https://doi.org/10.5194/nhess-2021-153
Preprint. Discussion started: 15 July 2021

Natural Hazards and Earth System Sciences
Discussions

Brief communication: Radar images for monitoring informal urban settlements in vulnerable zones in Lima, Peru

Luis Moya[1,3], Fernando Garcia[2], Carlos Gonzales[1], Miguel Diaz[1], Carlos Zavala[1], Miguel Estrada[1], Fumio Yamazaki[4], Shunichi Koshimura[3], Erick Mas[3], and Bruno Adriano[5]

[1]Japan-Peru Center for Earthquake Engineering Research and Disaster Mitigation, National University of Engineering, Tupac Amaru Avenue 1150, Lima 25, Peru
[2]Graduate School of Civil Engineering, National University of Engineering, Av. Túpac Amaru 280, Lima 25, Peru
[3]International Research Institute of Disaster Science, Tohoku University, Aoba 468-1, Aramaki, Aoba-ku, Sendai 980-8572, Japan
[4]National Research Institute for Earth Science and Disaster Resilience, Tsukuba, Ibaraki 305-0006, Japan
[5]Geoinformatics Unit, RIKEN Center for Advance Intelligence Project, Japan

Correspondence: Luis Moya (lmoyah@uni.pe)

Abstract. Lima city, Peru's capital, has about 9.6 million inhabitants and keeps attracting more residents searching for a better life. Many citizens, without access to housing subsidies, live in informal housing and shack settlements. A typical social phenomenon in Lima is the sudden illegal occupation of areas for urban settlements. When such areas are unsafe against natural hazards, it is important to relocate such a population to avoid significant future losses. In this communication, we present an application of Sentinel-1 SAR images to map the extension of a recent occupation of an area with unfavorable soil conditions against earthquakes.

1 Introduction

Urban sprawl in Latin America has been influenced by the people migration from rural areas to the cities, which have produced high-density urban areas. Informal settlement refers to the organization of people in search of housing who occupy unused land and perform collective actions to self-resolve their urban and social organization issues (Kapstein and Aranda, 2014). The urban growth in the capital city of Peru during the 20th century consisted mainly of informal settlements, which was motivated by the government policy of allowing people with low socioeconomic status to occupy unused land. Currently, the oldest informal settlements in Lima have obtained basic services, such as electricity and water. However, they are still vulnerable in terms of crime and security, accessibility, and natural hazards. In recent years, informal settlements have kept increasing countrywide. According to the Ministry of Housing, Construction and Sanitation (2021), 93% of the urban growth in Peru between 2001 and 2018 consisted of informal settlements. Frequently, informal settlements occupy unsafe zones against natural hazards. For instance, during the Niño Costero phenomenon in 2017, 63800 houses were destroyed due to river overflows. An economic loss of about $3124 million was estimated.

Remote sensing data have been used to extract information from urban and rural areas, such as land cover classification (Geiß et al., 2020), and detection of damaged buildings (Moya et al., 2021). Regarding informal settlements, a comprehensive

https://doi.org/10.5194/nhess-2021-153
Preprint. Discussion started: 15 July 2021


Natural Hazards and Earth System Sciences Discussions

study of its spatial morphology can be found in Taubenböck et al. (2018). A further study to consider the temporal effects is reported in Kraff et al. (2020). However, remote sensing studies to identify spontaneous informal settlements consisting of makeshift shelters are scarce. The relevance of this task is the geolocation of such settlements to perform prompt prevention actions, such a relocation when the settlements are located in vulnerable areas.

This study shows how a simple, yet effective, time series analysis of radar images from the Sentinel-1 constellation can map spontaneous informal settlements. We report a recent case in Lima, where a group of people settled in two hazardous unused land spaces. The rest of the manuscript is structured as follows. The following section reports a summary of the events that occurred in the two areas. Section 3 shows the time series analysis of the radar images. Finally, our conclusions are drawn in Section 4.

