Small Fish-pond Design for Debris Flow Disaster Measure with Kanako-2D

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Natural disasters related to debris flows have been increasing in Brazil. This phenomenon occurs mainly in rural and mountainous regions where farmers live without much support from public authorities. Therefore, it is necessary to seek structural preventive measures appropriate to the current situation of rural communities. An alternative is the construction of small fish-ponds along the river channel that support to mitigate the debris flow propagation. Therefore, the present study used the Kanako-2D model to analyze how different geometries and positioning of fish pond can influence on the debris flow propagation and deposition. The case study was carried out with the Böni creek catchment (2.27 km^2) which is located in the southern Brazil. The results of 5 different scenarios showed that the fish-pond location was more relevant than its geometry. If a pond is constructed at a less appropriate location, a much larger volume of the pond is required to break the downstream and to stop the debris flow. The fish-pond construction for debris flow disaster reduction can be considered a kind of socio-engineering and should be popularized more widespread in Brazil.

Key words: Kanako-2D, debris flow, fish-pond design, southern Brazil, socio-engineering

1. INTRODUCTION

Without adequate planning, expansion of agriculture, forestry, ecotourism, urbanization, water resources exploration, and hydroelectric power plant construction have been accelerated in mountainous regions in Brazil. Then, it results in the significant increase of debris flow disasters in this country (*Kobiyama et al.*, 2016).

Many European countries, Japan, USA and so on tend to construct check dams and/or barriers against these disasters (*Jakob and Hungr*, 2005). Mountainous and rural regions in Brazil have farmers´ villages which do not usually receive much support from municipal, state and national governments. Under such economic circumstances, these farmers have not been able to construct check dams, which requires simple and low-cost measures for Brazilian mountainous and rural communities.

Therefore, the objective of the present study was to investigate the simple fish-pond design for debris flow disasters reduction by using the Kanako-2D model proposed by *Nakatani et al.* (2008). As these ponds are small, simple and popular among farmers, their construction can be one of the solutions for debris flow disaster measures in Brazil.

The fish production by using the small pond will certainly increase farmers' income and also improve their food circumstances (*Guimarães*, 2012; *ACEB*, 2014). Furthermore, such ponds can be used as parts of irrigation facilities which also increase their income. That is why the pond construction has been promoted at the state and national levels in Brazil, for example, *Meschkat* (1975), *FAO-DNOCS* (1988) and *Assembleia Legislativa do RS* (2013). Therefore, the fish-pond construction should be even more widespread and popularized in order to ensure social and economic security.

There is a tendency where natural sciences intentionally deal with social systems as well as natural phenomena in order to advance themselves more. In this case, such natural sciences analyze interactions between natural phenomena that the sciences have investigated since their beginnings and social processes. For example, socio-hydrology (*Sivakumar*, 2012; *Pande and Sivapalan*, 2017), socio-hydraulics (*Kobiyama et al.*, 2018) and socio-geomorphology (*Ashmore*, 2015; *Mould et al.*, 2017). The socio-hydrology studies the interactions between social processes and hydrological processes while the socio-geomorphology between social processes and geomorphic processes. According to *Pande and Sivapalan* (2017), the socio-hydrology tries to understand the dynamics of coupled human-water systems. Therefore, it can be said that the aim of the socio-geomorphology is to the dynamics of coupled human-earth surface systems. It implies that these kinds of natural sciences cannot be established anymore without consideration on social factors.

This fact can be valid for the technology and engineering for natural disaster reduction. Analogically thinking, it is natural to desire that the socio-technology and socio-engineering concepts spread over the society more. As *Sharples et al.* (2002) emphasized, the design of human-centered technology is strongly required in Brazil. Thus, the present study would support a kind of socio-engineering.

2. MATERIALS AND METHODS

The study area is the Böni creek catchment (2.27 km^2) located at the border between São Vendelino and Alto Feliz municipalities, southern Brazil (**Fig. 1**). This area is located in the Serra Geral formation which characterizes a kind of Brazilian mountainous landscape, whose most areas are underlain by basalt (*Viero and Silva*, 2010). The predominant soils of this region are Entisols and Ultisols (*Flores et al.*, 2007). In December 2000, a rainfall-triggered debris flow occurred in this catchment, causing various damages with the death of 4 persons (*Godoy et al.*, 2015).

