Nature Based Landslide Risk Management Project in Sri Lanka

Nature-based Solutions (NbS) for Landslide Risk Management

Policy Brief (Summary)

September 2020

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Executive Summary

In recent years, nature-based solutions (NbS) for landslide risk mitigation have become a popular measure and are being effectively used in many Asian countries, such as Hong Kong, China, India, Nepal, Pakistan and Thailand. The experiences in those countries show that not all types of landslides can be mitigated through NbS alone. NbS will always help to enhance the effect of other mitigation measures such as conventional engineering measures.

In view of the above, the World Bank launched an Analytics and Advisory Services project in Sri Lanka on Nature-Based Landslide Risk Management, with the partnership of the National Building Research Organisation (NBRO), the mandated agency for landslide risk management in Sri Lanka. The project aims to raise awareness and deepen the knowledge on the role of nature-based and hybrid (combined nature-based and conventional engineering measures) solutions for landslide risk management within the country. The Asian Disaster Preparedness Center (ADPC) was roped in as an implementing partner to support and technically guide the project execution.

This policy brief summarizes the background, advantages, application aspects, and major challenges of NbS application for landslide risk management and suggestions for overcoming those challenges. The technical brief aims to create awareness and knowledge dissemination on NbS for landslide risk mitigation.

Abbreviations

BOQ	Bills of Quantities
NBRO	National Building Research Organisation
NbS	Nature-based Solutions
TNGA	Training Needs and Gaps Assessment

1. Introduction

The International Union for Conservation of Nature (IUCN) defines nature-based solutions (NbS) as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (IUCN 2016, 166). They can provide sustainable, cost-effective, and flexible approaches for disaster risk reduction. The Sendai Framework for Disaster Risk Reduction 2015–2030 highlights the importance of NbS as an effective technique to reduce disaster risk, adapt to climate change, and strengthen community resilience.

NbS can also help to achieve climate resilience by enhancing adaptive capacity and providing a vital link between sustainable socioeconomic development and biodiversity and ecosystem conservation. NbS can either be completely "green" (consisting of only ecosystem elements) or "hybrid" (combining ecosystem elements with conventional engineering measures or gray infrastructure, which refers to constructed structures often made out of concrete) (World Bank 2017).

In this report, nature-based landslide risk management involves the use of ecosystem elements, mainly vegetation, to mitigate slope instabilities. In this context, NbS is an umbrella term for various ecosystem-based approaches. The most common NbS approach to reducing landslide risk is "soil bioengineering": the use of "live cuttings and rooted plants imbedded in the ground in various arrangements and geometric arrays, in such a way that they serve as soil reinforcements, hydraulic wicks (or drains), and barriers to earth movement" (Gray and Sotir 1996, 3).

2. How Vegetation Can Improve Slope Stability and Prevent Surface Erosion?

In recent years, the depletion of forest cover in Sri Lanka's upper catchment areas seems to have exacerbated climate change, global warming, and the associated consequences (World Bank 2019d). This realization has focused attention on conservation of the upper watershed areas and ecosystem protection to mitigate the climate change impacts and related challenges from increasing hydrometeorological hazards—particularly, heavy rains and associated floods and landslides. Communities have traditionally believed that vegetation cover—forests, homestead orchards, and the like—help to prevent and mitigate these effects. Hence these sustainable ecosystem practices have long been considered proactive measures that not only prevent natural hazards but also enhance food and livelihood security.

2.1 Traditional Practices from Ancient Sri Lanka

Among the many indigenous traditional practices from ancient Sri Lanka cited as sustainable ecosystem solutions is the "Kandyan Home Garden" (photo 1). As practiced by the ancient up-country villages, it offers multiple social, economic, and environmental benefits, including prevention of natural hazards (Pushpakumara et al. 2016).