2 The urban settlement of Lima

Lima metropolitan face very frequently critical problems regarding the illegal occupation of unused land and land trafficking. The most recent occurred in April 2021, when two large areas in the outskirts of Lima were informally occupied by citizens (Figure 1). The people who participated declared to the local news that they were affected by the pandemic and cannot afford their rents any longer. The Morro Solar, located in the Chorrillos district, was first occupied on April 5, 2021. Then, the Lomo de Corvina sector, located in Villa El Salvador District, was occupied on April 12, 2021. According to the local news, about 5000 and 3000 people occupied the Morro Solar and the Lomo de Corvina, respectively. During this sudden occupation, lots were delimited with chalk, and makeshift shelters were built with wooden sticks and plastic sheets (See inset (iii) in Figure 1). It is worth mentioning that the government declared the Morro Solar as an intangible area in 1977 and a historical monument in 1986. The police, in coordination with the local authorities, removed the inhabitants that participated in the invasions in April 14 and April 28 in Morro Solar and Lomo de Corvina, respectively. However, the shelters were removed several days later.

The main concern this study addresses is that the occupied areas are unsafe against natural hazards. Luque and Núñes (2011) reported a geological evaluation of Inty Llacta, an informal settlement located close to the recently invaded area in Morro Solar. The referred report identified rockfalls and slope failure hazards, representing a severe danger to the inhabitants and buildings. Likewise, Medina et al. (2013) reported a technical evaluation of twenty-nine informal settlements located in the Lomo de Corvina sector and pointed out potential slope failure may occur at the referred areas. It was also mentioned that the west part of the Lomo de Corvina, where the recent invasion was located, is the most critical area and is not suitable for urban development.

Regarding seismic hazards, seismic microzonation studies have been performed in Metropolitan Lima, which included the implementation of field tests in the city's urban areas. Within the framework of these studies, the underlying soil deposits that conform to the capital city were classified into different zones depending on their mechanic and dynamic behavior. Thus, Zone I corresponds to the stiffest soil of the city and Zones IV and V to the most inadequate regions to be populated due to their particular bad soil conditions. In the case of Chorrillos district, it was divided into four zones, and the areas in Morro Solar are categorized as Zone IV mainly because of the steep slopes that might fail under the effect of strong motions (CISMID, 2010).

https://doi.org/10.5194/nhess-2021-153
Preprint. Discussion started: 15 July 2021

