong. However, there are several aspects that deserve improvement. Firstly, tidal disturbances have not been fully resolved. Although years of data can alleviate tidal effects, the lack of tidal phase matching may introduce spatial inconsistency in beach extraction. Future work can integrate tidal prediction models or on-*

site tidal data to select time series images with consistent tidal conditions, improving spatiotemporal accuracy. Secondly, the assessment of infrastructure squeeze is relatively simple: relying solely on impermeable surface expansion and buffer zone analysis cannot capture dynamic and detailed impacts. Higher resolution data and multi criteria models will improve the granularity of risk attribution. In addition, it can enhance the interpretability of integrated models. This study did not analyze the importance of features or the collaborative or redundant relationships between underlying models. Adding SHAP values or permutation importance analysis will clarify the contribution of each feature and optimize the model structure, reducing computational costs without sacrificing accuracy. Overall, this study establishes a solid benchmark for coastal beach research, balancing methodological rigor and practical value. Addressing the aforementioned limitations will further enhance its scientific impact and practicality for sustainable coastal area management.

Response:

Thank you for the valuable comments. Regarding the model interpretability issue, we have incorporated SHAP value analysis into the paper. Figure 7 presents the importance maps and average importance maps of features from 2016 to 2024. Specifically, we updated the content in **L255**, adding the analysis of feature importance. The revised text reads: "**We evaluated the variable importance of the model for the years 2016-2024 (Fig. 7). Based on the average importance ranking from 2016 to 2024, the top five features were Elevation (0.1270) > B3 (0.1242) > B2 (0.1049) > NDVI (0.0783) > VV (0.0600). When classified by feature category, the highest average importance was found in spectral features (0.3403), followed by index features (0.2458), topographic features (0.1847), texture features (0.1317), and polarization features (0.0975). The most important feature in each category was as follows: Elevation for topographic features, B3 for spectral features, NDVI for index features, VV for polarization features, and VAR for texture features.**"

By introducing SHAP value analysis, we are able to gain a clearer understanding of the contribution of different features to the model's results, particularly in terms of model optimization and feature selection. The use of SHAP values enhances the transparency of each feature's contribution, helping us identify key features in the model, optimize the model structure, and reduce computational costs. Furthermore, this analysis helps us better understand the collaboration or redundancy between underlying models, providing more room for optimization in future research.

Although multi-year data synthesis helps mitigate the tidal effects, the inconsistency in tidal phases remains a significant issue affecting beach extraction. The variability of tidal changes in different time periods and geographic areas often leads to spatial inconsistencies in multi-year data synthesis, resulting in inaccurate identification of beach areas. While the multi-year data synthesis method currently used reduces the impact of tidal fluctuations, the lack of precise tidal phase matching still introduces spatial errors. Therefore, future work can further integrate tidal prediction models and field tidal data to select

time series images with consistent tidal conditions. This approach would not only improve spatiotemporal accuracy but also effectively reduce spatial inconsistencies introduced by tidal variations, enhancing the accuracy of beach extraction.

In addition to tidal effects, the evaluation of infrastructure encroachment is another area for improvement in this study. Although we quantified the impact of infrastructure expansion on beach areas through impervious surface expansion and buffer zone analysis, this method is overly simplified and cannot fully capture the dynamic effects of infrastructure development. Infrastructure development is a complex process involving not only changes in impervious surface area but also land use types, urban expansion rates, and socioeconomic factors, all of which can have varying temporal and regional effects on beaches. To better capture these impacts, future research could consider using higher-resolution remote sensing data, along with time series analysis and multi-criteria models, to enhance the granularity of risk assessment and more accurately quantify the impact of infrastructure expansion on beaches in different regions and time periods.

Moreover, combining various data sources (such as nighttime light data and land use data) for multi-scale, multi-temporal integrated analysis will help reveal the complex relationship between human activities and beach degradation. This method will not only identify the beach areas most affected by human activities but also provide data support for policy-making, guiding the protection and sustainable development of coastal regions. For example, stricter protection measures could be implemented in high-risk areas (such as Shandong and Guangdong) to limit excessive development and infrastructure construction, thus mitigating beach degradation and ecosystem damage.

While several improvements have been proposed, there are still some technical and data challenges to overcome. For example, accurate tidal phase matching and the acquisition of high-resolution data may face certain technical limitations. Additionally, future research may need to consider integrating other types of data (e.g., field survey data) and more advanced machine learning methods (such as deep learning and reinforcement learning) to further enhance the model's predictive capability and adaptability.

In summary, this study provides a solid foundation for coastal beach research and ecological conservation, while also pointing out directions for future research. By addressing issues such as tidal effects and infrastructure encroachment assessment, we believe that we can significantly improve the accuracy of beach extraction and human impact assessment, thereby providing more reliable data support and decision-making for coastal ecosystem protection and sustainable development.