Title: Rapid assessment of abrupt urban mega-gully and landslide events with Structure-from-Motion photogrammetric techniques validates link to water resources infrastructure failures in an urban periphery.

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MS No.: nhess-2021-47

MS type: Research article

Editor comments:

Dear Authors,

first of all, I want to thank the referees for rassessing with care your manuscript. They have come with some other insightful comments.

Based on these I have dediced that your manuscript now needs moderate revisions. I advice you to carefully take into account of referees' comments to improve your work and its potential impact. Referee #2 suggests to move some parts to an appendix. I think that if these parts are short you can leave them in the manuscript, otherwise move them if this also improves readability.

Moreover, I invite you to improve the quality of plots (e.g. Fig. 2 and 8), as well as the font size of the maps' legends.

I am looking forward to receiving your revised manuscript.

Best regards,

David J. Peres

Dear editor,

Thank you very much for the opportunity to present a revised version of the manuscript. The reviewer feedback and your specific guidance are greatly appreciated. Below we describe what we have done on a point-by-point basis:

Reviewer 1

We thank the Reviewer for taking additional time to review this revised manuscript and offer suggestions for further improvement. Please find below our point by point response to your comments:

> The manuscript is much improved over the previous version. However, I would still like to point out a few minor revisions:
>
> - Figure 3c: this figure should be more emphasized as it represents a major achievement. It could be enlarged together with the legend (too small, you can't read the meters of change) that could be moved sideways out of the figure.

We greatly appreciate the reviewer's comment about the value of Figure 3c. Figure 3 has been revised so the panel c (now panel b) is emphasized with a greater level of magnification and coloring that is restricted to the spatial extent of the landslide. The legend is also magnified for readability.

> - Please add in section 2.3 also the specifications of the camera: Mpixels, focal length and sensor size.

These details have been added.

Reviewer 2

We thank the Reviewer for taking additional time to review this revised manuscript and offer suggestions for further improvement. Please find below our point by point response to your comments:

> With regard to the photogrammetric part, I remained doubtful about the highlight that is given here. There is nothing original to have three SfM surveys in rather easy field conditions. We are not at a top of a volcano for example (James et al., 2020) nor in remote regions that are known to be difficult to access due to safety issues (Dille et al., 2019). To me, most of the SfM part could be summarized in a appendix. One would then better highlight the added value of this research which

is an accurate record of unique geomorphic hazards. However, I leave it to the editor to make a decision about this part, based notably on the opinion of the other reviewer.

We appreciate the importance of concise presentation, and have attempted to strike a balance between different preferences among reviewers. That is, a prior round of review, there was a specific request from a reviewer and guidance from the editor to increase the level of methodological detail in the paper; this revision reflects our response to this request. Furthermore, the authors opinion is that the level of methodological detail is now within norms for a full length research article in a top quality journal such as NHESS. Furthermore, we are in agreement with the first reviewer that this level of detail will be informative and helpful to readers of NHESS who many not necessarily be familiar with SfM methodologies.

For each comments, I refer to the line of the manuscript without track changes.

Line 19: “deployed over a five-year period” is misleading. The SfM was used three times, once at three different sites, to study three hazards that were observed during a period of less than 2 years. The LiDAR data used to make DoD are from 2014. So, for the landslide and mega gully A, one can say that we have a study of 1 year with two data acquisition. For mega gully B, a study of 3 years.

Agreed. We have reworded the abstract to avoid creating the impression that SfM techniques were used continuously for five years.

“To obtain primary data on the size, frequency and triggers of abrupt mega-gullies and landslides in urban areas, rapid assessment methods based on Structure from Motion (SfM) photogrammetric techniques and watershed models were developed and deployed in Los Laureles Canyon, a rapidly urbanizing watershed in Tijuana, Mexico. Three abrupt earth surface hazards were observed over a five-year study period including two mega-gullies and one landslide, …”

Line 23. “that triggered the WRIFs”. I would say the return period of the rainfall that triggered the hazards…

The reviewer’s suggestion has been adopted.

Line 30. What definition/criteria is considered here to classify a gully as mega-gully?

Excellent question. We have added a sentence to the introduction to clarify what is meant by a mega-gully. The introduction now reads: “Mega-gullies and landslides are significant earth surface hazards in urban areas, particularly in marginalized neighborhoods on the periphery of large cities in low- and middle-income countries (Sidle et al., 2011; Anderson et al., 2014; Makanzu Imwangana et al., 2015; Fu et al., 2020). Whereas landslides refer to the movement of sediment down a slope, gullies are landforms comparable to small valleys or ditches that are carved by running water, and mega-gullies imply a width of at least 5 m (Makanzu Imwangana et al., 2015).”