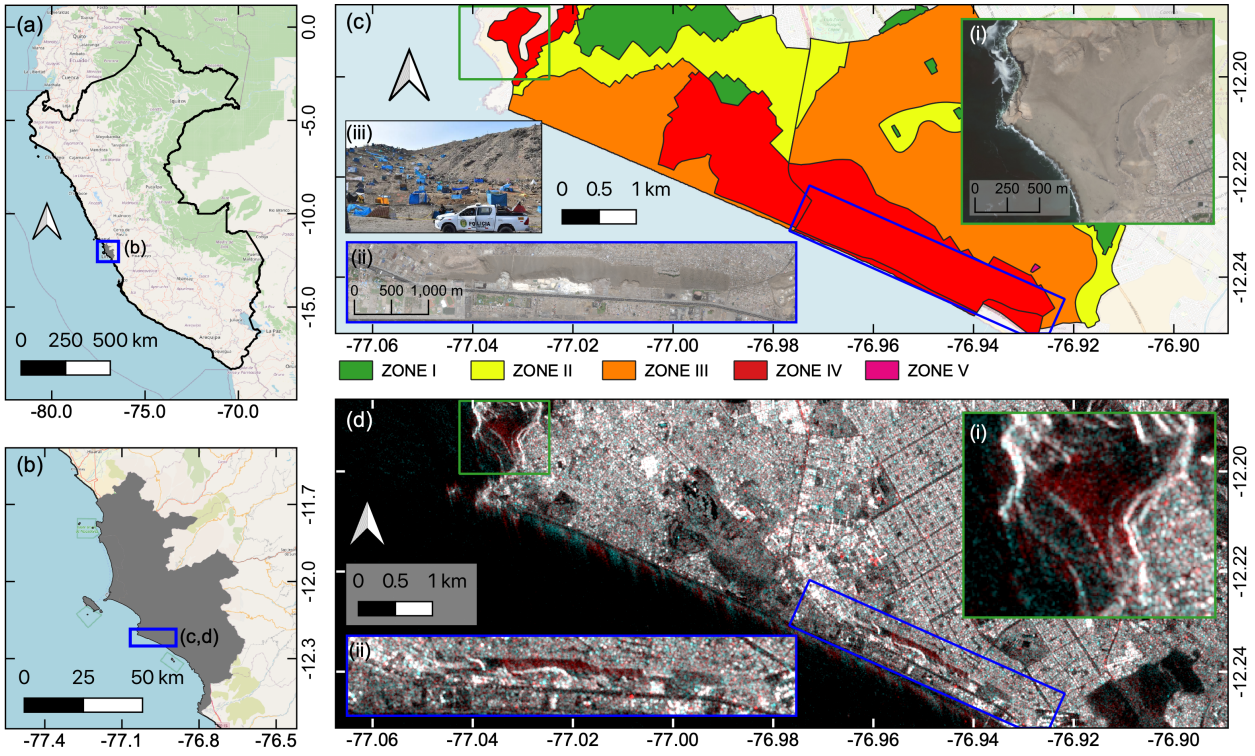

Figure 1. Location of the study area. (a) Location of Metropolitan Lima (blue rectangle) within Peru. (b) Location of the study area (blue rectangle) within Metropolitan Lima, which is partly located in the districts of Chorrillos and Villa el Salvador. (c) Seismic microzonation of the study area. The green rectangle denotes the location of inset (i), the Morro Solar. The blue rectangle denotes the location of the inset (ii), the Lomo de Corvina. The inset (iii) shows a photograph of the squatter settlement in Morro Solar. (d) Color composite of SAR backscattering intensity images. Red band: image recorded on April 14, 2021; Green and blue band: image recorded on December 03, 2020.

Furthermore, Lomo de Corvina is also classified as Zone IV due to the existence of deep eolian sand deposits and the largest fundamental vibration period found in Lima city, which is slightly larger than 1 s (CISMID, 2011). Recent studies have shown that Lomo de Corvina might evidence important values of amplification factors due to the generation and interference of surface waves along the slope (Gonzales et al., 2019). It is worth mentioning that the collapse of the light makeshifts built during the recent invasions may not have represented an effective danger condition to the inhabitants. However, non-engineering masonry houses could have been constructed in the short term if the inhabitants were not removed.

3 Informal settlements from earth observation technologies

This section shows how the informal settlements were observed from satellite imagery. Unfortunately, the areas of interest were cloud-covered in most of the days after the invasion. From the beginning of April 2021 until May 5, only one product from the

https://doi.org/10.5194/nhess-2021-153
Preprint. Discussion started: 15 July 2021

