Proposal of Hazard Connectivity Index for debris flow disaster management

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Abstract. The concept of connectivity and its index have been widely discussed and applied to environmental studies such as ecology, hydrology, geomorphology and hydrosedimentology. Supposing that this concept is very useful also in disaster risk management, we define the hazard connectivity associated to debris flows as the connectivity degree between the debris flow occurrence (trajectory) and the point of interest (location of house, person, and so on). Based on this definition, the Hazard Connectivity Index (HCI) associated to debris flow is proposed as: HCI = L/(x+L), where x is the shortest distance between the debris flow trajectory and the point of interest; and L is the runout distance of the debris flow or just mass movement. The HCI value varies from 0 to 1, being that its higher value indicates larger hazard condition. The HCI application to one case study showed that it can be useful in the analysis of the debris flow related hazard.

1 Introduction

Social vulnerability has been enhanced by land-use changes and population increase in mountainous regions in Brazil. Furthermore, climate change has intensified torrential rainfalls, and debris flows have frequently occurred in mountainous environment. Therefore, mountain management including a debris flow disaster management should be urgently established in Brazil [1]. One of the important measures to reduce the impact of such disasters is hazard mapping. For this purpose, various approaches have been proposed over the world.

After its use in ecology, the connectivity concept has been discussed in various sciences, for example, hydrology [2], geomorphology [3] and hydrosedimentology [4]. To express quantitatively the connectivity degree, i.e., disconnected, weakly connected, moderately connected, strongly connected, etc., a formula or index is required, for example, connectivity index of sediment [4].

This connectivity concept can be used in the context of the natural disaster management. If a certain natural phenomenon does not reach any human-activity area such as a house, a factory and a bridge, or if a human-activity area is not connected to this phenomenon, the disaster never takes place. Thus, the probability of disaster's occurrence can be considered similar to the possibility for human-activity area to be connected to the natural hazard.

Various indices have been proposed so far, but none has been directly aimed at disaster management [5]. For disaster management purposes, a simpler index would be better in terms of practicality.

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In this circumstance, we aimed to propose the Hazard Connectivity Index related to debris flow disasters. To promote the use of this index, we applied it to a case study in Brazil and showed one of its areas of application in hazard mapping.

2 Hazard Connectivity Index

In case of the debris flow occurrence, the important concern is if the initial mass movement reach the elements at risk, i.e., if the initial point of mass movement and the point of interest such as houses are connected by mass movement runout or not. In other words, the understanding of sediment connectivity can help to improve the assessment methodologies of hazard which causes disasters.

Therefore, in the debris flow disaster management, we suggest to use the term "hazard connectivity". Here, the hazard connectivity in this management is defined as the connectivity degree between the debris flow occurrence (trajectory) and the point of interest (locality of house, person and so on). In this sense, the distance becomes an essential parameter in case of debris flow assessment.

Hence, using two distances, a kind of safety parameter (*SP*) is firstly defined as follows:

$$SP = \frac{x}{x+L} \quad (1)$$

where x is the shortest distance between the debris flow trajectory and the point of interest such as house location; and L is the runout distance of the debris flow which influences on the point of interest. Theoretically, SP values vary from 0 to 1, where the smaller SP the larger hazard connectivity becomes.

Then, we propose the Hazard Connectivity Index (*HCI*) which is dimensionless:

$$HCI = 1 - SP = 1 - \frac{x}{x+L} = \frac{L}{x+L} \quad (2)$$

To explain *HCI* determination, Figure 1 demonstrates how to measure the values of *x* and *L*. We suppose here that an initiation of landslide at a zero order basin [6] triggers one debris flow and the sediments are deposited downstream. In Figure 1, a painted area (pink colour) presents a debris flow inundation area, and a point of interest is a house location. Then, a distance *x* is firstly measured. After that, a distance (*L*) between the end point of x on the debris flow area and the debris flow initial point can be measured. Thus, the *L* value can be sometimes a part of the total runout of the debris flow; meanwhile *x* is the shortest distance to the inundation area. Note that *L* is normally a curved distance.

