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Community-based landslide risk reduction: a review of a Red Cross soil bioengineering for resilience program in Honduras

Abstract Effective long-term participation of communities in disaster risk reduction measures in landslide-prone areas continues to be a challenge. This study aims to evaluate the extent to which community-based soil-bioengineering techniques allow for effective mitigation of shallow landslide events given technical, environmental, economic and socio-cultural sustainability criteria. The Red Cross has been implementing community-based disaster risk reduction programs aimed at increasing resilience at the community level in Honduras since 2005. Since 2010, 230 landslide hazard sites have been stabilized using soil-bioengineering measures (the use of living plant material to provide certain engineering functions) based on a carefully and systematically developed partnership with local communities. In 2018, an assessment of 73 sites established between 2010 and 2014 showed that (1) 83% of the sites were adequately maintained and (2) 69% of the sites fulfilled the function of soil stabilization. A cost–benefit analysis was conducted for two sites and indicated a cost–benefit ratio of 4.5 and 6 respectively. Some of the key factors for these high success rates include the fact that bioengineering is a locally adapted, easily implemented, cost-effective technology that offers landowners multiple benefits by increasing food security and creating income-generation opportunities. The Red Cross has recognized the importance of empowering communities by building self-confidence so that they can ultimately take responsibility for their own future. The creation of well-functioning local emergency committees has proven highly effective in achieving this goal. When adequately trained, these committees are able to support the replication and maintenance of disaster-risk reduction measures at the community-level in the long term. This case study supports the hypothesis that carefully designed participatory approaches are essential for achieving sustainable, long-term transformative change and risk reduction.

Keywords Landslide risk reduction · Resilience · Community-based disaster risk management · Soil-bioengineering · Red Cross · Honduras

Introduction

Implementing effective landslide disaster risk management (DRM) requires both developing technically sound mitigation measures and a focus on social and institutional vulnerability so as to maximize the long-term effectiveness of interventions. In many cases, mitigation measures can only be effective if the population and the authorities continue providing an adequate level of maintenance (Furedi 2007; Haque and Etkin 2007). This is particularly true in developing countries, where communities are proportionally more affected by natural hazard-induced disasters. The level of risk present within a socio-economic and political system is fundamentally linked to the way risk can be reduced inside that system. Thus, we must address disaster risk reduction (DRR) in a transdisciplinary way by building community resilience and considering cultural perspectives and socio-economic dimensions, rather than simply addressing technical aspects. Economically speaking, mitigation costs are two to four times lower than disaster costs (Kull et al. 2013). The goal behind involving local communities in the design and implementation of mitigation measures is based on the hypothesis that participatory processes facilitate societal learning, foster stakeholders' trust in the results and strengthen their commitment. As such, participatory approaches are fundamental for fostering innovation and achieving sustainable transformative change (Chilvers and Kearnes 2015; Glass et al. 2013; Hostettler and Bolay 2014; Maskrey 1989; Murphy 2007; Pretty 1995; Schmidt and Pröpper 2017; Wamsler 2017).

Decentralization can also help increase local participation as well as improve efficiency (Bahadur et al. 2013; UN/ISDR and UN/OCHA 2008). In developing agricultural countries, exposed populations are often spread out over large areas with steep slopes and heavy rainfall. The spatial resolution of the slope failure hazard assessment must therefore match the scale of the instability when designing and developing effective risk reduction programs (Anderson et al. 2011). This often means focusing on micro-scale land use management, typically at the household level. This is especially the case in the tropics, where landslide inventories often underestimate the number of shallow slope failures resulting from the considerable uncertainty of aerial photo interpretation because of dense vegetation (Zaitchik et al. 2003). When community-based disaster risk mitigation becomes a priority for municipalities and local communities, the implementation of best practices, including adequate land-use policies, can be facilitated and the positive effects of development programs amplified (Burby et al. 2000).

The objective of this study is to understand whether community-based disaster risk measures, such as soil-bioengineering, help to strengthen community resilience in disaster-prone areas. Based on a case study in Honduras, the research aims to answer the following questions: (1) To what extent do community-based soil-bioengineering techniques allow for effective mitigation of soil erosion and shallow landslides in the study area, given technical, environmental, economic and social criteria for evaluating the overall sustainability of this approach? (2) What are the key factors for the success or failure of community-based slope stabilization programs?

Community resilience: the Red Cross approach

For the International Federation of the Red Cross (IFRC), a resilient community (1) is knowledgeable, healthy and can meet its basic needs, (2) is socially cohesive, (3) has economic opportunities, (4) has well-maintained and accessible infrastructures and services, (5) can manage its natural assets and (6) is connected (IFRC 2014). The Swiss Red Cross (SRC) recognizes these characteristics as necessary foundations for building and/or strengthening the absorptive, adaptive and transformative capacities necessary for resilience building (SRC 2016). The SRC is a private, humanitarian, non-profit organization. It is the recognized Red Cross Society of Switzerland and a member of the International Red Cross and Red Crescent Movement. The goal of its international program is to contribute to healthy living and improved disaster risk management capacities among particularly vulnerable and underprivileged people and communities (SRC 2013).

The Honduran Red Cross (HRC), with the support of the Swiss Red Cross (SRC), is implementing a community-based disaster risk management (CBDRM) program in Olancho, Honduras. It started in 2005 following several emergency and relief operations, including those experienced during Hurricane Mitch and Tropical Storm Gamma.[1] Applying a community-based approach, community committees are organized, trained, equipped, officially recognized and linked to the national disaster management system. Prevention and disaster risk mitigation builds on risk studies (including geological, hydrological, geomorphological and meteorological factors) in combination with communities' traditional risk knowledge and coping mechanisms. Prevention and mitigation measures are defined, prioritized and established in a participatory way based on this combined knowledge. Capacity building also takes place at the level of local authorities. Risk studies serve as tools for risk-oriented decision making and are officially recognized and integrated in municipal development and investment plans. Measures include "green" ecosystem-based measures as well as "grey" infrastructure.

Soil-bioengineering for landslide mitigation

Landslide management has not been adequately addressed, mainly due to a lack of financial resources, even in the most developed countries (Kumar 2010). Identifying adequate cost–benefit strategies for different mitigation measures is an ongoing challenge. The Working Group on Landslides of the International Union of Geological Sciences (IUGS WG/L) has determined that the appropriateness of measures for landslide risk reduction depend on the following: (a) engineering feasibility, (b) economic feasibility, (c) legal/regulatory conformity, (d) social acceptability and (e) environmental compatibility (Popescu and Sasahara 2009).