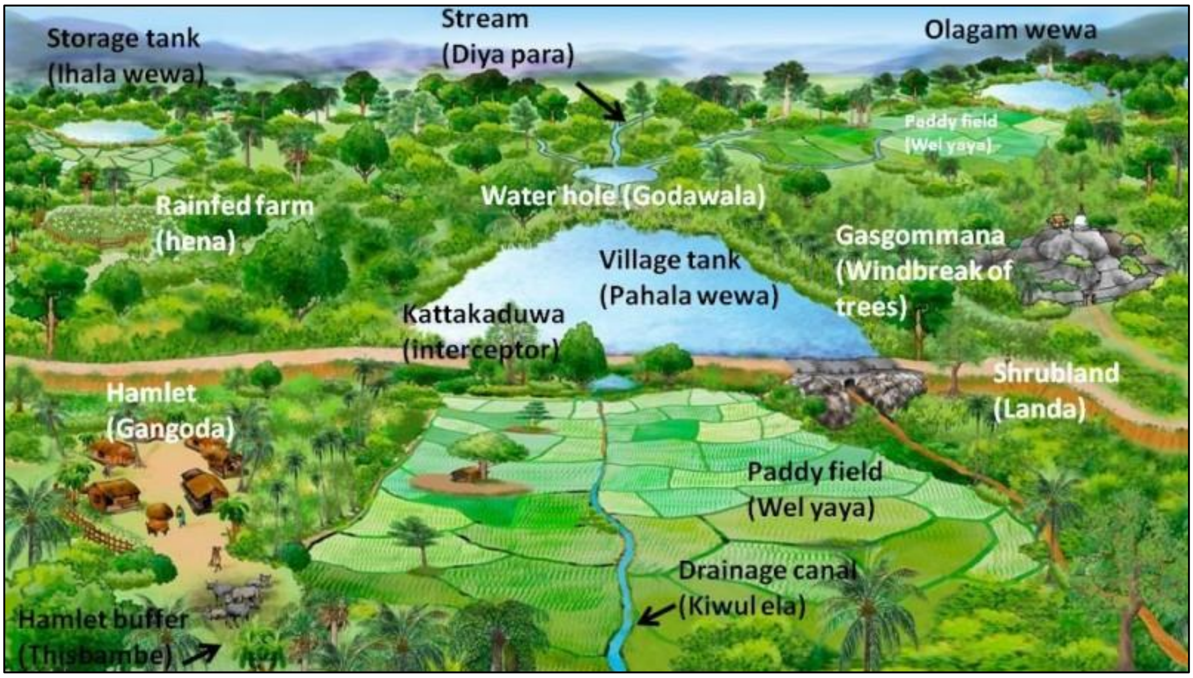
The mixed-vegetation systems found in ancient Kandyan Home Gardens provided vital services and consisted of a set of special characteristics to prevent hazards such as landslides, soil erosion, and the like. Because such home gardens were on higher ground, the flood and drought risk were also kept to a minimum. The system gradually ceased to exist in the 20th century after the British introduced new commercial crops such as coffee, tea, rubber, coconut, and so on.

Photo 1 A Typical Kandyan Home Garden in Sri Lanka

Source: Pushpakumara et al. 2016. © D. K. N. G. Pushpakumara.

A similar example of traditional knowledge was the series of connected village irrigation tanks organized within a micro-watersheds in ancient Sri Lanka called "Ellanga Gammana" (roughly "Cascaded Tank Village"), which contributed to efficient water management through conservation of upper catchment areas. Farmers from the dry zone in the North Central, North Western, and Uva provinces of Sri Lanka—who over millennia created, developed, and maintained the system of cascaded ponds and tanks—considered ecosystem protection as integral to the societal development process, which ensured sustainable rural development, maintained continuity and improvement of the country's food and livelihood security, and minimized the impact of natural hazards (Geekiyanage and Pushpakumara 2013; Somaratne et al. 2005). As shown in Figure 1, irrigation tanks are often not isolated tanks but a part of larger interconnected system of tanks called a "tank cascade system" that connect a series of tanks with their own microcatchments. (For example, the Malwathu Oya basin in North Central Province has 179 associated cascade systems.)

Figure 1 Schematic Diagram indicating Components of the Ancient "Ellanga Gammana" (Cascaded Tank Village), Sri Lanka



Source: "Components of a Village Tank System," Ecological Restoration of Kapiriggama Cascade Tank System web page, IUCN Sri Lanka, 2016. ©International Union for Conservation of Nature (IUCN) Sri Lanka. Reproduced, with permission, from IUCN Sri Lanka; further permission required for reuse.