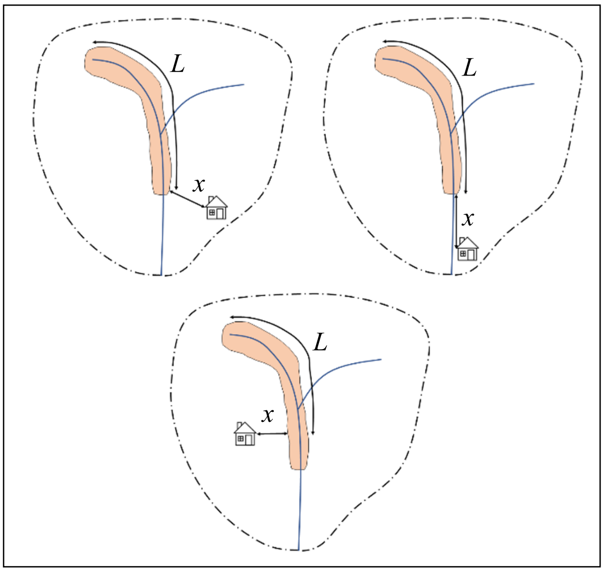

Fig. 1. Determination of the shortest distance between the debris flow trajectory and the interesting point such as house location (*x*); and the runout distance of the debris flow (*L*).

The determination of *x* and *L* permits to calculate *HCI* values. Some examples of its calculation are shown in Figure 2 where the *HCI* values indicate the hazard degree at the house locality, i.e., the locality's connectivity degree to debris flow occurrence. When the debris flow reaches the house, the house will be destroyed substantially, independent of their sizes. Therefore, the situation with *HCI*=1 indicates the disaster occurrence. In debris flow disaster management, the situation with *HCI* value over 1 should be considered equal to that with *HCI*=1. In other words, the whole area of the debris flow occurrence (pinkly-painted area) has *HCI*=1. Hence, we set up that *HCI* values vary between 0 and 1.

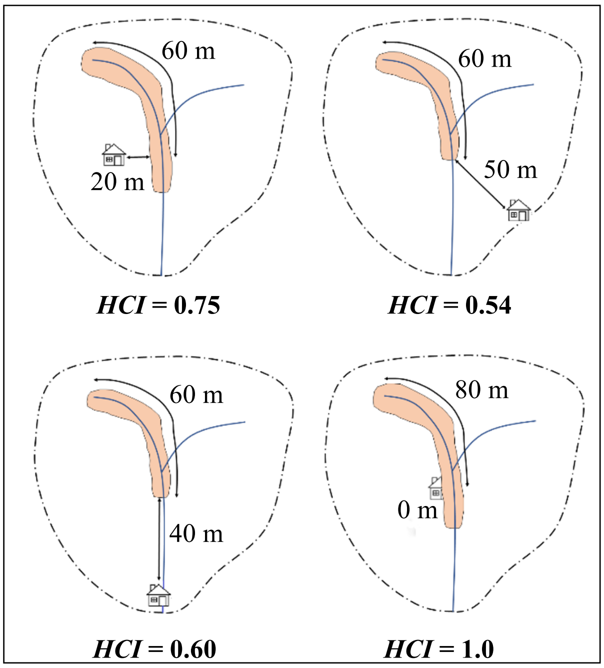

Fig. 2. Some examples to calculate *HCI* values.

Residents usually look at common hazard maps and tend to be interested only in whether their houses are inside or outside a hazard area. However, the *HCI* value gives a relative understanding of how safe their houses are, even if they are outside the area.

3 Application of Hazard Connectivity Index

With a combination using SHALSTAB [7] and KANAKO-2D [8], a hazard map of debris flows was elaborated for a certain area of Igrejinha municipality, southern Brazil [9]. Then, we added the *HCI* zoning onto this map. Here we considered a landslide initiation point as the starting point of the runout distance. And in this case study, this point was determined with the SHALSTAB simulation [9].

Figure 3 demonstrates the different zones based on the *HCI* values from 1.0 to 0.6. The debris flow transport and deposition areas generated by the Kanako-2D simulation are presented as the zone with *HCI*=1. Supposing that this simulation performance is satisfactory [9], this zone can be considered very highly hazardous.

