Reviewer 2

Reviewer #2: This manuscript presents a follow-up to the work of Moya et al. (2024) by introducing a semi-supervised CNN methodology that uses Sentinel-2 optical imagery to identify new informal buildings in metropolitan Lima, Perù. The main advantage over previous methodologies are that by using Sentinel-2 imagery, more settlements are captured as SAR -based signal disturbance limits the detection of buildings in urban areas. Overall, the work represents a meaningful contribution to the fields of urban remote sensing and risk-informed urban management. However, I have some comments and suggestions that could further improve the clarity, presentation, and interpretation of the manuscript.

Main Reply:

We truly thank the reviewer for the very deep comments provided to us. In the following, we address each comment individually. For each reviewer's remark, we present two sections: (i) our response to the comment and (ii) a description of the corresponding modifications made to the manuscript. All changes introduced in response to the reviewer's comments are highlighted in blue in the revised manuscript.

Comment 01:

Line 267: I believe the manuscript would benefit from a more in-depth description of how these geometrical distortions affect SAR imagery and, consequently, the segmentation result. While the authors fairly cite speckle noise, little information is provided regarding other signal distortions such as layover, foreshortening, and shadowing, which can significantly affect urban areas. I suggest better framing these limitations of SAR imagery to further support the use of Sentinel-2 data in the relevant discussion section.

Answer:

We have expanded the discussion on the limitations of SAR imagery by describing the effects of foreshortening, layover, and radar shadowing in the foothill areas surrounding Lima. We also explain how these distortions, together with speckle noise, may affect the detection of informal settlements located on steep terrain.

Changes in manuscript:

Lines 298-310

This study builds upon the work presented in Moya et al. (2024), where large clusters of recent settlements were identified through changes in the backscatter of SAR satellite imagery. An important challenge in the use of SAR imagery to map urban expansion in Lima is that, unlike the city center, the urban fringe is largely located in foothill areas, as depicted in Figures 2 and 7. In such environments, geometric distortions occur in SAR imagery due to the side-looking geometry of the radar system (Ulaby and Long, 2014). Points located at elevations higher than the mean ground level are closer to the radar than they would be if they were located at the mean ground level. Consequently, these points appear displaced in the SAR image and may

overlap with other targets. The side of a hill or mountain facing the radar therefore appears compressed, an effect known as *foreshortening*. This distortion becomes more severe on steep slopes, where the mountain peak may appear closer to the radar than its base, producing the effect known as *layover*. Furthermore, hills and mountains generate shadow regions on slopes facing away from the radar because these areas are not illuminated by the radar beam. These effects are relevant for the identification of informal settlements in Lima because many newly urbanized areas mainly develop on steep hillsides at the urban fringe. In such environments, geometric distortions may alter the apparent shape, size, and location of built-up features, while shadowed regions may completely obscure small settlements. In addition, small urban clusters may not be detected because of speckle noise in SAR imagery. Consequently, not all settlements were captured in those SAR-based analyses. Here, we map the entire

Comment 02:

The quality of figures should be improved. In particular, the basemaps in Figures 3 and 8 are difficult to read. I suggest using a simpler basemap without labels and manually adding only the most relevant information to make the location of the study area immediately readable and informative, without providing too much redundant information. I also suggest to add the degree of latitude and longitudes, as already suggested by the other reviewer. Also, the legend of Figure 11c seems blurry to me and I noticed what it seems to be a typo in the last label (“Urban Grouth”)

Answer

Following the advisor's recommendation, we redesigned the figures with a simpler basemap (ocean in light blue and land in gray) to improve readability. In addition, the degree of latitude and longitude were added in the coordinates.

Furthermore, Figure 11 was regenerated at a higher resolution, and the typographical error noted by the reviewer was corrected, replacing "Urban Grouth" with "Urban Growth."