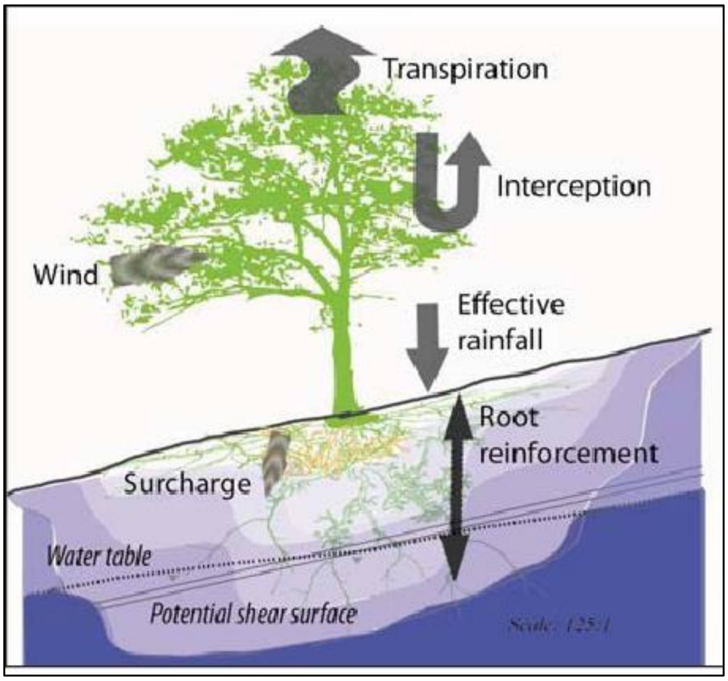
2.2 Relevance of Ancient Practices to Modern Nature-based Solutions

Comprehensive scientific analyses to determine how these traditional practices reaped societal benefits have documented the contributions of vegetation cover to sustenance of soil fertility, increased productivity of agricultural lands, and protection of natural ecosystems and biodiversity, among other benefits. The analyses also find that these key features of nature-based ancient practices, within upper watersheds, are associated with slope protection, prevention of soil erosion, and flood and drought risk mitigation.

The most important characteristics of vegetation cover concern its mechanical and hydrological properties and processes (figure 2). The primary mechanical effects of vegetation on slope stability are reinforcement of soil by roots and protection of the soil surface from surface erosion as well as gully formation (Forbes and Broadhead 2013).

Roots of certain trees and plants penetrate more deeply than others and may pass through potential slip surfaces, thereby anchoring the soil. The mechanical properties of tree roots that improve slope stability are associated with the physical characteristics of the root system, such as root anchoring capacity, root tensile strength, soil-root friction, root elastic strength, root cross-sectional area, lateral friction, and capacity for buttressing and anchoring (Fatahi, Khabbaz, and Indraratna 2010; Forbes and Broadhead 2013).

Figure 2 Influence of Trees on Slope Stability



Source: Forbes and Broadhead 2013. ©Food and Agriculture Organization of the United Nations (FAO). Reproduced, with permission, from FAO; further permission required for reuse.

The effectiveness of vegetation in protecting slopes depends on the architecture of the root system, rooting depth relative to potential failure planes, and the roots' density and distribution. Branching, root elasticity and strength, and root-soil cohesion also affect the roots' reinforcement properties. Root depth and distribution are the most important properties for slope stabilization because the deeper the tree roots extend, the more planes of weakness they will pass through. However, the root-soil cohesion decreases rapidly as water saturation increases; roots will more commonly slip rather than break, especially under saturated conditions. In shallower soils, tree and shrub roots may anchor the soil mantle to the slope and increase shear strength (Forbes and Broadhead 2013). In summary, the extent to which roots can strengthen the soil depends on the physical and chemical composition of the soil and the strength and morphology of the root.

The beneficial hydrological effects of vegetation relate to its ability to extract water from the soil and intercept rainfall, allowing rain to evaporate before reaching the soil. Vegetation cover can help to drain excess water from the slope through different planting configurations that enhance drainage, hence avoiding saturation and slumping of earth materials. Vegetation also helps reduce pore-water pressures within the slope by extracting water from the roots and transpiring through the leaves. These effects reduce soil moisture content and delay the onset of soil saturation levels that trigger landslides.

Different species also have different interception capacity. Some trees have more extensive root systems than most other plants and can extract moisture from the soil at considerable depth. Generally, most roots are in the top meter of the soil; taproots and sinkers extend much deeper (Forbes and Broadhead 2013).

3. Potential of NbS for Landslide Risk Management in Sri Lanka

NbS can be used foremost as a proactive measure for climate change adaptation and for reducing the impact of resulting weather extremes that lead to hazard events such as landslides, floods, drought, soil erosion, and wildfire. In line with the sustainable practices of ancient Sri Lanka as well as the favorable benefits and properties of vegetation cover, as noted earlier, NbS has a reasonable scope for reducing risk from such hazards.

