Response to Natural Hazards and Earth System Sciences Reviewer 2

Manuscript: https://doi.org/10.5194/nhess-2022-20
Review: https://doi.org/10.5194/nhess-2022-20-RC2
Date: 30-March-2022

Dear Reviewer,
Thank you for your positive feedback and comments on our manuscript. We look forward to incorporating your suggestions in a revised manuscript submission. Please find our initial response to your specific comments in **bold**, with revised text in green.
Sincerely,
C. Scott Watson (on behalf of all co-authors)

Specific comments:

line 49: It might be interesting to mention more clearly the selected sustainable development goals (SDG).

We have modified the text to specifically mention SDG 11, which is most relevant to our study.

Reducing disaster risk and losses is the aim of the global Sendai Framework for Disaster Risk Reduction 2015–2030 (UNDRR, 2015) and is integral to achieving the UN sustainable development goals (SDGs). Specifically, Goal 11 to 'make cities and human settlements inclusive, safe, resilient and sustainable' targets reducing deaths and socio-economic impacts associated with disasters with a focus on the most vulnerable (UN General Assembly, 2015). Successful risk reduction in 'tomorrow's cities' requires people-centred decision making to support a transition from disaster response to risk-informed planning (Galasso et al., 2021).

Figure 1: There is no reference to figure 1a in the text.

We now refer specifically to Fig. 1a in the introduction and section 4.3.

Greenspace is associated with multiple impacts on urban and natural systems (Fig. 1a)…

Quito includes multiple types of greenspace that provide ecological, social, and disaster risk reduction benefits (Fig. 1a, 7).

Line 109. "In this study, we define a style of greenspace relevant to disaster risk reduction that is quantifiable using optical satellite data". I think it would be interesting to add a couple of lines here describing the type of style sought.

We have added additional text to introduce the type of greenspace we focus on.

In this study, we analyse a style of greenspace relevant to disaster risk reduction that is quantifiable using optical satellite data. Specifically, we focus on low gradient open spaces that are vegetated. We do not consider specific greenspace amenities such as recreation facilities, or accessibility restrictions, which cannot be determined using satellite data alone.

Section: lines 136 - 154. Well done section. However, I would expect to find the same logical line in the text as in Figure 2 (or the opposite). For example, Figure 2d is now mentioned in the text before Figure 2c.

We have now restructured this paragraph and made small text amendments to follow the structure of Fig. 2, starting with the earthquake hazard, which is a main motivator of this work, then covering volcanoes, landslides, and floods. The text now reads:

Quito is surrounded by active faults (Fig. 2a) and the Global Earthquake Model estimates (Pagani et al., 2018) at the regional scale indicate a relatively high seismic hazard with a Peak Ground Acceleration (PGA) of 0.55-0.9 g (with a 10% probability of exceedance in 50 years) (Fig. S1). Similarly, Beauval (2018) estimate a PGA of ~0.4-0.6 g or Quito in a return period of 475 years. The Quito Fault System creates seismic hazard across the city, with a maximum earthquake size estimated at Mw 6.6 and a recurrence time of ~150-435 years (Alvarado et al., 2014). Earthquake scenario damage models show that the highest rates of potential building damage are associated with areas of highest social vulnerability (Valcárcel et al., 2017). Volcanic eruptions also pose significant risk to large populations. Quito lies 12 km from the active volcano Guagua Pichincha, where activity over the past decades has been characterised by small explosions, ash, and gas emission (Loughlin et al., 2015). Past eruptions have covered Quito in ash, for example, the 1660 eruption ash deposits are ~10 cm thick in central Quito (Robin et al., 2008). Recent pyroclastic flows and surges have been channelled by topography away from Quito to the west, but potential volcanic hazards in Quito include secondary lahars as well as ashfall, which are mapped using knowledge of historic eruptions (IG-EPN, 2019) (Fig. 2c). Quito's road network, and water supply, are also all vulnerable to flows and especially ash from multiple volcanoes (Wilson et al., 2012; Loughlin et al., 2015). Landslides and floods are both extensive natural hazards in Quito owing to the steep topography, intense rainfall, and filling of natural drainage channels to create building space (DMQ, 2018; Castelo et al., 2018; Domínguez-Castro et al., 2018). Landslides are concentrated on the steep slopes of Quito's periphery and ravines (Fig. 2d), whereas flood events are spread across Quito's urban extent (Fig. 2e).