Line 40: “that occur abruptly”. That would be nice to have a time definition of what “abruptly” means.

We agree. We added “within a few hours” as our definition of abrupt.

Line 43: “the formation of mega-gullies as gradual”. These are research that show that such gullies can form quickly, sometimes in a few hours. (e.g., Moeyersons et al., 2015)

We have revised the text to acknowledge work in tropical environments that has documented abrupt mega-gully formation. The authors appreciate the opportunity to further refine our contribution. The narrative now reads: “The literature mainly characterizes the formation of mega-gullies as a result of landscape changes such as deforestation, roads, and urban development (Archibold et al., 2003; Adediji et al., 2013; Makanzu Imwangana et al., 2015; Zolezzi et al., 2018), although there have been studies documenting abrupt mega-gully formation in tropical environments (e.g., Moeyersons et al., 2015).”.

Lines 53-54. I do not agree with the following. “but (rotational) soil slides are the most common landslide type and abrupt events have been recognized as a significant threat to public safety”. Large landslide events triggered by heavy rainfall are commonly associated with the occurrence of hundreds/ thousands of slope failures of the avalanche type. Debris/mud flows are also commonly reported in such context. Rotational slope failures, much less. With respect to the significant threat to public safety, overall, rotational slides are usually rather slow

movements as compared to avalanches and flows. In addition, part of the displaced material is usually not much disturbed. Consequently, rotational slides are certainly one of the less threatening type of landslides when it comes to public safety. I suggest that this part of the sentence proposed by the authors be deleted as, independently from the issues I raised here, it does not really bring an essential piece of information.

We appreciate this feedback. The text has been revised to state that rotational slides are the most common type of landslide in the Tijuana metro area, as follows: "Landslides refer to a wide range of phenomena associated with the downslope movement of earthen material (e.g., rock or soil) under the influence of gravity. In the Tijuana metropolitan area, rotational soil slides are the most common landslide type and abrupt events have been recognized as a significant threat to public safety (Oliva-González et al., 2014)."

Lines 58-59: "In summary, there are multiple lines of evidence that both water resources infrastructure failures (WRIFs) and rainfall contribute to abrupt earth surface hazards within urbanizing areas." This sentence sounds a bit in contradiction with the originality of this study when it says that these are multiple lines…

Lines 60-63. The authors insist on the occurrence of mega gullies from WRIFs that were not covered by former research, but do not really say the same with respect to landslides.

Lines 58-64. This part starts with a focus on landslides, then sinkholes and then gullies… That is a sequence that seems a bit awkward.

We greatly appreciate these points and have worked to tighten up our rationale as follows," Earth surface hazards that occur abruptly (within a few hours) are of particular concern from a safety and damage perspective, because there is little time for warnings and other emergency response measures. The literature mainly characterizes the formation of mega-gullies as a result of landscape changes such as deforestation, roads, and urban development (Archibold et al., 2003; Adediji et al., 2013; Makanzu Imwangana et al., 2015; Zolezzi et al., 2018), although there have been studies documenting abrupt mega-gully formation in tropical environments (e.g., Moeyersons et al., 2015). In both agricultural and urban areas, gully formation is associated with rain-generated runoff (Valentin, et al., 2005). However, mega-gullies may also form abruptly in the presence of a high velocity water jet from a pressurized pipe, a process similar to hydraulic mining used in mining operations in California during the 19th century (Gilbert, 1917). Furthermore, under rapid urbanization with limited oversight of design and construction, water supply systems are vulnerable to breaks that trigger hydraulic

mining and the abrupt formation of mega-gullies on time scales of hours to days. In Tijuana, Mexico, local authorities have observed hazardous mega-gullies from pipe breaks and hydraulic mining (Chief of Civil Protection, Tijuana Mexico, personal communication, 2016), but the phenomenon has not been documented in the literature. Landslides may also occur abruptly. Landslides refer to a wide range of phenomena associated with the downslope movement of earthen material (e.g., rock or soil) under the influence of gravity. In the Tijuana metropolitan area, rotational soil slides are the most common landslide type and abrupt events have been recognized as a significant threat to public safety (Oliva-González et al., 2014). Landslides occur when the weight of earth material down a slope exceeds its strength (Highland and Bobrowsky, 2008), a process known as overloading that typically occurs with high soil moisture content following rainfall (Kuo et al., 2018; Valenzuela et al., 2018; Zhuo et al., 2019; Monsieurs et al., 2019; Marino et al., 2020). Recent studies have also shown that leaky pipes and septic tanks contribute to overloading (Demoulin and Hans-Balder, 2021). In summary, there is emerging evidence that both water resources infrastructure failures (WRIFs) and rainfall can contribute to abrupt earth surface hazards within urbanizing areas. Furthermore, WRIFs have been documented to play a role in other land surface processes such as the generation of sinkholes (Kim et al., 2018), erosion (Guo et al., 2013), and destabilization of soil (Van Zyl, et al., 2013). However, the occurrence of abrupt mega gullies and landslides from WRIFs and the interdependence with rainfall is not well documented or understood, which is important to address given the threat of fatalities posed by abrupt hazards and the global growth of urban areas in the Anthropocene (Criqui, 2015; Ercoli et al., 2020).”