In July 2016, field survey with GPS navigator was carried out in order to delimit the scars of this debris flow, to identify its three zones: source, transport (1D channel) and deposition (2D area), to estimate the total sediment volume flowing into the channel, and also to establish the common input parameters for all the computational simulations.

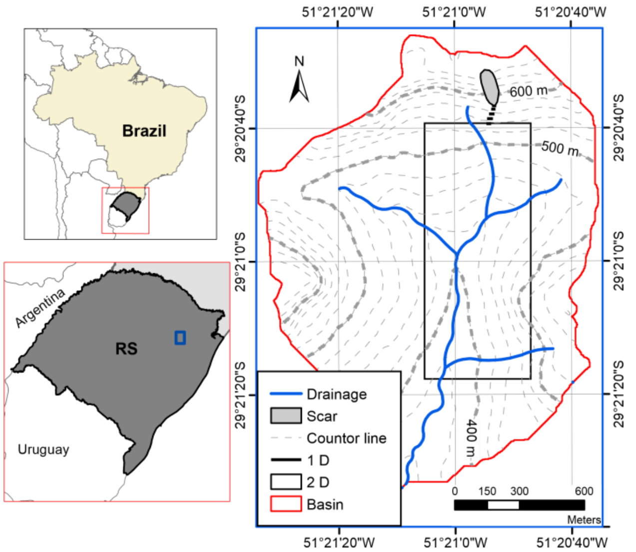

Fig. 1 Location of the study area

The Kanako 2D is a physically-based computational model developed by *Nakatani et al.* (2008). Its version used in the present study, i.e., KANAKO-2D v2.0.0, has a graphical interface defined friendly by the developers themselves. The model simulates the flow from its entrance in the channel with 1D equations and the propagation and deposition in the alluvial plain is simulated with 2D scheme. The more detailed explanation of this model is encountered in *Nakatani* (2008).

The terrain information files generated from the digital elevation model (DEM) with an element size of 2.5 m x 2.5 m were used for the Kanako-2D simulations. The values of the common input parameters for all the simulations are shown in **Table 1**.

Parameter	Value	Parameter	Value
Simulation time	1800 s	Angle of internal friction	37^o
Simulation time step	0.01 s	Concentration of movable bed	0.65 m^3/m^3
Diameter of material	0.45 m	Manning´s coefficient	0.03 s/m$^{1/3}$
Mass density of bed material	2650 kg/m^3	Interval of 1D calculation points	23 m
Mass density of fluid phase	1000 kg/m^3	1D calculation points	5
Coefficient of erosion rate	0.0007	1D calculation width	15 m
Coefficient of deposition rate	0.05	Mesh size of 2D calculation	2.5 m x 2.5 m
Sediment concentration	50%	2D calculation points	472 x 196

Table 1 Input data for Kanako-2D simulation

In order to verify the adequate locality and size of fish-pond along the channel in the catchment, the present study carried out simulation with 5 scenarios characterized with different conditions of fish-pond.

The insertion of the ponds was performed directly in the DEM before each simulation. For this purpose, a raster of the same resolution as the DEM was manually constructed, which allowed containing the desired configuration of the ponds. To insert the pond into the DEM, this raster was used for a mathematical operation between the rasters by using a geoprocessing software.

The Case 0 without fish pond represents the former situation before the debris flow disaster occurrence. Just after the debris flow occurrence in 2000, the inhabitants (local farmers) of the destroyed house constructed one fish pond which exists till now. This is the current situation represented by the Case 1 with the pond P1 (6850 m^3 = 3425 m^2 x 2 m). The Cases 2, 3 and 4 show planned ponds P2, P3 and P4, respectively. Though the volumes of P1, P2 and P3 are approximately equal, the depth of P2 and P3 is twice as large as that of P1. The difference between P2 and P3 is their orientation. In the Case 4, the volume of the planned P4 is very large (30,000 m^3 = 100 m x 60 m x 5 m) (**Table 2**). The locality of P2 and P3 is about 100 m upstream from P1, meanwhile, P4 about 400 m upstream from P1.