Soil-bioengineering is defined as "The use of living plants or cut plant material, either alone or in combination with inert structures, to control soil erosion and the mass movement of land in order to fulfil engineering functions" (Howell 2001). Bioengineering not only has a high success rate, but is also more sustainable, environmentally-friendly and affordable than many other available options. By incorporating agro-forestry and water management, it is one of the most cost-effective strategies for shallow landslide and soil erosion mitigation. It can also help in promoting rural development in general, while improving vulnerability and reducing risk at the community level (Harari et al. 2017; Kumar 2010). Though soil-bioengineering is increasingly promoted in countries in the Global South, many local communities still do not have extensive hands-on experience with this technique. This gap in knowledge is often still addressed through pilot projects headed by international agencies and development actors, with the aid of manuals, networks and platforms. The international scientific community is paying increasing attention to this subject and investigating evidence-based results regarding degrees of effectiveness (Harari et al. 2017). The results of these studies highlight the need to better assist and promote the dissemination of results from operational studies by working with local engineers and stakeholders on joint projects and cooperative initiatives (Stokes et al. 2010). Bioengineering techniques, along with civil and social engineering measures, can considerably reduce the overall cost of slope stabilization, which remains a key factor for many developing nations (Harari et al. 2017; Kumar 2010).

[1] https://www.swissinfo.ch/spa/cruz-roja-suiza-ayuda-a-damnificados-hondure%C3%B1os/4902310

Study area

The study area is located in the Olancho department in Honduras, where the Honduran and Swiss Red Cross are aiming to strengthen disaster resilience among vulnerable communities through CBDRM programs. Currently, the program has been implemented in 75 communities in 3 municipalities: Catacamas, Dulce Nombre de Culmí and San Esteban (Figs. 1 and 2).

According to the 2016 Human Development Report (UNDP 2016), Honduras' Human Development Index for 2015 was 0.625, which puts it in the "medium human development" category at 130 out of 188 countries and territories. The illiteracy rate is 18% in San Esteban and Catacamas, and 23% in Dulce Nombre de Culmi, with the average years of schooling ranging from 5 to 5.9 years. The main economic activities include agriculture, farming, forestry and fishing (Table 1).

The study area covers 12,060 km^2 with altitudes between 450 and 1500 m above sea level. Its geology comprises Palaeozoic to Cenozoic metamorphic rocks and volcanic sediments overlaid by Neogenic fluvial sediments. This vast region is characterized by moderately formed hilly landscapes with slopes up to 35° (Fig. 2). Outside the valley bottoms, the steep slopes are typically covered with medium (< 2 m thickness) to shallow (< 0.5 m thickness) sandy to clayey soils. The climate is tropical, and during the rainy season, which extends from May to October, heavy rainfall can cause severe soil erosion and trigger shallow landslides that often have negative repercussions on local communities.

Methodology

Determination of risk

The methodology used to determine risk was designed by the Swiss Agency for Development and Cooperation (COSUDE) and the Centre for Territorial Studies of Nicaragua (INETER) (INETER and COSUDE 2005). It was adapted so that both specialists and the technical staff of institutions and local governments can use it without specific technical skills or specialization. First, the level of threat and vulnerability is determined by the SRC/HRC team. This serves as the basis for determining risk in a practical, simple way that facilitates its implementation and decision-making. A data processing methodology (based on GIS tools) is used to create thematic maps. However, an in situ understanding of the geomorphology of the study area and overall community context is established through a study of the historical background and field visits. A risk study with a characterization of the study areas where critical sites (medium to high risk areas) are located is conducted in each municipality, along with the creation of maps indicating threats. Historical (or past) signs indicating areas that have been affected by slope/hillside instability are used as a reference. Likewise, potential signs indicating areas that might be affected in the future are also observed. Table 2 provides an overview of the criteria used for the identification of landslides.

The slope instability phenomena observed in the study area can be identified as translational landslides, rotational landslides and debris flows according to Cruden and Varnes' (1996) classification. They are referred indistinctly to as shallow landslides which, together with soil erosion, represent the hazard of concern in this study. In addition to heavy rainfall, other triggering factors included cutting into slopes to build dwellings, changes in soil use, changes to the original geometry, erosion or undermining of the base of the hillside or slope and overloading of the hillside.