Natural Hazards and Earth System Sciences
Discussions
Open Access
EGU

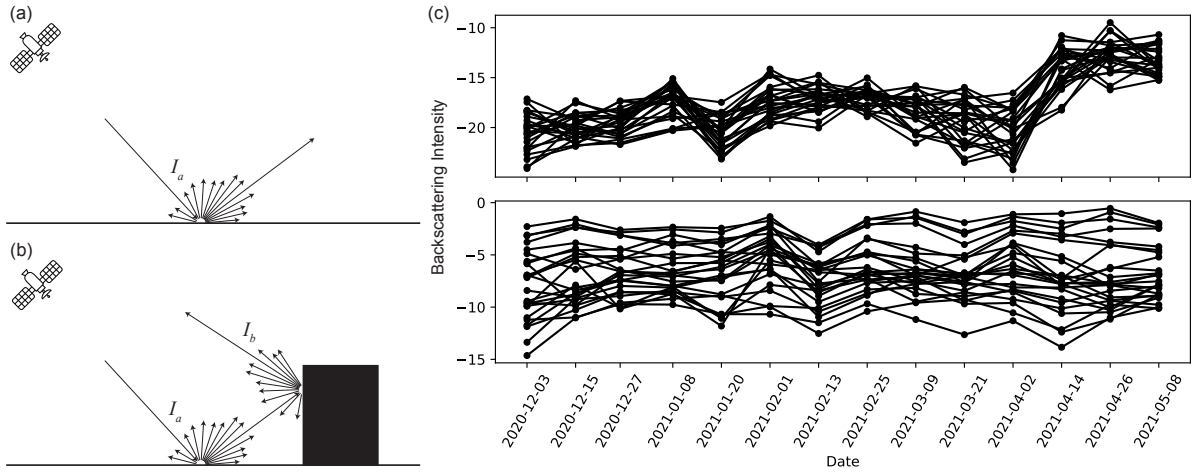

Figure 2. (a) Diagram of the radar pulse, I_a, backscattered from the ground. (b) Diagram of the radar pulses backscattered from the ground, I_a, and the makeshift shelter, I_b. (c) Top: SAR backscattering intensity time series at some representative points of the recently invaded land in Morro Solar. The sudden increment from April 14 denotes the change of the backscatter mechanism from the mechanism shown in 2(a) to that shown in 2(b); Bottom: SAR backscattering intensity time series at some points of an old informal settlement located close to the recently invaded land.

Figure 3. Sentinel-1 SAR-based map of the recent informal settlement in Morro Solar (a), and Lomo de Corvina (b).

Sentinel-2 constellation recorded on April 20 was cloud-free. On the other hand, synthetic aperture radar (SAR) images are designed to pass through the clouds; thus, we focus on SAR images from the Sentinel-1 constellation. Figure 1d shows a color composite of backscattered intensity recorded on different dates. The red band denotes an image recorded on December 10, 2020, and the green and blue band denote the image recorded on April 14, 2021. Red tones are observed in the new informal settlements, which express an increment of the backscattering in time. Such increment is originated from the double bounce scattering mechanism produced by the shelters. Figures 2a and 2b depict a scheme of the backscattering mechanism under two scenarios. When the radar pulses emitted by the satellite reach a flat area, only a small fraction of the energy is backscattered

https://doi.org/10.5194/nhess-2021-153
Preprint. Discussion started: 15 July 2021


Natural Hazards and Earth System Sciences Discussions

to the sensor (Figure 2a). In the presence of an object (Figure 2b), the radar pulses bounces-off the ground towards the object, and then it is reflected from the object to the sensor. Therefore, a larger fraction of the energy is backscattered to the sensor. In the case of the new informal settlements, such objects are indeed the makeshift shelters. We exploit this pattern to map the extent of the occupied area. Figure 2c shows the time series backscattered intensity at some representative points of the recently occupied areas (top) and existing built-up areas (bottom). As expected, a clear increment is observed in the invaded area from April 14. 2021. Therefore, to map the recently occupied areas, a threshold for each pixel coordinate is computed. The threshold is set as the average plus two times the standard deviation of the time series backscattering intensity until April 2, 2021. Then, if the backscatter intensity recorded on April 14, 2021, is greater than the threshold, it is assumed that the area is occupied. Figure 3 depicts the extent of the invaded areas in Morro Solar and Lomo de Corvina.

The results show that a recent squatter settlement could be identified from radar images. Considering the open access to Sentinel-1 imagery, it represents an opportunity to implement a sustainable, low-cost system to monitor informal urban growth over unsafe areas and perform hazard mitigation actions, such as relocation. Prompt measures can prevent significant losses to society. For instance, the mapped settlements are 438,000 m^2 and 265,300 m^2 in Morro Solar and Lomo de Corvina, respectively. Note from Figure 3b that the computed area in Lomo de Corvina is underestimated because of the layover effect of SAR images on steep slopes. From a visual inspection of the urban settlements nearby the recently occupied areas, we estimated a total of 3051 houses in Morro Solar and 1595 in Lomo de Corvina that would have been exposed to strong ground motion amplification and potential landslides during earthquakes.

4 Conclusions

Informal urban growth is a recurrent problem in Peru that has increased in recent years. When the settlement is located in a hazardous area, an assessment of the extent of the occupation can be valuable to perform a proper relocation. In this study, we analyzed a recent informal settlement in two areas in Lima, the capital of Peru, through SAR images of 10 m pixel resolution. A time-series analysis was performed to identify increments of the backscattering intensity at the areas occupied by the settlements. An increment in the SAR intensity is observed from April 14, 2021, which is consistent with local media information regarding the dates of the invasion. We identified 438,000 m^2 occupied in the Morro Solar, and 265,300 m^2 at Lomo de Corvina. One limitation is that the area identified at Lomo de Corvina is underestimated because of the significant layover effect in steep slopes. A future extension of this work will implement an automated monitoring system of informal settlements in unsafe areas against natural hazards. The monitoring system, constrained by the acquisition dates of Sentinel-1 images, can identify settlements within few days. However, through a potential integration of other satellite constellations, a near-real time monitoring system can be achieved.