Based on field data, *Michel* (2015) found that the soil mean depth on the slopes in the study region is 2 m. Therefore, with the consideration of the landslide areas (10,000 m^2), the total sediment volume into the transport channel for the event occurred in 2000 was calculated 20,000 m^3. This value was used for all the simulation.

Case	Pond	Dimensions	Volume
0	No pond	-	-
1	P1	3425 m^2 x 2 m	6850 m^3
2	P2	35 m x 45 m x 4 m	6300 m^3
3	P3	50 m x 35 m x 4 m	7000 m^3
4	P4	100 m x 60 m x 5 m	30000 m^3

Table 2 Ponds´ characteristics.

The input hydrograph in the 1D component of the model was constructed based on the triangular hydrograph theory of *Whipple* (1992), with a rise time of 1/3 of the total time (99 s), i.e., the calculated rise time is 33 s. By using the formula proposed by *Rickenmann* (1999) and the total sediment volume of 20,000 m^3, the hydrograph peak flow rate was calculated 382 m^3/s. These values are just estimated without field monitoring confirmation.

3. RESULTS AND DISCUSSION

Fig. 2 demonstrates that the Kanako 2D has a good performance to simulate the debris flow which occurred in 2000 and also permits to analyze the pond effect on debris flow deposition in the Böni creek catchment.

In **Fig. 2**, the deposition thickness (Dt) can be positive and negative. Its positive and negative values mean the deposition and erosion, respectively. The Case 0 satisfactorily reconstructed the deposition areas occurred in the 2000´s debris flow disaster (**Fig. 2a**).

As mentioned above, just after this disaster, local farmers constructed one simple fish-pond (P1). Then the Case 1 verified P1´s performance against the same debris flow occurrence, demonstrating that P1 could totally stop the sediment flow. However, it is observed that a part of the sediment reached an existing house (**Fig. 2b**), which suggests that the pond should be constructed at more upstream area.

Fig. 2c demonstrates that the P2 could stop all the sediments and its volume is less than that of P1. The P3 whose volume is slightly larger than those of P1 and P2 also stopped all the sediment (**Fig. 2d**). It is noted that the pond´s orientation is different between P2 and P3, where P2 is elongated perpendicular to the stream direction and P3 parallel to the stream. In the present calculation condition, P2 is more effective than P3. However, if the topography (gradient) around pond installed in the neighborhood of the protection target is steeper, or when the reaching volume of debris flow is larger, this tendency cannot be always true. Therefore, it would be necessary to verify the influence of various conditions in the future.

Though its volume is very large, P4 could not effectively store the sediment because of the high flow velocity at the P4 locality. A part of the sediment that was not deposited in P4 reached very close to the place of the houses (**Fig. 2e**). Thus it can be said that the pond locality is very important to have a good effectiveness of sediments capture and storage.

The results from 5 scenarios permit to say that the P2 is the best design for debris flow disaster reduction in the case of the Böni creek catchment.