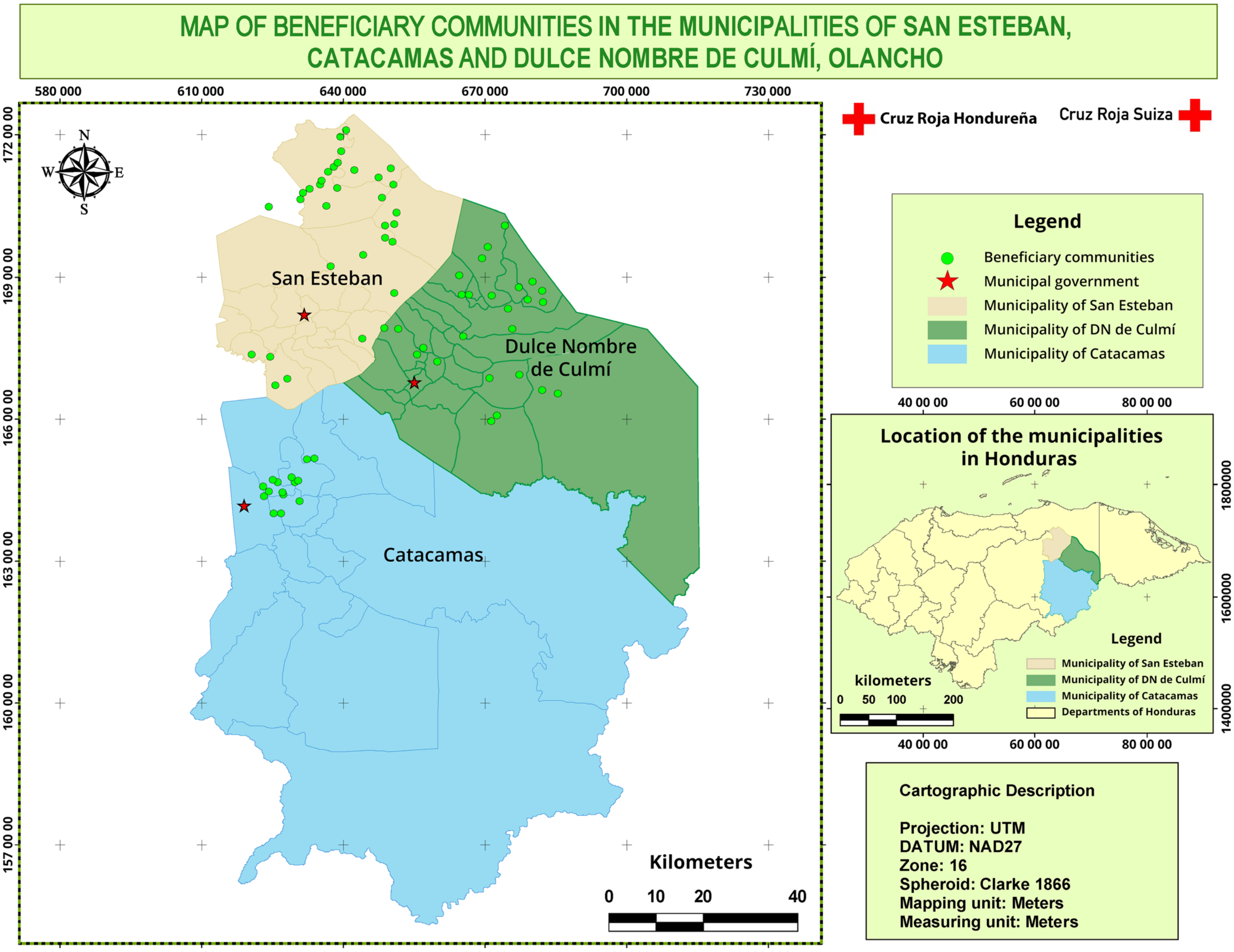

Fig. 1 Location of study area in Honduras (Author: HRC)

Determining the level of threat

The threat resulting from slope instability depends on the frequency and intensity of a given event. In this study, three frequency classes were considered: Less than every 10 years (high frequency), every 10+ to 50 years (medium frequency) and every 50+ years (low frequency). Similarly, three classes of intensities were retained (low, medium and high) based on the volume and velocity of the mass displaced measured with the help of extensometers and inclinometers when applicable (Table 3). When measurements were not feasible, the velocity was estimated based on indicators observed in the field such as cracks in the soil (see methodology in INETER and COSUDE 2005). In the case of slopes exposed to soil erosion in addition to shallow landsides, only the latter phenomenon was considered to compute the threat level.

Once the event's frequency and intensity have been determined, another matrix (Table 4) was used to determine the level of threat (low, medium or high).

Determining the level of vulnerability

Physical, economic, environmental and social (organizational and institutional) factors are considered in order to determine the vulnerability of a community. Values for these factors are obtained through qualitative interviews with key informants and local leaders.[2] When the value of each vulnerability factor has been obtained, they are averaged to obtain the overall vulnerability, thus producing a numerical value that can be compared with the ranges established in a matrix to determine whether the value is low, medium or high. Communities with an average vulnerability indicator of more than three are considered extremely vulnerable, between 2 and 3 very vulnerable, between 1 and 2 vulnerable and between 0 and 1 not very vulnerable. For example, a community with the following vulnerability values, physical (2.38), socio-cultural (2.71), institutional (2.75), economic (1.0) and environmental (1.9), will have an overall average of 2.15 and therefore considered a very vulnerable community.

[2] https://www.ifrc.org/vca

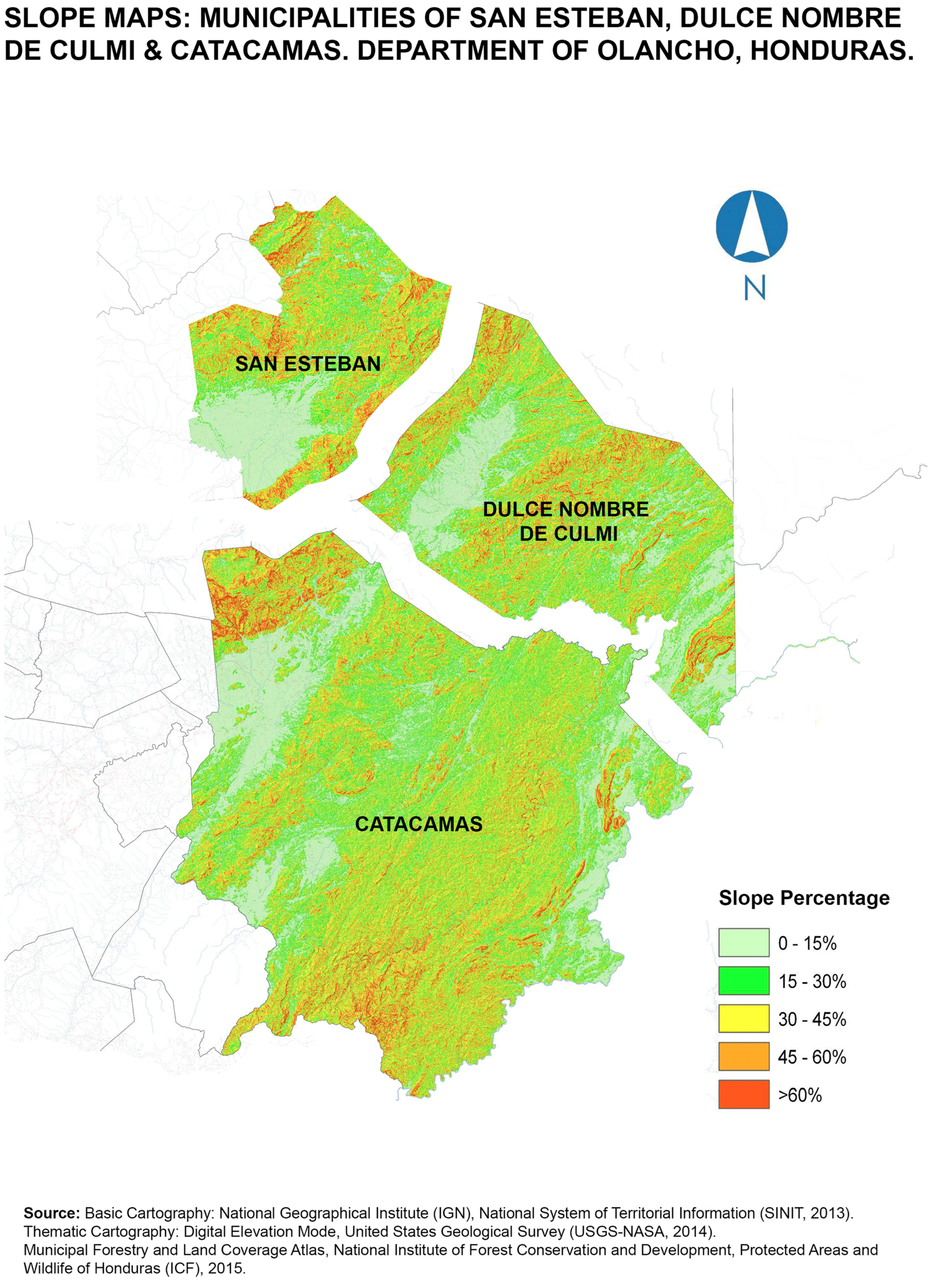

Fig. 2 Slope maps of San Esteban, Dulce Nombre de Culmí and Catacamas based on ICF's open source Municipal Forestry Atlas-2015 (Author: Clarisa Vasquez)

Table 1 Characteristics of beneficiary communities

	San Esteban	Dulce Nombre de Culmí	Catacamas
Area (km^2)	1962	2925	7173
Population	26,180	30,540	122,190
Rural population	80%	87%	55%
Illiteracy rate (2013)	18%	23%	18%
Average years of primary schooling (2013)	5.5	5	5.9
Main economic activities: agriculture, farming, forestry and fishing	66%	84%	54%

Demographic data source: Instituto Nacional de Estadística (INE) Honduras, XVII Censo de población y VI Vivienda

Determining the level of risk

Once the level of threat and vulnerability has been determined, the level of risk is deduced based on a matrix (Table 5). If a site's risk level is medium or high, it is considered "critical".