Line 74. “a 5-year observational study”. That is misleading (as already said for the abstract) as one could understand that topographic data of the mass movement have been collected several times over the same sites during a 5 year period. I suggest to rephrase or, simply, to delete “5-year observational”.

We have adopted the reviewer’s suggestion. Thank you.

Line 226. “by Highland and Bobrowsky (2008) in USGS (2021).” is a strange way to refer to a work.

Agreed. This has been revised.

Line 340: “SfM photogrammetric techniques have been widely used to quantify geomorphic changes in many environments with equivalent resolution compared

to more sophisticated topographic techniques (i.e. TLS, LIDAR).” With such a statement, the authors somehow stress that the data acquisition part of their research is somehow rather “common”; hence somehow in line with my previous comment on the originality and highlight of the SfM.

Thank you for bringing this to our attention. This sentence has been removed, and the paragraph works better now for summarizing errors and reflecting on the value of the data in the context of accuracy standards and modeling needs.

Line 195: The year of urbanization of the neighborhoods was 1980 (landslide), 2010 (mega-gully A), and 2002 (mega-gully B), respectively. In lines 400-401, the following is said: “our mega-gullies developed over single storm events with little or no latency between urbanization and formation, and pose significant “abrupt” hazards to the population “ In other words, mega gully A formed 4 years after urbanization while mega guly B formed 15 years after. Can we say that 15 year is little latency? Can you confirm this? For example, the work by Makanzu Iwanaga et al (2015) shows that gullies from 5 to 10 years after incipient urbanization. This part needs rephrasing and be better nuanced according to what is said in line 195.

We greatly appreciate this very important point. Is important to note that the time of urbanization in Tijuana Mexico are not necessarily equal to the age of water infrastructure because there is a delay in the installation of the infrastructure. Hence, there is latency between urbanization and formation of “abrupt” erosion hazards which depends on the delay in the installation of the water infrastructure. We revised the text to clarify this: “While other studies highlighted mega-gullies that develop over years (Archibold et al., 2003; Makanzu Imwangana et al., 2014) or hours (Moeyersons et al., 2015), our mega-gullies can develop over single storm events due to WRIFs, and pose significant “abrupt” hazards to the population. Any latency between urbanization and WRIFs is due to delay in the installation of water infrastructure, as settlement and road construction commonly precedes installation of sub-surface water infrastructure by several years”

Line 415. I do not find the reference Demoulin et al. (2021).

We apologize for the oversight. The correct reference is Demoulin and Hans-Balder (2021) which is already listed in the references section. The text has been corrected.

Lines 436-437. “were monitored for a 5-year period”. Here I have a comment similar to line 74. What has been done here is to study three mass movements that were observed in a period of less than 2 years. In line 444, this is correctly formulated.

We agree and appreciate the excellent suggestion which has been adopted.

Line 453: that is the first time that “precondition” is mentioned. Such a key terminology should be firstly mentioned in the discussion.

We agree and have updated the discussion with usage of “precondition”. Specifically, we write: “The observed landslide was triggered by a storm event, but the event was preceded by the water main leak creating the preconditions for a landslide.”

Line 456: “presented major safety hazards to downstream communities and ecosystems at the neighborhood and watershed scale”. The safety issue is not really studied here. It should no be mentioned in the conclusion I think.

We appreciate this important point and have tightened up this point with greater specificity as follows, “Mega-gullies caused by WRIFs were larger than features generated by local rainfall and runoff, produced a significant amount of sediment on an event basis, interrupted water supplies for a month, and disrupted public transportation and life quality for roughly 6 months. Furthermore, the WRIF-triggered landslide damaged more than 20 homes and put roughly a hundred people at risk, also affecting public transportation and quality of life permanently.”

Reference list: they must be checked carefully. For example, Van Den Eeckhaut et al. (2007) is not mentioned in the text.

We apologize for the oversight. We removed this reference and carefully checked both the references section and the overall citations throughout the manuscript.