Such proven NbS, by increasing the natural forest cover and the forest plantations, could provide sustainable, cost-effective, and environmentally friendly measures that can reduce the effect of climate change, climate variability, and associated hazards. In addition, the expansion of areas covered with a wide range of non-forest tree resources—in the form of home gardens and rubber and tea plantations—can be a suitable substitute if farmers can be encouraged to restore the areas where deforestation has taken place in recent years. And while NbS provides a barrier to wildfire expansion, it also can be effectively applied for rehabilitation and reforestation of depleted forest patches in water catchment areas left unattended, because such areas are vulnerable to the aforementioned array of hazards.

For landslide risk mitigation, Sri Lanka has largely relied on engineering solutions, and the application of nature-based and hybrid approaches for landslide risk management remains limited. In line with the demonstrated successes of NbS in many Asian countries (Dhital, Kayastha, and Shi 2013; Fatahi, Khabbaz, and Indraratna 2010), risk-informed NbS can be implemented in Sri Lanka as an effective future measure for mitigating landslide hazards—stabilizing the most-vulnerable slopes and (to a great extent) preventing soil erosion.

3.1 Soil Bioengineering Techniques

Although not all types of landslides may be mitigated through NbS, there are several possible applications. For example, soil bioengineering techniques can be effectively used for mitigating risk in larger vulnerable areas; areas that have a potential for shallow, slow-moving landslides; and larger areas abandoned after past landslides that show signs of reactivation and have a high landslide hazard potential (World Bank 2019a). Such areas generally become vacant because of landslide-associated relocation, and NbS can be effective in rehabilitating such areas and ensuring long-term stability. The role of vegetation or soil bioengineering techniques to manage deep-seated landslides is considerably limited, but reducing the soil moisture by tree roots can still help avoid build-up of excessive soil water pressure.

Bioengineering techniques not only offer hazard-risk mitigation and economic benefits but also contribute to sustainable development practices—enhancing the aesthetics of the environment and reducing the ecological impacts of construction, maintenance, and operations. Specifically, soil bioengineering techniques are used for greening the areas and improving the aesthetic appearance (natural beauty) of the overall slope in addition to increasing slope stability. In urban areas, where NbS are used as a stand-alone practice or hybrid solutions are implemented to improve slope stability, it is proven scientifically that it helps to counter the urban heat island effect (ADB 2016).

3.2 Hybrid Solutions

The studies carried out under the current World Bank-sponsored, NBRO-implemented "Nature Based Landslide Risk Management" project (World Bank 2018a, 2018b, 2019a, 2019b, 2019c) show that landslide hazards can be mitigated cost-effectively when conventional engineering solutions are combined with NbS using appropriate vegetation (hybrid solutions), as shown in photo 2.

Photo 2: Hybrid Solutions Used in Padiyapelella Landslide Mitigation Process, Sri Lanka

a. Before implementation of any mitigation measure	b. After implementation of conventional engineering measures	c. After implementation of NbS measures

Source: ©National Building Research Organisation (NBRO). Reproduced, with permission, from NBRO; further permission required for reuse.

Note: "Hybrid" solutions refer to conventional engineering solutions that are combined with nature-based solutions using appropriate vegetation.

Such hybrid solutions are more sustainable than conventional engineering solutions and can be introduced to selected sites to improve the stability already achieved through engineering measures. They can also help to address the challenges arising from long-term maintenance. It is anticipated that the impacts of NbS will grow exponentially with time. As root systems become more developed and penetrate more deeply, the vegetation cover can be expected to further stabilize the slopes while the tree cover and effective root system further reinforce the subsurface formations.

Southeast Asian countries such as Hong Kong, China; Malaysia; and the Philippines have employed vegetation in ground treatment for fragile slopes more than other countries (Fatahi, Khabbaz, and Indraratna 2010). The current best practices in such countries show that NbS is among the most suitable landscape treatments for improving the stability of man-made slopes and engineering works on natural terrain, also providing added value in terms of enhancing the slopes' appearance and making them ecologically acceptable and sustainable.