Data collection

Risk studies were conducted in three municipalities in the Olancho Department in Honduras. Technical fact sheets were established for each of the 230 critical sites identified and treated (Fig. 6 and Fig. 7). These include the following: geolocation, slope inclination, surface area, number of family members in landowning household, nature of the bioengineering technique applied, total cost and contributions of landowners, photos of the site and level of risk (medium or high). In addition to the data collected through a survey conducted among 90 households and 10 semi-structured expert interviews between February and March 2018, the study draws on data collected by Red Cross staff on a continuous basis since the inception of its soil-bioengineering program in 2010.

In 2018, a detailed assessment of 73 selected critical sites stabilised through soil-bioengineered measures between 2010 and 2014 was conducted. Each site was visited by a Red Cross engineer together with the respective landowner. The assessment regarding maintenance function was conducted based on the following criteria: (a) the vegetation is clean and trimmed, (b) shows no signs of avoidable deterioration (dead, collapsed, fallen or rotten vegetation) and (c) three out of five plants are growing well. A further 157 sites established between 2015 and 2017 were also assessed according to the same criteria. Assessment of the soil stabilization function is based on visible deterioration (e.g. signs of soil erosion), especially after heavy rainfall events. An area-wide, intensive revegetation of steep slopes with permanent vegetation can reduce the disposition for shallow, spontaneous landslides, provided that the root depth is below the potential landslide slip plane. This effect is particularly notable on slopes at the limit of the critical gradient, but also has a positive effect on steeper slopes. Hazard reduction results from the reduced frequency of slope instabilities. In the case of a landslide event, the intensity (thickness of the slight break) nonetheless remains unchanged. Scientific studies show that intensive root penetration can increase the critical gradient to develop slope instabilities by up to 5° (Rickli 2017). In situ visits were made to assess all the critical sites. Historical signs were used to understand the dynamics of these processes over time, while potential signs were used to identify sites that had not been affected in the past but might be in the future, given their characteristics (geomorphological, geological, hydrogeological, vegetative, structural, etc.) (see Table 2).

Table 2 Criteria for the identification of landslides (adapted from INETER and COSUDE (2005))

Typology of signs according to their nature	Historical (past) signs	Potential signs
Geomorphological	Land in small depressions, undulating terrain, escarpments and/or counter-slopes, etc.	Land in small depressions, undulating terrain, cracks opening up in the ground
Geological	Outcropping of unsettled or loose rocks in landslide scars, irregularly-shaped structures, etc.	Maps of fractures in favour of the slope, unsettled or loose rocks, irregularly-shaped structures, loose or crumbly material
Hydrogeological	Relative abundance of water (areas of lusher vegetation), soil saturation, the appearance of marshes at the head, middle and foot of the landslides, rerouting of rivers, etc.	Relative abundance of water (areas of lusher vegetation), areas in which water rises or spouts Soils that are continuously damp or wet
Vegetation	Existence of vegetation typical of humid areas, crooked and/or tilted trunks, broken/tense roots, sudden breaks in the vegetation cover, etc.	Existence of vegetation typical of wet areas, tense roots, Trees that are crooked, curved or warped at the lower part of the trunk
Structural	Leaning poles, taut or slack cables, leaning or cracked houses or constructions, cracks or undulations in the pavement, fences or hedges out of position, etc.	
Toponomy	Place names that might suggest terrain instability, such as *Cerro de Agua* (water hill) and *Cerro Partido* (divided hill)	Same as the historical signs
Historical	Accounts or documents of past events	

Table 3 Landslide intensity matrix (mainly rotational landslides) (INETER and COSUDE 2005)

Volume (m^3)	Velocity (cm/year) > 10	2–10	< 2
> 100,000	High	High	Medium
50,000–100,000	High	Medium	Low
5000–50,000	Medium	Low	Very low
< 5,000	Low	Very low	Very low

Table 5 Table to determine risk level (INETER and COSUDE 2005)

Threat	Risk level		
High	High	High	Medium
Medium	High	Medium	Medium
Low	Medium	Medium	Low
Vulnerability	**High**	**Medium**	**Low**

Information regarding the precise methodology the Red Cross, developed to establish partnerships with local communities, was provided by one of the co-authors. This was supplemented by existing reports and conducting semi-structured interviews with four Red Cross staff members and three local emergency committee members.

Establishment of community local emergency committees (CODEL)

The HRC/SRC acts in areas where HRC/SRC disaster intervention (with humanitarian aid) is necessary and followed up with more long-term development programs. Initially, a risk study is conducted involving a multidisciplinary team that includes Red Cross staff, geologists, hydrologists, foresters, civil engineers and GIS specialists. Based on the study, critical sites prone to landslide, soil erosion and floods are identified (Table 6). HRC/SRC then facilitates the prioritization process for intervention at the community level. The risk study lasts 3 to 4 weeks and identifies at-risk areas through analysis of satellite images, topographical maps, soil profiles and existing data. This is then followed by field visits. Collaboration between the HRC/SRC and the communities in the study area always follows the same methodology (Fig. 3):

After mutual interest in collaborating is expressed by both the HRC/SRC and the municipality, employees from the municipality accompany HRC/SRC staff in order to establish a positive connection with the communities. If the risk assessment shows that a particular community is at risk, the HRC/SRC staff return and organise a community meeting. During this meeting, the HRC/SRC shares project ideas and the risk assessment results with the community, specifies what type of support the HRC/SRC might provide (as well as what is expected from the community in regards to their contributions) and seeks to establish a basic consensus in terms of community acceptance and commitment.

Next, a community workshop is organized, during which the concept of a *Red Cross Community* is presented. The HRC/SRC then organises the CODEL for the implementation of subsequent projects and to build trust, commitment and a reliable partner organization within the community. The CODEL's composition may vary during the first 6 months until it becomes clear which community members are truly dedicated and reliable in terms of supporting DRR activities. The CODEL then becomes a strategic partner of the HRC/SRC for all future disaster risk reduction interventions.