Changes in manuscript:

Figure 3:

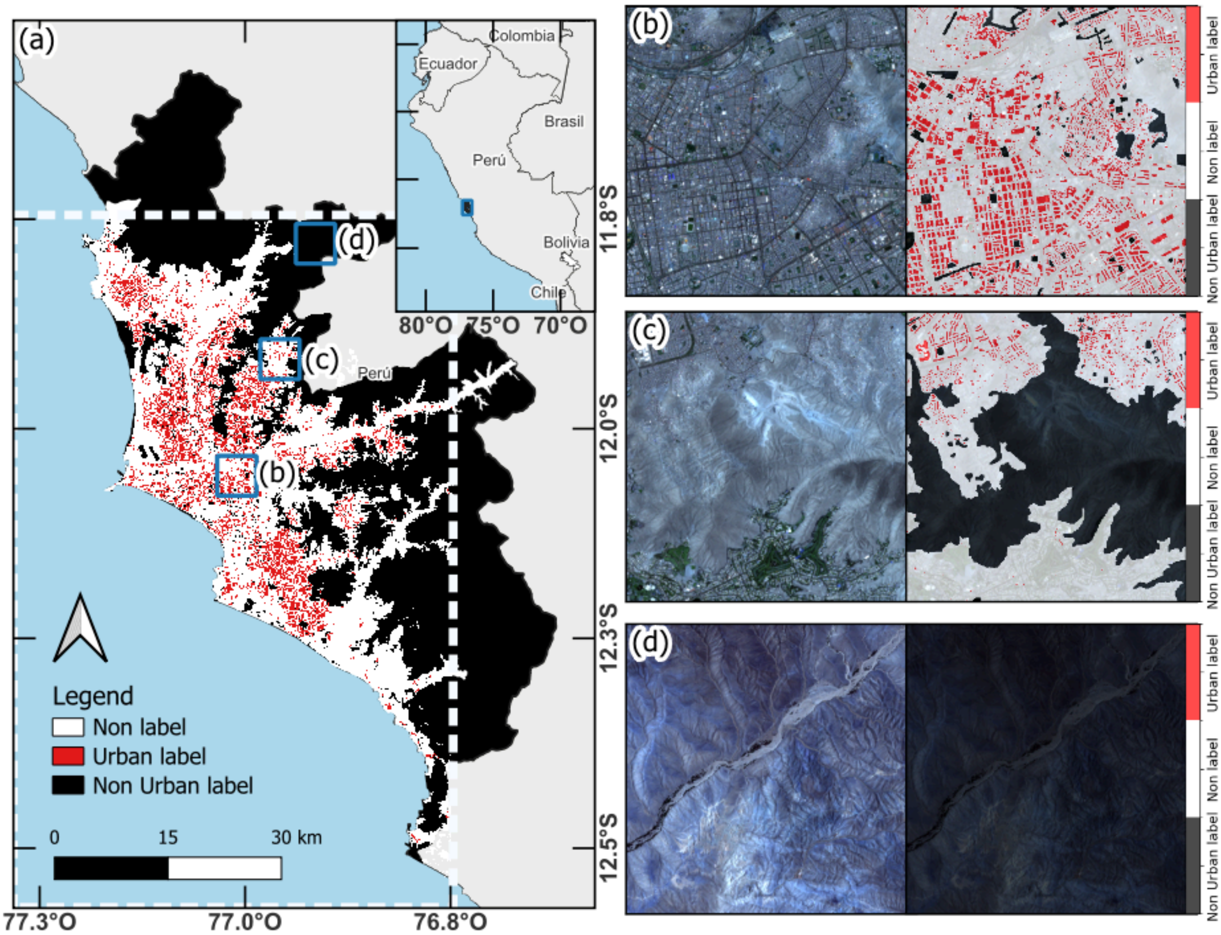


Figure 8:

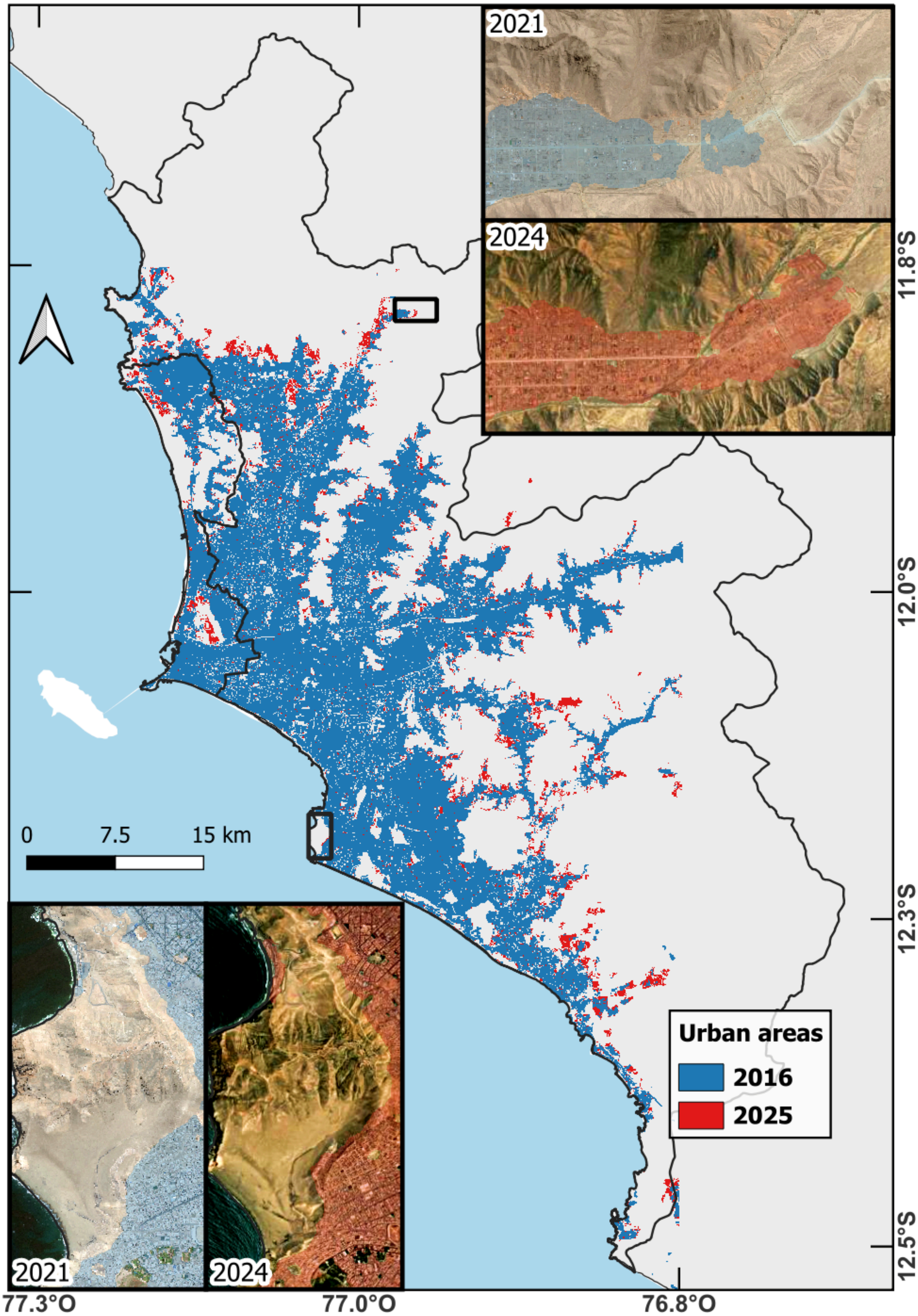
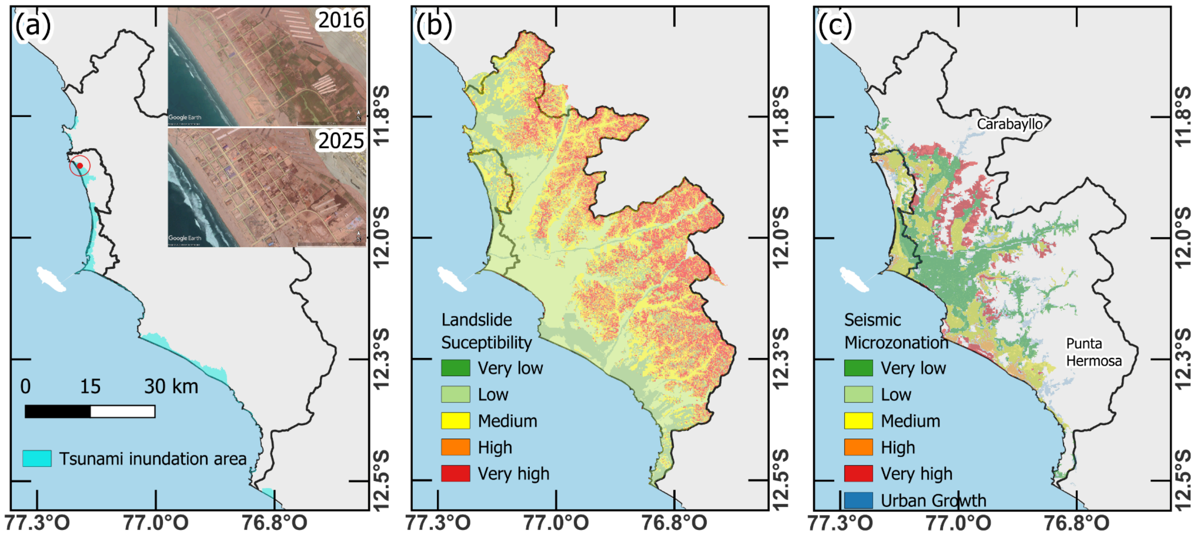