Author contributions. LM, FG, CG, and MD conceived and designed the study. All authors contributed in the analysis of the data, discussion of the results, and preparation of the manuscript.

https://doi.org/10.5194/nhess-2021-153
Preprint. Discussion started: 15 July 2021


Natural Hazards and Earth System Sciences
Discussions

Competing interests. The authors declare that they have no conflict of interest.

Acknowledgements. This work was partly supported by the Concytec–World Bank research program "Improvement and Extension of the services of the National System of Science, Technology and Technological Innovation" 8682-PE through its executing unit PROCIENCIA [contract 038-2019], the JSPS Kakenhi 17H06108, and the TCPAI Center and the Core Research Cluster of Disaster Science at Tohoku University (a Designated National University).

https://doi.org/10.5194/nhess-2021-153
Preprint. Discussion started: 15 July 2021

References

CISMID: Seismic microzoning of Chorrillos distric (Spanish), http://sigrid.cenepred.gob.pe/docs/PARA%20PUBLICAR/CISMID/Chorrillos%20Informe%20Microzonificacion%20Sismica%20MVCS-CISMID.pdf, last accessed on 4-May-2021, 2010.

CISMID: Seismic microzoning of Villa el Salvador distric (Spanish), http://sigrid.cenepred.gob.pe/docs/PARA%20PUBLICAR/CISMID/Chorrillos%20Informe%20Microzonificacion%20Sismica%20MVCS-CISMID.pdf, last accessed on 4-May-2021, 2011.

Geiß, C., Zhu, Y., Qiu, C., Mou, L., Zhu, X. X., and Taubenböck, H.: Deep Relearning in the Geospatial Domain for Semantic Remote Sensing Image Segmentation, IEEE Geoscience and Remote Sensing Letters, pp. 1–5, 2020.

Gonzales, C., Sekiguchi, T., and Nakai, S.: Parametric Study on the Seismic Response of Two Contrasting Populated Slopes in Lima, Peru, in: Proceedings of the XVI Pan-American Conference on Soil Mechanics and Geotechnical Engineering (XVI PCSMGE), pp. 2009–2016, 2019.

Kapstein, P. and Aranda, E.: Las periferias interiores de Lima: localización e identificación de los barrios focos de vulnerabilidad. El caso de San Cosme, Revista INVI, 29, 19 – 62, 2014.

Kraff, N. J., Wurm, M., and Taubenböck, H.: The dynamics of poor urban areas - analyzing morphologic transformations across the globe using Earth observation data, Cities, 107, 102 905, 2020.

Luque, G. and Núñes, S.: Technical Report No. A6532: Geological-Geotechnical evaluation of rockfall in the Inty Llacta settlement, District of Chorrillos, Lima (Spanish), in: Instituto Geológico Minero y Metalúrgico, 2011.

Medina, L., Gómez, D., and Benavente, C.: Technical Report No. A6637:Technical Inspection of Geological Hazards in Human Settlements of The Lomo De Corvina Sector (Spanish), in: Instituto Geológico Minero y Metalúrgico, 2013.

Ministry of Housing, Construction and Sanitation: Presentación de nueva Ley de Desarrollo Urbano (Spanish), https://www.gob.pe/institucion/vivienda/informes-publicaciones/1846852-presentacion-de-nueva-ley-de-desarrollo-urbano, last accessed on 8-May-2021, 2021.

Moya, L., Geiß, C., Hashimoto, M., Mas, E., Koshimura, S., and Strunz, G.: Disaster Intensity-Based Selection of Training Samples for Remote Sensing Building Damage Classification, IEEE Transactions on Geoscience and Remote Sensing, pp. 1–17, 2021.

Taubenböck, H., Kraff, N., and Wurm, M.: The morphology of the Arrival City - A global categorization based on literature surveys and remotely sensed data, Applied Geography, 92, 150–167, 2018.