Capacity building of the CODEL members not only focuses on DRR (e.g. bioengineering techniques for slope stabilization) but also includes institutional (e.g. how a committee should be organized and function) and managerial aspects (e.g. how a project should be implemented). This training helps to build capacity and raise awareness at the community and individual levels. The CODEL's role in awareness raising is essential, as it is the point of entry for the beneficiaries; is instrumental in generating trust and commitment; and provides support. Once CODEL members have acquired the basic skills, the HRC/SRC begins a *Vulnerability and Capacity Assessment* (VCA) (2- to 3-day workshops) at the community level. The assessment includes hazard, resource and evacuation maps developed using a participative approach. The results of the VCA and scientific municipal risk studies are then shared in community and/or municipal meetings. The municipal risk studies serve as input for the preparation of Municipal DRR Plans, which in turn are incorporated into the Strategic Municipal Development Plans through a highly participative process. Cross-checking community-based VCA with the scientific risk studies allows for better risk awareness for communities.

A community action plan (which covers preparedness and mitigation activities for 1 year) is developed with the CODEL. Building a stable working relationship with a community can take one to 2 years. The HRC/SRC interacts with a number of different community organizations (water committees, health committees, schools, etc.), which makes it easier to use an integrated approach and make progress in several areas at the same time, e.g. in health (planting nutritious crops and practicing better hygiene), education (establishing emergency plans, generating a culture of disaster prevention) and environmental conservation (e.g. reforesting degraded areas, legal protection of water catchment areas). In the following weeks, the HRC/SRC visits each home in the community to look at both DRR and health issues. This stage is time intensive but contributes substantially to the success of the program implementation. For example, during these visits, family emergency plans are developed (based on the risk maps created in collaboration with the community) and linked to community-level plans.

In parallel, the HRC/SRC begins work on the critical sites identified during the risk studies, VCA and family emergency plans. The critical

Table 4 Matrix to determine level of threat (INETER and COSUDE 2005)

Intensity	High	High	High	Medium
	Medium	High	Medium	Low
	Low	Medium	Low	Low
	Frequency (return period in years)	High 1–10	Medium 10–50	Low 50–200
		Frequency		

Table 6 Example of the description of critical sites based on the risk studies conducted in the three municipalities. (Author: HRC)

Municipality	No. of critical site in the risk study	Description	Level of risk
Catacamas			
Jamasquire	SC 7	Unstable slope with landslides, falling boulders, mud and debris flows	High
	SC 9	Unstable slope with translational (planar) landslides and debris flows	High
La Jagua	SC 8	Landslides, flows and falling boulders,	High
Dulce Nombre de Culmí			
Río Blanco	SC 1	Rotational landslide, debris flows and cattle tracks	High
Mata de Maíz	SC 18	Translational (planar) landslide	Medium
Los Ángeles	SC 71	Rotational landslide	High
San Esteban			
Jocomico	SC 1	Cattle tracks, orange peel and debris flows	High
	SC 18	Rotational landslide and flooding	High

sites are verified with community representatives and the families involved. To develop soil-bioengineering measures, families contribute 25–30% of the cost of the slope stabilization process (i.e. labour, tools and planting material). Contribution by the community is critical to ensure greater commitment and better buy-in, which facilitates project implementation and long-term maintenance of the project activities.

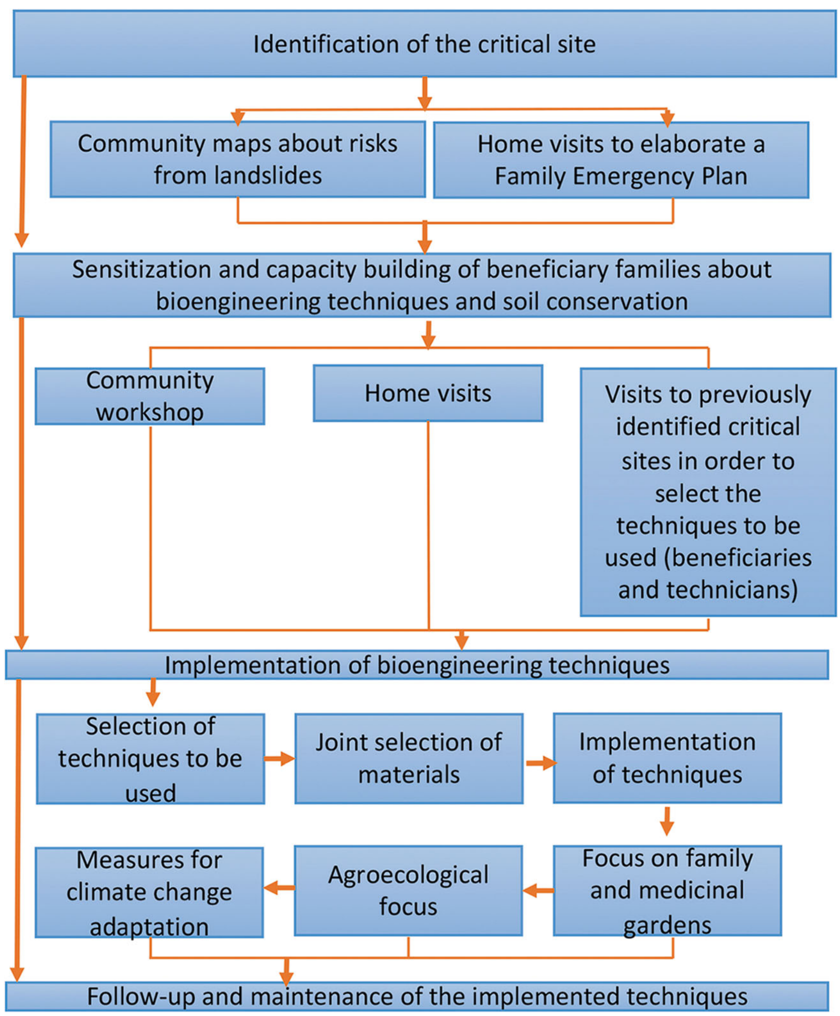

Fig. 3 Development of a participative process for slope stabilization through soil-bioengineering (Author: Carmen Paguada, HRC)

Results

Results are structured according to socio-cultural and environmental/technical sustainability.

Socio-cultural sustainability

A number of local partners (academics and government employees) stated on several occasions that "If we work with the Red Cross, then the community will believe us because the Red Cross always delivers". It is the HRC/SRC's policy to make follow-up visits to the communities on a regular basis and to ensure transparency on how funds were used at the community and municipal level. This is important for addressing corruption and increasing the accountability of municipalities and other government structures. Combined with effective communication, this is one of the key factors for earning the population's trust and building a sustainable, long-term working relationship. Of the 75 emergency committees established, 74 were still functional in 2018 (Table 7).