2021
2024
11.8°S
12.0°S
12.3°S
12.5°S
0
7.5
15 km
Urban areas
2016
2025
2021
2024
77.3°O
77.0°O
76.8°O

Figure 11:



Comment 03:

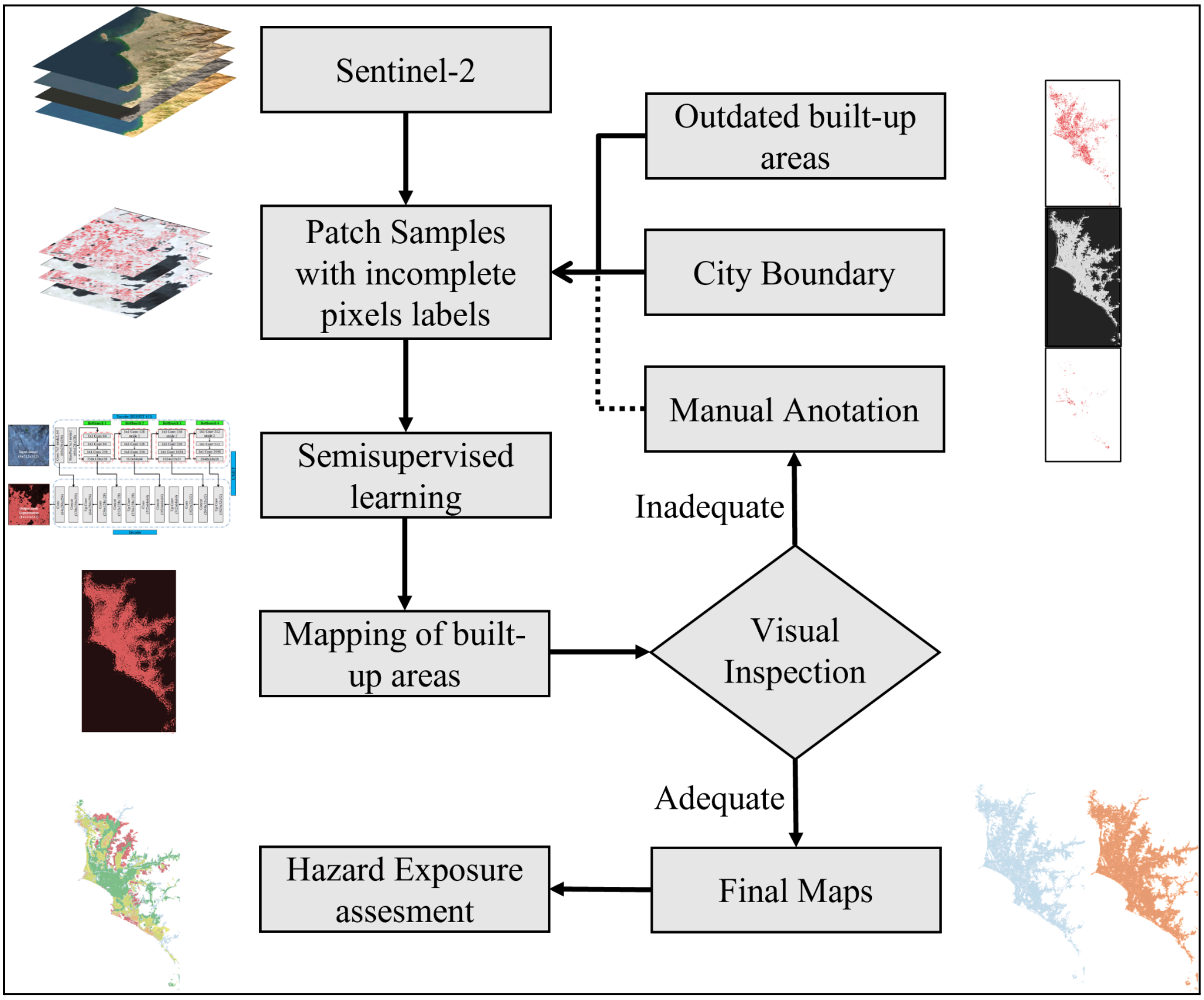
Line 45: The introduction is well written and adequately covers the topic addressed by the manuscript. Likewise, the methodology is clearly presented. An illustrative figure summarizing the mapping workflow—including the Sentinel-2 imagery used as input and the main steps of the proposed built-up area detection approach—would further improve reader comprehension.