4. Major Challenges to NbS Application in Sri Lanka for Landslide Risk Management

There are several significant challenges in promoting NbS for landslide risk mitigation in Sri Lanka. Among them, landslide risk mitigation designers lack confidence in the use of vegetation for slope stabilization. A lack of knowledge about soil bioengineering and landscaping measures to stabilize unstable slopes often limits designers in applying such solutions in landslide countermeasures. To make the situation worse, the government and donor community involved in landslide risk mitigation interventions have shown limited interest in allocating more resources for associated research, capacity building, and knowledge enhancement of the landslide professionals to address the capacity gaps concerning NbS application in landslide risk management.

The general perspective is that properly designed and installed vegetative portions of systems should become self-repairing, with only minor maintenance to maintain healthy and vigorous vegetation. Soil bioengineering frequently mimics nature by using locally available materials and minimal heavy equipment and is an inexpensive way to treat slope stabilization. However, because of poor understanding of suitable plant species that can be used for improving strength, the properties of subsoil formations have been one of the main areas of concern.

Moreover, NbS are often unique to particular areas—and context-specific. The success of such measures often depends on the contextual setting in terms of ecosystems, climate zones, elevations, the geo-environment, and so on (Cohen-Shacham et al. 2016). This highlights the unique nature of NbS in application and hence the need for specialized judgment in design and planning not only by traditional experts such as geotechnical engineers and engineering geologists but also by others such as agronomists, landscape architects, botanists, and land use planners. Without such expertise, the selection and use of appropriate plants and vegetation for soil bioengineering applications could be overlooked because of the unavailability of proper studies on suitable plants and criteria for selecting different plant species for the diversity of services expected from the vegetation used for stabilizing slopes (Ganepola et al. 2019; World Bank 2019a, 2019e). Table 1 compares the NbS, hybrid, and gray approaches to mitigation practices.

In addition to consideration of plants' general and specific qualitative features, there has been an increasing focus on using plant traits as screening criteria to help engineers identify suitable species for slope stabilization. Geotechnical engineers who wish to apply soil bioengineering techniques need to identify the plants that contribute most to the mechanical strength that will increase stabilization through bioengineering. Therefore, if NbS is to be used freely by landslide professionals as a mitigation technique—whether as a stand-alone practice or as a hybrid measure—several challenges must be addressed:

- The dearth of (how-to) manuals, guideline documents, and the like featuring the plant characteristics and suitable screening processes for selecting appropriate plants
- Development of appropriate bioengineering and landscaping measures
- Absence of or limited capacity for qualitative assessment of the impacts and contributions of vegetation cover.

Table 1 Comparison of NbS, Hybrid, and Gray Solutions for Landslide Risk Management

Mitigation measure(s)	Characteristics	Typical applicability	Unit cost range	Socioeconomic and environmental aspects
Nature-based solutions (NbS)	Predominant focus is on soil bioengineering techniques. Stability will increase with time (according to the	More advisable for larger areas in low-risk nonresidential areas	Moderate if locally available materials and minimal heavy equipment are used Inexpensive if designed as self-	More appealing aesthetic appearance Environmentally friendly technique

	plants' rate of growth). Frequent maintenance is necessary.		repairing, with only minor maintenance	Community participatory outreach Can help counter urban heat island effect
Hybrid solutions (gray)	Conventional civil and geoengineering measures are mixed with soil bioengineering techniques. Soil bioengineering is used to increase stability and erosion control. Frequent maintenance is necessary.	Can be applied in high-risk residential areas (for protection of infrastructure) as well as in any medium- to high-risk nonresidential areas	High to very high (because routine maintenance needs to be factored in)	More appealing aesthetic appearance More environmentally friendly Can involve community participation Can help counter urban heat island effect
Gray solutions	Stability is gained through application of conventional civil and geoengineering measures. Only minor maintenance is required.	Can be applied in high-risk residential areas (for protection of infrastructure) as well as in any medium- to high-risk nonresidential areas	Moderate to high	Not as aesthetically appealing Less environmentally friendly Cannot blend easily with the surroundings

Note: "Hybrid" solutions combine ecosystem elements with conventional engineering measures or gray infrastructure.

5. Training and Capacity-Building Requirements for the NBRO and Other Practitioners or Contractors

The World Bank's Global Facility for Disaster Reduction and Recovery (GFDRR) noted in 2016 that, despite its significant investment in boosting developing countries' capacity to understand emerging disaster risks, reduce vulnerabilities to natural hazards, and adapt to climate change, "capacity development is often considered secondary to larger activities" (GFDRR 2016).