Environmental and technical sustainability: maintenance and quality of established bioengineering sites

The 230 critical sites where bioengineering measures were implemented were chosen according to the following criteria: (1) level of risk determined by a risk analysis (medium or high); (2) landowner's willingness to collaborate and contribute (by providing planting material and labour) and (3) the absence of other development organizations active in the same area. Between 2010 and 2014, 73 critical sites in 23 communities were identified and stabilised with soil-bioengineering techniques. The following techniques were used: curved/tiered live hedges, horizontal catchment fences, V-shaped catchment fences, Herringbone fascine drainage and Wooden check dams.

Different variations and combinations of measures exist depending on the specific conditions of each site. The following example illustrates one such combination. At the rear of a community school in the municipality of Dulce Nombre de Culmí, there was a slope where water had accumulated in the upper section due to the formation of a counter-slope. The team succeeded in draining the water off with drainage fascines (green works) and redirecting it to a drainage system (grey works) before connecting it to a community drainage system. Valerian herbs (*Valeriana officinalis*) were planted along the contour curves to help stabilize the terrain and reduce runoff and erosion.

Between 2015 and 2017, 157 additional slope stabilization sites were established in 31 communities (similarly based on soil bioengineering measures but with a more integrated agro-environmental focus). Not only do these improved techniques stabilize the slopes, but the terraces created also provide an opportunity to plant medicinal herbs, recycle rainwater, produce organic vegetables/fruits and compost.

In total, 230 critical sites exposed to slope instability affecting 43 communities were identified in the study area between 2010 and 2017, of which 139 presented a high risk and 91 a medium risk. In 90% of the sites, slope inclination ranged from 30 to 35°. Of the 230 critical sites, 85% contained a family orchard, 71% a medicinal garden, 27% had a vermicomposting system to fertilize the family orchard, 25% had a drainage system and 30% a rainwater harvesting system. This integrated approach provided a variety of benefits, which proved attractive to many landowners and acted as an incentive for their involvement in the project. Furthermore, the preliminary investigation shows that, for each hectare of stabilized slope planted with vetiver grass (*Vetiveria zizanioides*) and/or valerian herbs (*Valeriana officinalis*), up to 60 tons of CO^2 can potentially be captured per year.[3]

In 2018, a detailed assessment of the 73 sites developed between 2010 and 2014 showed that 1) 83% were adequately maintained; and 2) 69% fulfilled their function of soil stabilization (Fig. 4). The main goal of the project was reducing the risks caused by hillside or slope processes which include landslides and erosion.

An assessment conducted in 2018 of the previously established sites showed that, through the creation of 230 SB sites, slope failure risk was reduced for 3228 people (Table 7). The measures taken help to lower overland water flow velocity and reduce runoff. This reduces the loss of the fertile layer by limiting erosion and promotes fertility as a result of the biomass produced by the vegetative material it generates. This also helps in draining the runoff water that accumulates on the counter-slopes, redirecting it towards less affected areas or where it can be put to use (e.g. it is drained into artificial lakes with fish farms, or used to water crops). Herringbone-type drainage fascine that limits the triggering effect of (intense and prolonged) rain is an example of this. Cutting into the slope in a vertical or inclined manner to generate terraces or build dwellings is often a contributing factor. The drains built as part of the process (some using green measures and others using grey measures) help to reduce the risk of being affected by rain or river flooding.

Discussion

Participation has long been heralded as a way to create ownership and empower individuals and communities and thus as a prerequisite for lasting change (Chambers 1983; Pretty 1995; Scolobig et al. 2016; Whyte 1991). The flexibility of the HRC/SRC in the thematic orientation of its projects has greatly contributed to creating positive, stable relationships with communities. The HRC/SRC covers health interventions (including sanitation and hygiene, water supply management, reforestation, watershed protection and bioengineering measures) and also works with cattle owners to improve their pastures. However, recognizing the value of being able to respond to community-identified needs and addressing those needs jointly is relatively recent (Kull et al. 2013; Schmidt and Pröpper 2017; Wamsler 2017). The results show that the approach developed by the Red Cross has very promising results in terms of socio-cultural, environmental, technical and economic sustainability. Seventy-four out of the 75 of the emergency committees created between 2010 and 2017 were still functioning in 2017, which is key for ensuring adequate maintenance for the restored critical sites and continuing to support the uptake of the bioengineering measures by additional affected households. At the environmental/technical level, an average of 73% of all sites established in the same period still fulfilled their soil stabilization function in 2017. Furthermore, the HRC/SRC has systematically begun conducting cost–benefit analyses (CBAs), which are extremely useful for establishing priorities among HRC/SRC interventions, given limited financial resources. To date, two full cost–benefit analyses were conducted by an external evaluator, who also trained the HRC/SRC team in conducting cost–benefit analyses independently (SDC 2015). Both CBAs conducted in 2017 by the external expert showed that the bioengineering measures implemented were cost-effective. One analysis looked at flood and landslide risk protection for a school using contour planting, pile walls with plants, drainage fascines and an improved drainage system based on civil engineering techniques (hybrid approach). The cost–benefit ratio was evaluated at 4.5. The other analysis concerned flood and landslide risk

[3] http://ingenieriaviva.es/servicios/area-verde/

Table 7 Number of critical sites per community, number of exposed persons and cost–benefit analysis

	San Esteban	Dulce Nombre de Culmí	Catacamas
Total number of critical sites	72	91	67
Total number of exposed persons	523	1443	1262
Total number of communities with critical sites	14	19	10
Number of cost–benefit analysis conducted and cost–benefit ratio	1 (6)	1 (4.5)	–
Emergency committees created between 2010 and 2017 (Functional emergency committees in 2017)	32 (32)	28 (27)	15 (15)

Data source: Honduran and Swiss Red Cross internal monitoring and evaluation reports (2010–2018)

protection for two exposed homesteads. It used similar soil-bioengineering techniques and had a cost–benefit ratio of 6 (cost–benefit ratio between 2 and 5 is considered cost efficient, cost–benefit ratio over 5 is considered highly cost efficient (SDC 2015)). This is largely due to the fact that SBs are relatively easy technologies to implement, which the vegetative material used is available locally, and that landowners are systematically involved in the development of the sites and responsible for their maintenance (Fig. 5). The integrated approach to slope stabilization gradually developed by the HRC/SRC, based on their strong technical capacity, responds to a variety of community needs, not just soil stabilization. This is a key reason for the HRC/SRC's success.