Answer

We thank the reviewer for this constructive suggestion. To improve the clarity and accessibility of the methodology, we incorporated an updated workflow figure summarizing the complete mapping framework. The figure illustrates the Sentinel-2 imagery used as input, the semi-supervised training strategy, the segmentation process, and the subsequent urban expansion and hazard exposure analyses.

Changes in manuscript:

Figure 5:



Comment 04:

I suggest referring to the methodology using a specific name rather than the term "ours", particularly in Table 2. A designation such as "CNN-SS" would improve clarity.

Answer

The methodology is now consistently referred to as **CNN-SS** throughout the manuscript, including Table 2.

Changes in manuscript:

Lines 174:

spatial information. Residual connections link the blocks, preventing accuracy loss in deep networks. Figure 4 illustrates the encoder–decoder process used to produce the segmentation mask. For convenience, the proposed methodology is hereafter referred to as CNN-SS (Convolutional Neural Network with Semi-Supervised learning).

For model calibration, only images recorded after 2021 were used to include the built-up areas detected by Moya et al. (2024).

Line 197:

overlapping patches were allowed to increase the sample size, some validation samples partially overlap with training samples, which explains the similar behavior of the training and validation loss curves shown in Figure 6.

To assess the performance of CNN-SS, we compared our results with the World Settlement Footprint (WSF) 2019 (German Aerospace Center, 2023). The WSF is a global 10 m resolution binary mask delineating human settlements. It was generated

Caption of Figure 7:

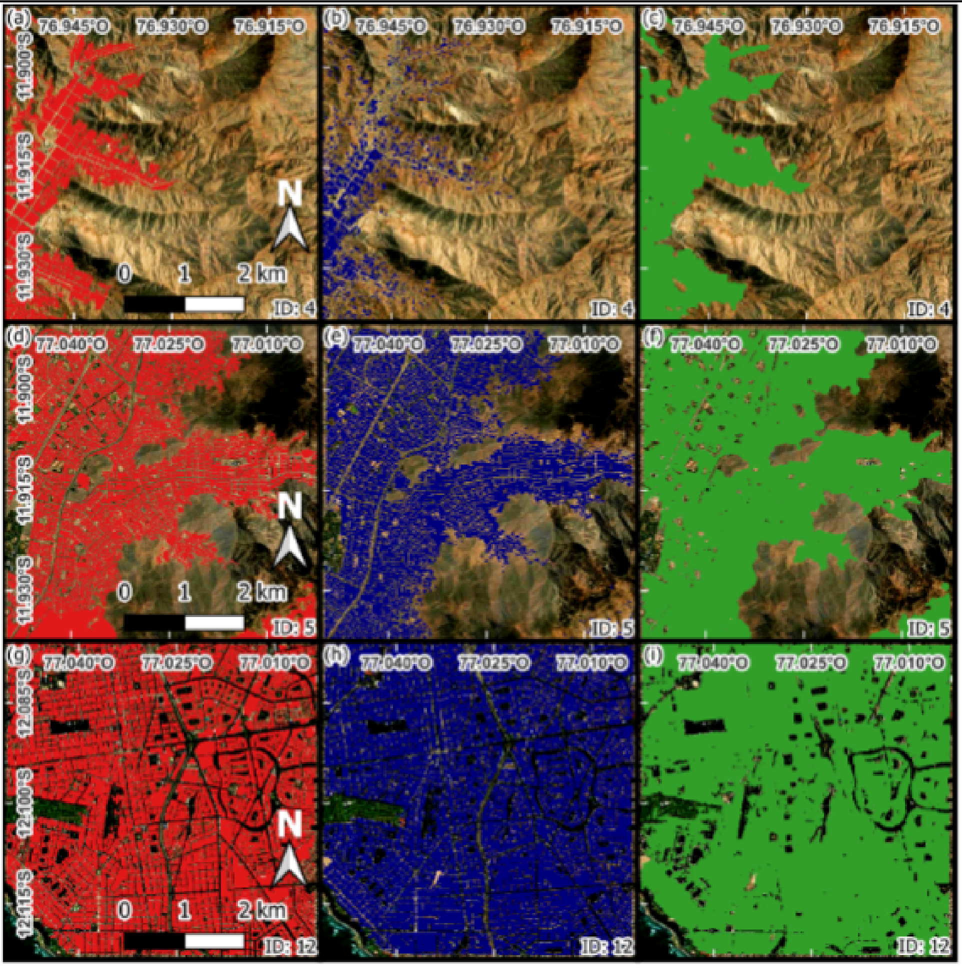


Figure 7. Comparison of built-up areas obtained from the proposed methodology, the WSF product, and the reference built-up map. Built-up areas detected by CNN-SS are shown in green (right), those from the WSF are shown in blue (middle), and the reference built-up areas are shown in red (left). Basemaps: Google, ©2024 MAXAR.

Table 2:

Table 2. Validation results comparing WSF and CNN-SS-based classification across different areas in Lima.

Type Area	Model	Precision			Recall			F1-Score		
		U	NU	Av.	U	NU	Av.	U	NU	Av.
Consolidated	WSF	**0.8483**	0.7833	0.8158	0.8174	**0.8187**	**0.8180**	0.8326	**0.8006**	**0.8166**
	CNN-SS	0.7680	**0.9066**	**0.8373**	**0.9464**	0.6454	0.7959	**0.8479**	0.7540	0.8010
Peripheral	WSF	**0.7295**	0.9180	**0.8238**	0.6061	**0.9515**	0.7788	0.6621	**0.9345**	0.7983
	CNN-SS	0.5810	**0.9881**	0.7846	**0.9526**	0.8518	**0.9022**	**0.7218**	0.9149	**0.8183**
Remote	WSF	**0.3989**	0.9928	**0.6958**	0.1605	**0.9979**	0.5792	0.2289	**0.9953**	0.6121
	CNN-SS	0.3132	**0.9994**	0.6563	**0.9268**	0.9824	**0.9546**	**0.4682**	0.9908	**0.7295**
Ocean	WSF	-	1	-	-	1	-	-	1	-
	CNN-SS	-	1	-	-	1	-	-	1	-

Line 206:

Figure 7). It is important to note that WSF underwent post-processing to remove roads (German Aerospace Center, 2023), whereas CNN-SS considers roads as built-up areas. For a fair comparison, road pixels were excluded from the validation process. Model performance and WSF accuracy were evaluated using *precision*, *recall*, and the *F1* score metrics.

Comment 05:

Line 232: "...as well as steep rocky slopes due to their high geological risk." Please clarify what is meant by "high geological risk." The sentence is currently ambiguous and should be revised for clarity.

Answer

The sentence has been modified.

Changes in manuscript:

Line 261

gravels, and sedimentary deposits with gravelly layers at shallow depths; SM Zone II comprises medium-dense to dense sands and medium-to-stiff silty–clayey soils; SM Zone III includes coastal deposits of deep loose to medium-dense sands and soft to medium silts and clays; SM Zone IV is characterized by thick aeolian sands and loose marine deposits prone to liquefaction

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as well as steep rocky slopes identified as areas of high geological hazard due to their susceptibility to rockfalls, landslides, and debris flows triggered by earthquakes; and SM Zone V includes landfills and waste-material deposits resulting from anthropogenic activities throughout Metropolitan Lima. This classification also incorporates vibrational parameters obtained from geophysical surveys, such as the fundamental site period and the average shear-wave velocity in the upper 30 m (Vs30). Accordingly, SM Zone I is characterized by short fundamental periods (shorter than 0.2 s) or flat H/V spectral ratios and the

Comment 06:

Overall I believe that the results of this work provide valuable insights for stakeholders concerned with uncontrolled urban expansion and its relationship to disaster risk reduction planning. I suggest that, after these minor clarifications and comments are addressed, the manuscript is suitable for publication in NHESS.

Answer

We sincerely thank the reviewer for the positive evaluation of our work and for recognizing its relevance to urban expansion monitoring and disaster risk reduction planning. We also appreciate the constructive comments provided throughout the review process.