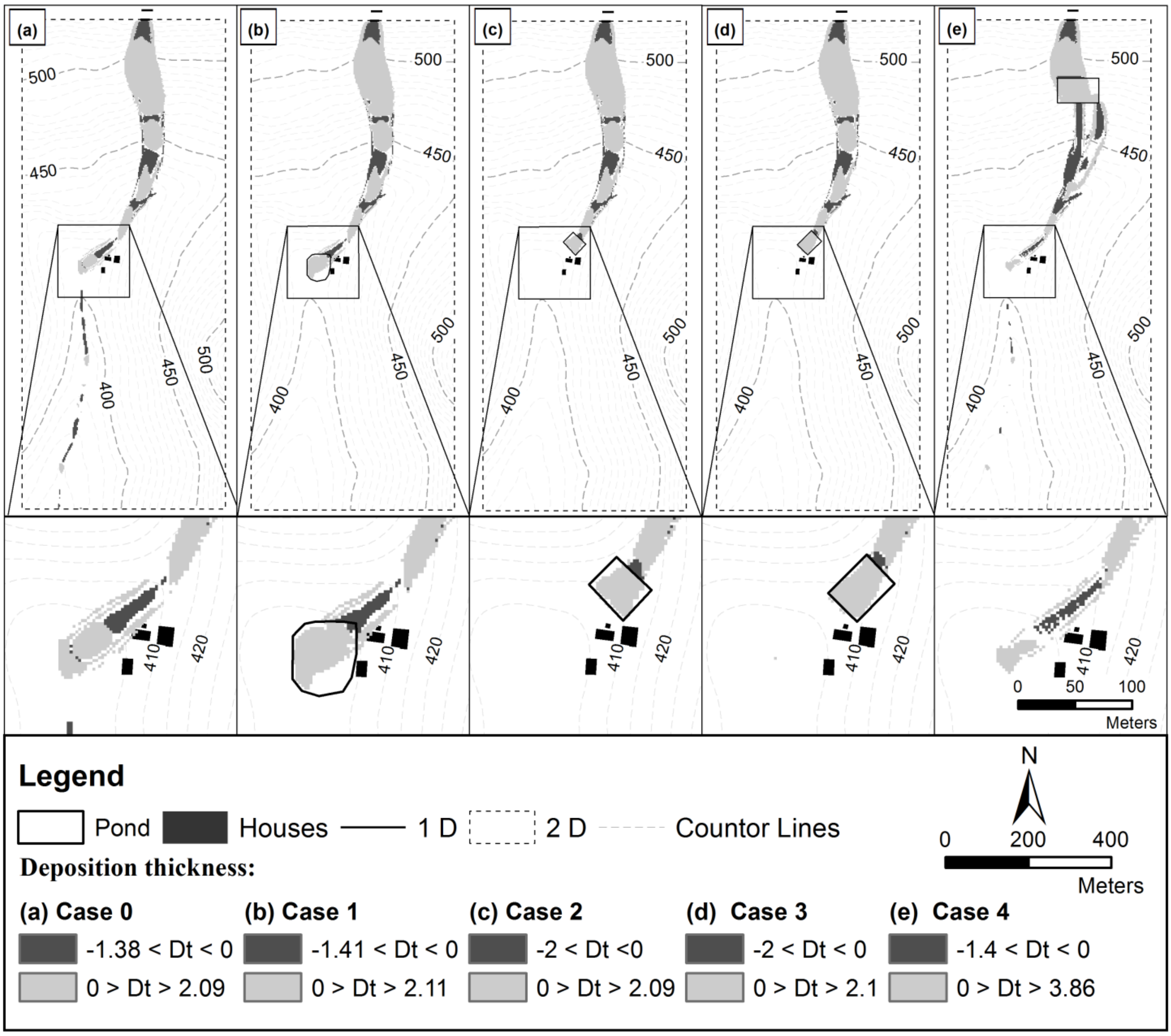

Fig. 2 Deposition areas of debris flow in Böni creek catchment with 5 different cases: (a) Case 0; (b) Case 1; c) Case 2; (d) Case 3; and (e) Case 4.

To understand the deposition feature inside a pond, **Fig. 3** demonstrates the transversal section and longitudinal profile in four different ponds. Note that the longitudinal profile shows the topographic feature along the thalweg and the transversal section passes the pond´s center, being perpendicular to the thalweg. It is observed that the deposition surface presents its lineament transversally, which creates the lens shape with the largest deposition thickness normally near the thalweg point.

When the debris flow is moving down, it digs the stream-bed at the upper part of the pond. This phenomenon occurred very slightly in the Case 4 with P4. In the Case 1 to 3, the sediment concentration of the debris flow reaching to the pond was small. Then, at the upper part of the pond the erosion strongly occurred by removing materials because of the steep step gradient. On the other hand, in the Case 4, erosion did not occur notably due to the high sediment concentration in the vicinity of the upper pond area.

4. CONCLUSIONS

The debris flow triggered by a heavy rainfall in the Böni creek catchment (southern Brazil) in 2000 was investigated with the Kanako-2D. The model showed the good performance to simulate the deposition area reconstructed with field survey conducted in 2016.

Because of current social and economical situations in Brazilian rural and mountainous regions, simple fish-ponds construction can be thought one of adequate measures to reduce debris flow disasters.