Furthermore, the HRC/SRC recognizes the importance of empowering local communities by building their confidence so that they continue risk-reduction activities on their own initiative. Ultimately, communities must take responsibility for their own future. One of the key factors of success is the creation of well-functioning, community-based local emergency committees. If committee members are adequately trained, they will be able to support the replication of disaster risk reduction measures and ensure the maintenance of established sites at the community level. However, a key challenge remains in maintaining the communities' enthusiasm over the long term. This is why it is critical to carefully design and prepare the phasing out of Red Cross program activities so that CODEL committees can gradually learn to function without the HRC/SRC's assistance. During the programs they implement, often over many years, the HRC/SRC builds and maintains regular contact with the communities in which they intervene. At the same time, the HRC/SRC staff help build the capacities of the community emergency committees so that they can implement and scale-up their own programs and ultimately become autonomous. Empowering people is the key to fostering communities' ability to believe in themselves and their development potential. The positive cost–benefit ratio and the many benefits families gain by implementing bioengineering are strong incentives for landowners to maintain and replicate soil-bioengineering measures.

Obstacles for the implementation of bioengineering measures

One important obstacle includes reaching an agreement with the landowners of critical sites (Figs. 6 and 7). The HRC/SRC organizes exchanges between community landowners by bringing the beneficiaries of successful SB measures together with those who are yet to become involved or are interested but want to see for themselves first. Between 2015 and 2017, the HRC/SRC organized around 50 such exchanges per year. Landowners who are initially not willing to engage can often be convinced based on positive examples in surrounding communities. Pioneer participants appreciate the benefits of having vegetable and fruit plantations on the terraces created through soil stabilization methods and the resulting decrease in soil erosion. This positive experience encourages others to adopt similar practices and thus enhances upscaling at the community level. Several landowners of stabilized sites expressed the sentiment that what "before was a risk is now an opportunity". Furthermore, community members who are not directly involved but own houses exposed to slope failure risks often approach pioneer participants for assistance in implementing soil-bioengineered measures. However, secure land tenure is a prerequisite for this.

Without constant maintenance, soil-bioengineering loses its capacity to provide protection and conservation (Harari et al.

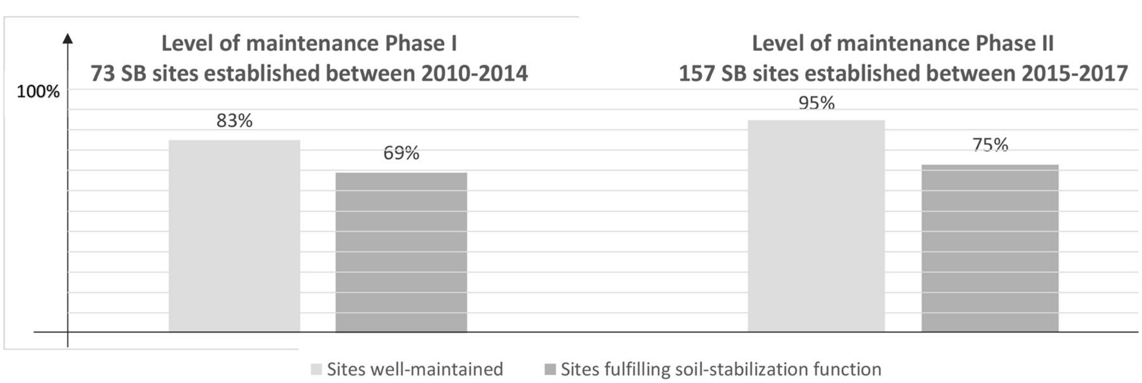

Fig. 4 Maintenance levels and soil stabilization functions of soil-bioengineering sites established during different time periods

Fig. 5 Soil-bioengineering measures for slope stabilization in Honduras. From left to right: wattle fence, dry wall of crude stones, and berm construction stabilized with vetiver. (Silvia Hostettler, EPFL)

2017). Maintenance of the assessed sites appears to decrease over time; 95% of the sites established between 2015 and 2017 were well maintained compared with 83% for sites established between 2010 and 2014. This confirms the constant challenge of ensuring long-term maintenance. Communities are expected to implement upscale and maintain disaster risk reduction measures without outside assistance over the long term. Ensuring long-term sustainability remains a struggle, as some communities will disengage. A widespread attitude of expecting government assistance and a lack of true initiative seems to prevail in the study area. Encouraging behavioural change is therefore crucial to ensuring long-term change. Sooner or later, the HRC/SRC will inevitably phase out their involvement in communities considered capable of managing their own disaster risk reduction measures. Yet, despite the training of competent local emergency committees, this is a difficult step. The survey results show that every household interviewed would prefer that the HRC/SRC remain present, as fears that the community might backslide on the progress made without the former's support and lapse back into inactivity are strong. This last point highlights the need for the HRC/SRC to improve their exit strategies.

Conclusion

This case study confirms that the systematic development of collaboration with communities has a decisive influence on the sustainability of disaster risk reduction measures. Soil bioengineering allows potential risk scenarios to become opportunity scenarios by using the spaces generated to create ecological orchards as an added value and community incentive. This contributes to sustainability by partially fulfilling beneficiaries' everyday needs. One of the objectives is for families to learn about the effectiveness of the techniques implemented in critical sites (bioengineering and soil conservation techniques), as well as agro-ecological measures so to replicate them on their own land and thus generate sustainable development processes at a livelihood level. Such approaches should therefore be increasingly promoted to support the implementation of the Sendai Framework. The key elements used to build this relationship by the HRC/SRC include the following: long-term project duration (contact with the communities for five to 10 years); scientific risk studies combined with participative and inclusive mapping; analysis of vulnerability and capacities in each community; establishment of community disaster management committees; regular visits to the communities; reliable delivery of promised services, which also requires a contribution from the community; and developing community leaders' capacity building for project management. The high degree of credibility the Red Cross has established through long-term community-based projects is a result of the reliability, flexibility and transparency of its approach, which aims to create a high level of ownership of the measures implemented, trust and commitment from communities. This has led the Swiss Red Cross to strengthen its policy of promoting and implementing community-based mitigation and bioengineering in terms of (i) providing conceptual support and capacity building through learning events and (ii) focusing more closely on community-based mitigation and green measures in policy dialogue.

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Compliance with ethical standards

Disclaimer The contents of this article reflect the views of the authors, who are responsible for the facts and the accuracy of the data represented herein.