Figure 22: "Hydro-meteorological events" refers to floods? Because Line 138 refers to floods.

We have amended Figure 2 to refer to 'flood events' to match the text.

Line 171 refers to mud-flows. Perhaps they could be mentioned in the section between line 136 and 154.

We have now added mention of mudflows and a supporting reference here:

Following heavy rainfall, mudflows are also a hazard on the lower and increasingly urbanised slopes of Pichincha (Perrin et al., 2001).

Perrin, J. L., Bouvier, C., Janeau, J. L., Ménez, G., and Cruz, F.: Rainfall/runoff processes in a small peri-urban catchment in the Andes mountains. The Rumihurcu Quebrada, Quito (Ecuador), Hydrological Processes, 15, 843-854, https://doi.org/10.1002/hyp.190, 2001.

Line 181. I think it would be useful to read before chapter 3.1 a short section that would briefly summarise what the following separate chapters will cover. In other words, to immediately understand the logical line followed by the authors to achieve the objectives described in lines 106-110. A few lines are enough. The feeling I had in my first reading was that I was not clear what to expect in the methodology.

We have now added a summary to introduce the key components of the methodology.

The following section details our methodology to quantify Quito's historical urban growth and investigation of future urban growth scenarios. We investigate Quito's growth in conjunction with topographical information and hazard datasets to reveal how Quito's exposure to hazards is changing through time. We then define a methodology to map greenspace that is potentially suitable for disaster risk reduction, considering the spatial distribution in relation to socioeconomic data, and per person accessibility if the spaces were used as an emergency refuge. These data are then used to reveal optimum locations for the designation of new protected greenspaces to enhance disaster risk resilience in Quito.

Line 183. Do the authors mean 3a?

Yes – we have made this correction.

Section 3.1. In this section the urban expansion from 1986 to 2020 is analysed using land cover classification based on satellite imagery. My question is: in figure 2b, the authors already show a map of urban expansion from government data. Why this was not enough? Maybe because of the resolution? I think it is useful to explain further.

Firstly, we wanted to update the existing dataset (Fig. 2b), which only showed urban growth to year 2015. Secondly, there is potential bias in this existing dataset that we alluded to this in the discussion and how now added further clarification. However, we did not include a cross-comparison analysis between both urban growth datasets. Essentially, we are using the satellite image analysis as a mechanism of mapping urban growth that avoids potential bias that could occur in in the existing urban growth dataset (Fig. 2b). The provenance of each time stamp in this map is not known, though is likely to be related to official city maps. These maps may not include informal settlements unless such settlement becomes officially recognised and 'regularised'. Satellite data analysis therefore presents an alternative method that is consistent in its application 1986–2020 and is able to capture informal settlements. We have now labelled the settlement of Atucucho that is mentioned in the discussion on Fig. 5 to demonstrate that this previously informal settlement was reflected in the satellite image classification.

The formation date is labelled as 2003 in Open Government data (Fig. 2b), which likely reflects its origins as an informal settlement that was potentially not included in official maps until 2003.

Section 3.1. Is this analysis carried out for Land Cover AOI only? Please specify.

Yes – we have now clarified:

Urban growth for the period 1986 to 2020 was derived by applying a land cover classification workflow to 30 m resolution Landsat satellite imagery for the Land Cover AOI (Fig. 2a, 3a),

Line 221. Clarify the 2 AOIs as per lines 124 and 125.

The text was modified to read:

The 30 m SRTM DEM was used to extract statistics on the elevation and slope within the land cover change area of interest (AOI), which encompasses the smaller city AOI (Fig. 2a).

Section lines 220 - 235. Why were GCP and CP not used? I think this issue needs to be better explained in the text.

Since the Pleiades satellite data were supplied with rational polynomial coefficients by the vendor, GCPs were not required in this case to process and geolocate the imagery. Our comparison with ICESat-2 data was an independent check on the vertical DEM accuracy. We have clarified the text and added a supporting reference (Zhou et al., 2015).

All imagery was delivered with radiometric processing to reflectance and processed using rational polynomial coefficients (RPCs) without ground control points (e.g. Airbus Defence and Space, 2012; Zhou et al., 2015).