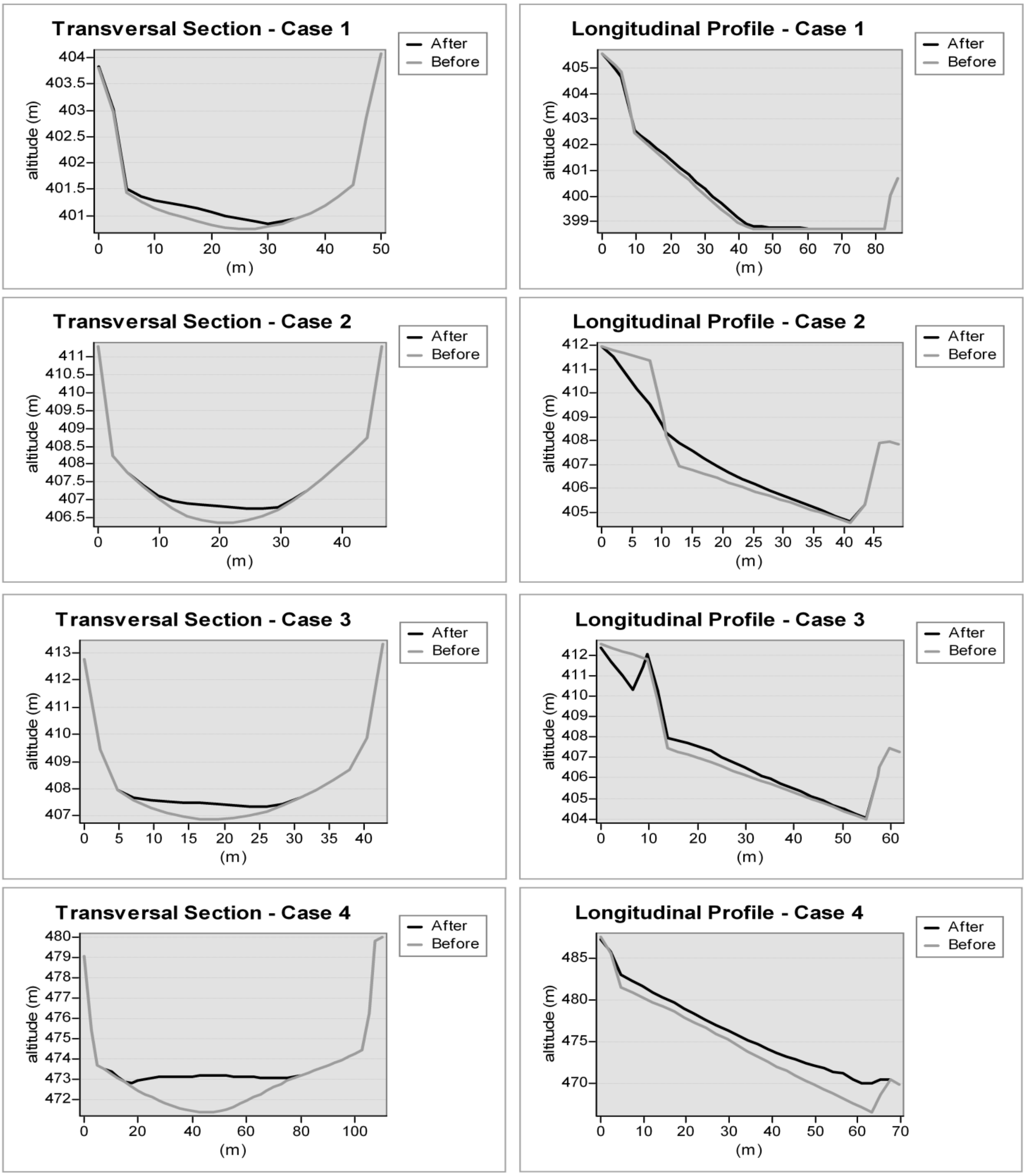

Fig. 3 Transversal section and longitudinal profiles in cases with reservoir before and after the simulations.

Though the present study showed that the pond locality has strong influences on the debris flow storage and deposition, a quantitative formula to establish pond design was not obtained. In order to obtain more adequate design of fish-ponds and more quantitative procedure, computational modeling with detailed and intensive field survey should be carried out in the future.

The present study mentions that the objectives of small fish-pond construction are to increase income for farmers, to improve their food circumstances, and to reduce the debris flow damage. Hence, the fish-pond construction can be called one of fruits of socio-technology and/or socio-engineering.

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