Abbreviations

CBA, **Cost–benefit analysis; CBDRM, community-based disaster risk management,** *CODEL*, **Community local emergency committees;** *DR*, **Disaster resilience; HRC/SRC Honduran and Swiss Red Cross;** *ICL*, **International Consortium on Landslides;** *IFRC*, **International Federation of the Red Cross/Crescent;** *IUGS*, **International Union of Geological Sciences;** *LDR*, **Landslide disaster risk;** *LRR*, **Landslide risk reduction;** *SB*, **Soil-bioengineering;** *UNISDR*, **UN International Strategy for Disaster Risk;** *UNDP*, **United Nations Development Program;** *WASH*, **Water, sanitation and hygiene;** *WLF*, **World Landslide Forum;**

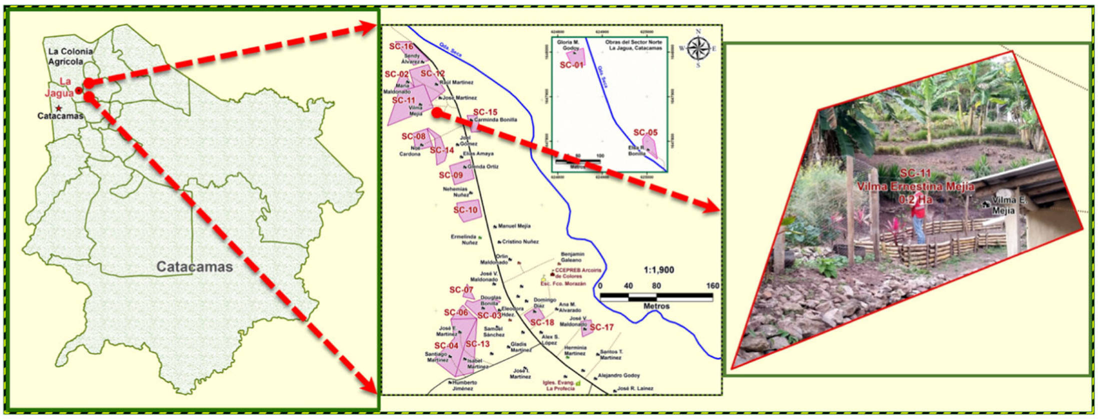
Sitio crítico N° 11. Comunidad de La Jagua, municipio Catacamas.

Cruz Roja Hondureña

Con el apoyo técnico y financiero de:

Cruz Roja Suiza

FECHA DE INTERVENCIÓN
04/04/2016
PROPIETARIO S.C
VILMA ERNESTINA MEJIA



COORDENADAS DEL S.C	ÁREA S.C	ELEMENTOS EXPUESTOS	AMENAZA	NIVEL DE RIESGO
625131 1647363		1 VIVIENDA (2 MUJERES)	DESLIZAMIENTO E INUNDACIÓN	ALTO

DESCRIPCIÓN DEL SITIO CRÍTICO

La vivienda se localiza en la comunidad de La Jagua, la cual fue construida en las faldas de una ladera inestable con una pendiente aproximada de 55% y se identificó durante el proceso de elaboración del Estudio del Riesgo del municipio

El aprovechamiento inadecuado del sitio sin la mínima implementación de técnicas de conservación de suelo, la pendiente alta y las intensas precipitaciones que se registran durante la época lluviosa entre otros contribuyen a la inestabilidad de la ladera e incrementar el riesgo de afectación de los elementos expuestos.

Por otro lado la escorrentía generada y la erosión hídrica producida contribuyen a la perdida de fertilidad del suelo, lo que combinado con la falta de espacios adecuados para la producción, limiten la posibilidad de contar con huertos familiares que contribuyan a solventar parte de las necesidades cotidianas de la familia.

En función de lo anterior se ha tomado a bien realizar la intervención de este sitio considerando los enfoques y tecnologías que utiliza el proyecto y que generan un cambio al pasar de un escenario de riesgo a un escenario de oportunidades.

TECNOLOGÍAS UTILIZADAS

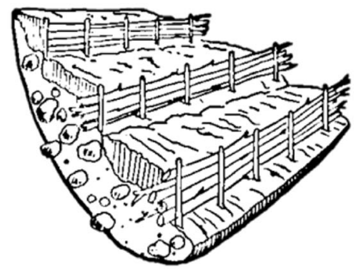
* BARRERAS VIVAS DE VALERIANA Y ZACATE LIMÓN
* VALLAS DE RETENCIÓN CON BAMBÚ
* MURO DE CONTENCIÓN DE PIEDRA
* SISTEMA DE DRENAJE CON ACERA

Barreras vivas, vetiver y zacate limón *Técnica que consiste en sembrar hileras de planta perennes o de crecimiento denso en contra de la pendiente. Esta técnica disminuye la velocidad del agua de lluvia que se escurre por la superficie del suelo, aumentando la filtración de la misma reteniendo nutrientes.*

Fig. 6 Example of fact sheet created for each of the 230 identified and treated critical sites

Valla de Retención Horizontales con Bambú: *Se utilizan para contralar los sedimentos y detener la erosión de las laderas. Se construyen a partir de tallos/troncos de bambú muerto, reforzadas con estacas germinables que van a seguir creciendo una vez colocadas en el suelo. De esta manera evitar la erosión de su estructura física hasta que las plantas establecidas puedan proporcionar protección contra la erosión permanente.*

Además son útiles para reforzar zonas de pendiente inclinadas y taludes de relleno, donde el exceso de humedad podría generar deslizamientos rotacionales



El sistema de drenaje con acera: *permite desalojar el agua que no se logra infiltrar o retener en la parte alta de la ladera a través de las barreras vivas o las vallas de retención, evitando que las paredes de adobe absorban humedad.*

INVERSIÓN REALIZADA	
Medidas Utilizadas	**Valor en Lps.**
BARRRERA VIVAS EN TERRAZAS (VETIVER 188 ML)	7,056.00
BARRERAS VIVAS (ZACATE DE LIMÓN 45.5 ML)	546.00
VALLAS DE RETENCIÓN (BAMBU 22 ML)	5,415.30
MURO DE RETENCIÓN (PIEDRA 17 ML)	6,484.48
DRENAJE DE CONCRETO	5,050.00
ABONERA	750.00
OTROS (FRUTALES, ECOFOGÓN, KIT DE HERRAMIENTAS)	6,067.00
TOTAL	**31,368.78**
INVERSIÓN DE LA FAMILIA	**6,850.00**
INVERSIÓN DEL PROYECTO	**24,518.78**

RESULTADOS OBTENIDOS

Se ha reducido la cantidad de humedad a nivel de la vivienda expuesta, no se han registrado en dos años, deslizamientos ni daños a la infraestructura. Obteniendo otros beneficios adicionales como: belleza escénica, huerto familiar y medicinal con producción sostenible, entre otros.

El Sitio Crítico fue construido con el aporte del proyecto juntamente con los beneficiarios. Así mismo el mantenimiento del sitio crítico se realiza con la mano de obra de los beneficiarios generando el involucramiento y empoderamiento en el manejo adecuado y sostenible del mismo.

*De izquierda a derecha, imagen 1. Barreras vivas con vetiver, imagen 2. Drenaje con acera , imagen 3. Muro con piedras y huerto medicinal

Fig. 7 Fact sheet

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