Since the Pleiades DEM was processed without GCPs, we assessed the accuracy using Ice, Cloud and land Elevation Satellite (ICESAT-2) altimetry data.

Zhou, Y., Parsons, B., Elliott, J. R., Barisin, I., and Walker, R. T.: Assessing the ability of Pleiades stereo imagery to determine height changes in earthquakes: A case study for the El Mayor-Cucapah epicentral area, Journal of Geophysical Research: Solid Earth, 120, 8793-8808, 10.1002/2015jb012358, 2015.

Line 272: interesting use of TWI. My fear is that using it for a highly urbanised area will cause a lot of bias. This issue should be better discussed later in the chapter on results and discussion.

We agree that there is bias in urbanised areas due to the presence of a subsurface drainage network that is not represented in the DEM. The study that we cite discussed the assumption that this subsurface network is overwhelmed in a flood event, such that the flow is routed on the surface and therefore comparison with the TWI is appropriate. We have added the following supporting text:

We have added the following text to Section 3.3.

Notably, this method does not account for the subsurface drainage network present in an urban setting, and therefore represents an assumption that this subsurface drainage network is overwhelmed during the flood event, such that all flow passes over the DEM (Kelleher and McPhillips, 2020).

We have modified the text in the discussion:

Flood events in Quito that were recorded in Ecuador's Open Government database were evaluated alongside a TWI derived from the 10 m resolution Pleiades DEM, noting that this does not account for subsurface drainage.

We have added text to 5.3 Future work:

Additionally, our investigation of flood events alongside a TWI would benefit from a better understanding of the capacity and distribution of the subsurface drainage network within Quito, particularly where natural drainage channels are blocked (e.g. Aragundi et al., 2016). Nonetheless, our assumptions that all flood water would flow on the surface represents a worst-case scenario during a flood event where the artificial drainage network is at capacity.

Chapter 3.4.2: Did you validate or measure the accuracy of the results? The use of an orthophoto in some sample areas is sufficient.

We are not sure if this refers to 3.4.2 or 3.4.1. The high resolution orthoimage could be used to accuracy assess the normalised difference vegetation index (NDVI) that underpins the disaster risk reduction greenspace classification. Misclassification in an urban environment observed by other studies (references below) could be due to shadows, particularly cast by buildings. We have now included an accuracy assessment of the NDVI using a random sample of 100 patches (200×200 m) where we report correct and incorrectly classified greenspace referring to the Pleiades orthoimage. Incorrect classifications had a small overall impact. The results are reported in Supplementary Table 3 and in Section 3.4

In some cases, shadowed areas, for example due to buildings, display similar NDVI values to vegetation (Leblon et al., 1996; Yamazaki et al., 2009). We therefore used 100 randomly sample patches (200×200 m) to evaluate the NDVI classification. Incorrect classifications had a small overall impact, accounting for 0.4 % of the evaluated NDVI area (Table S3) with a mean patch size of 13±16 m^2.

Supplementary Table 3. Evaluation of Pleiades-derived NDVI (Section 3.4) using a random sample of 100 patches (200×200 m).

Classification	Area (m^2)	Percentage of total
Correct	1,815,963	99.6
Incorrect	6,748	0.4

Leblon, B., Gallant, L., and Granberg, H.: Effects of shadowing types on ground-measured visible and near-infrared shadow reflectances, Remote Sensing of Environment, 58, 322-328, https://doi.org/10.1016/S0034-4257(96)00079-X, 1996.

Yamazaki, F., Liu, W., and Takasaki, M.: Characteristics of shadow and removal of its effects for remote sensing imagery, 2009 IEEE International Geoscience and Remote Sensing Symposium, 4, https://doi.org/10.1109/IGARSS.2009.5417404, 2009.

Line 341: In your estimation, are these results in line with government data on urban expansion?

We chose not to make direct comparisons between the satellite derived and existing urban expansion dataset since we do not know how the latter were derived. Generally, the observed spatial pattern is similar (e.g. Fig. 2a, 5a); however, the density of built up areas is different. For example, the southeast area of Quito is lower density urban development in our classification, whereas in Fig. 2a the area is fully shaded as urbanised, which is the case throughout. Therefore Fig. 2b potentially reflects an 'urban zone' designation, regardless of the density of development within each polygon.