As one of *HCI* applications, Table 1 shows the number of possibly-affected houses according to *HCI* zoning of Figure 3. Many houses are located in zones with relatively-higher hazard. These residents should be informed this situation.

4 Final remarks

Introducing the connectivity concept, we proposed the Hazard Connectivity Index for debris flow disaster management. Just after establishing the debris flow occurrence maps, the determination of this index can be performed only with geometric analysis on them, which does not require much knowledge or technique.

Since there are different mechanisms of debris flow incitation, the starting point of debris flow needs to be determined correctly, which can be the challenge for disaster managers. Furthermore, the definition of the whole trajectory (runoff distance) is also an important procedure to have better performance of *HCI*. Anyway, *HCL* is useful in cases where *L* and the entire debris flow runout have uncertainties, because – at the end – this proposal simply adds buffer lines around the inundation area.

To verify the *HCI* applicability more, several case-studies should be necessarily executed in different geographic settings.

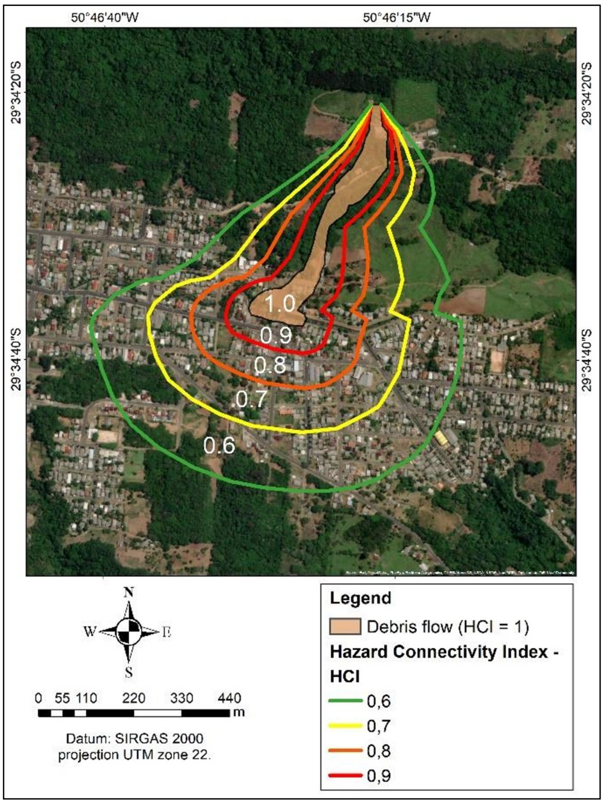

Fig. 3. Hazard Connectivity Index map in a part of Igrejinha municipality, southern Brazil.

Table 1. Number of possibly-affected houses corresponding to different values of *HCI* in Figure 3.

***HCI* zoning**	**Possibility (%)**	**No. possibly-affected houses**
1.0	100%	28
0.9-1.0	90-100	27
0.8-0.9	80-90	59
0.7-0.8	70-80	98
0.6-0.7	60-70	201

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References

1. M. Kobiyama, G.P. Michel, R.F. Goerl, Int. J. Erosion Control Eng. **11**, 3 (2019)
2. C.M. Pringle, Ecol. Appl. **11**, 4 (2001)
3. E. Wohl, F.J. Magilligan, S.L. Rathburna, Geomorph. **277** (2017)
4. F. Zanandrea, G.P. Michel, M. Kobiyama, G. Censi, B.H. Abatti, Catena **204** (2021)
5. T. Heckmann, M. Cavalli, O. Cerdan, S. Foerster, M. Javaux, E. Lode, A. Smetanová, D.Vericat, F. Brardinoni, Earth-Sci. Rev. **187** (2018)
6. Y. Tsukamoto, H. Minematsu, IAHS-Publ. **165** (1987)
7. W.E. Dietrich, D.R. Montgomery, *SHALSTAB: A digital terrain model for mapping shallow landslide potential*. NCASI (1998)
8. K. Nakatani, T. Wada, Y. Satofuka, T. Mikzuyama, Int. J. Erosion Control Eng. **1**, 2 (2008).
9. A.G. Franck, J.S. Gusmão, M. Kobiyama, Rev. Geonorte **12**, 40 (2021)