Figure 6: Looking at the boxplots in 6a and 6b I notice that the city will tend to lower in elevation and occupy more sloping areas. Is it correct? This fact should be described in the text. Consider adding some lines in line 464.

This is correct. We mentioned this in the results (4.1), though not in the discussion. We have now added the following text to section 5.1:

We observed that expansion of Quito and future projections tend towards lower elevations (Fig. 6a) and steeper slopes (Fig 6b), the latter of which is associated with encroachment into areas of high landslide susceptibility (Fig. 6c, d).

Line 418. This fact could be remarked in the conclusions

We have added the greenspace are per person values into the conclusion where the disparity is mentioned.

We also found a disparity between access to greenspaces across socio-economic classifications, with low-medium groups having less access to designated greenspace (3 m^2 per person for the 'low' classification compared to 8 m^2 for 'high').

Figure 9b and c: I suggest the of PDFs, which better describe distributions with high presence of outliers.

We have changed Fig. 9b and 9c to show violin (kernel density) plots with boxplots overlaid to better represent the data distribution.

Line 448: top ten? Hard to make sense just by reading the caption. Trying to make the caption self-explanatory

We have clarified this caption:

Figure 11. Top ten ranked DRR greenspaces (red) and other nearby DRR greenspaces (pink) derived using a maximum capacitated coverage network analysis, which finds the greenspaces capable of accommodating the most people within 800 m using a minimum space requirement of 3 m^2 per person (Section 3.4.2).

Line 547-548. Enrich this concept.

We have added additional text to this paragraph relating to both landslide hazards and the TWI in response to an earlier comment.

Methodological improvements could include multi-temporal and potentially higher resolution datasets, for example landslide susceptibility information that reflects changing land cover and therefore an evolving hazard (Emberson et al., 2020). For example, a dynamic landslide susceptibility map could consider a potentially increased landslide hazard due to road cuttings in areas undergoing urban development (Froude and Petley, 2018), and the dynamic nature of landslide hazard in response to precipitation events (Kirschbaum and Stanley, 2018). Additionally, our investigation of flood events alongside a TWI would benefit from a better understanding of the capacity and distribution of the subsurface drainage network within Quito, particularly where natural drainage channels are blocked (e.g. Aragundi et al., 2016). Nonetheless, our assumptions that all flood water would flow on the surface represents a worst-case scenario during a flood event where the artificial drainage network is at capacity.

Froude, M. J., and Petley, D. N.: Global fatal landslide occurrence from 2004 to 2016, Nat. Hazards Earth Syst. Sci., 18, 2161-2181, 10.5194/nhess-18-2161-2018, 2018.

Kirschbaum, D., and Stanley, T.: Satellite-Based Assessment of Rainfall-Triggered Landslide Hazard for Situational Awareness, Earth's Future, 6, https://doi.org/doi:10.1002/2017EF000715, 2018.

Line 554: enrich the discussion by describing the limitations arising by the use of low-resolution data.

We have modified this paragraph to outline the potential limitations:

Use of EO-based datasets broadens the applicability of our methods to other cities. Whilst other sources of multi-spectral satellite imagery (e.g. 3 m resolution Planetscope or 10 m resolution Sentinel-2) could still delineate the types of greenspaces relevant to DRR (e.g. Fig. 8 inset), we relied on a high resolution Pleiades DEM to provide topographic relief information on the greenspace DRR suitability. Global 30 m resolution DEMs could likely substitute this in some cases, though they are potentially less suitable in densely built urban environment where flat open greenspaces are interspaced with tall buildings and trees for example (Fig. 12a), which cannot be distinguished in 30 m elevation models. Here, elevation and slope values derived from 30 m resolution DEM represent an average of features (for example buildings, cars, and trees) within the 30 m cell. Therefore, the topography of greenspaces is resolved in less detail.

Line 565: cite some numbers (square metres expressed in line 517?)

We made a change addressing this from an earlier comment. The text now reads:

We also found a disparity between access to greenspaces across socio-economic classifications, with low-medium groups having less access to designated greenspace (3 m^2 per person for the 'low' classification compared to 8 m^2 for 'high').