To promote NbS as an appropriate measure for landslide risk management, it is essential to have a systematic approach to building the capacity of landslide professionals. Without adequate capacity and mechanisms for implementation of NbS, it will be impossible to achieve the expected results. The present project initiated a Training Needs and Gaps Assessment (TNGA) survey to understand existing approaches to landslide disaster risk management; determine the level of application of nature-based landslide risk management activities; and identify the competencies, knowledge, skill gaps, and organizational expectations for capacity development. The TNGA survey revealed that, to boost the confidence of landslide professionals in application of nature-based and hybrid solutions for mitigating landslide risk, several specific needs and capacity-building efforts must be designed (World Bank 2018a):

- A framework for screening the vulnerable areas and an approach for site selection
- A numerical modeling process for evaluating the impact of vegetation in slope stabilization, identifying the factors that help strengthen the subsurface formations, and quantifying the impact of soil bioengineering techniques in stabilizing the vulnerable slope
- Procedures related to instrumentation, monitoring, and evaluation of impacts during the postimplementation period
- A methodology for selecting plant species whose features and characteristics match the requirements identified through modeling, such as root reinforcement effects, capacity to improve the hydrological regime, and so on
- Design aspects, including a sequential process in preparing a landscape plan for specific site and plan implementation (such as preparation of bills of quantities [BOQs], work plans, budgeting, and the like). A BOQ is a document used for tendering in the construction industry that itemizes materials, parts, and labor (and their costs).

The common finding, in this regard, is that it is essential to adopt a strategic approach to developing the required capacities—an approach that includes conduct of related research toward addressing the information and data gaps as well as initiation of a more collaborative, coordinated effort to deal with increasingly limited resources. The planned project-initiated training under different thematic areas will focus on theoretical understanding of the subjects, knowledge gaps, skills, and competencies needed to promote NbS for landslide risk management.

6. The Way Forward: Future Opportunities for Breaking the Barriers

- *Build the Capacity of Professional Staff Engaged in Landslide Risk Reduction*

In keeping with the findings of the TNGA survey, the project team organized several training events with the participation of invited resource persons from various institutions and countries that have a wider experience in application of NbS in landslide risk management (table 2). The thematic areas selected for training were

- "Application of Google Earth Engine (GEE) Platform for Land Cover Monitoring and Satellite-Based Rainfall Estimation";
- "Nature Based Landslide Disaster Risk Management (Part 1)," covering the theoretical aspects; and
- "Nature Based Landslide Disaster Risk Management (Part 2)," covering the practical aspects, such as slope stability analysis, approaches to stabilization of unsaturated slopes through soil

bioengineering measures, numerical modelling, and quantitative assessment of vegetation's effectiveness in protecting slopes.

The training events were organized to be participatory, providing mostly hands-on experience on various aspects so participants could interact freely with the resource persons. The participants were selected from the NBRO, universities, and other institutions involved in landslide risk mitigation-associated functions, including the Road Development Authority, Land Use Policy Planning Department, Urban Development Authority, local governments, and so on. Further, a study tour was organized for a group of NBRO scientists to get firsthand experience of some implemented NbS measures in Thailand's Chiang Rai Province (World Bank 2019d).

Table 2 Training Sessions Conducted under the Project

No.	Name of training	Period	No. of participants
1	Application of Google Earth Engine (GEE) Platform for Land Cover Monitoring and Satellite-Based Rainfall Estimation	October 1–4, 2018	32
2	Nature Based Landslide Risk Management Training (Part 1)	November 12–13, 2018	28
3	Study tour to Bangkok and Chiang Rai, Thailand, to study different types of implemented nature-based solutions	February 6–10, 2019	4
4	Nature Based Landslide Risk Management Training (Part 2)	May 30–31, 2019	34

- *Deliver Guidelines for Landslide Risk Management Planning through NbS Application*

It will be useful to deliver a guidelines document on NbS applications for landslide risk management planning. The guidelines would benefit landslide risk management professionals, other relevant stakeholders, and individual practitioners engaged in the design, implementation, and monitoring of NbS and hybrid solutions for landslide risk mitigation as well for erosion control under a range of physical conditions. The nature-based, and especially hybrid, solutions for landslide risk management that will be presented in the document will be chosen specifically to satisfy the needs of stakeholders in Sri Lanka (Ganepola et al. 2019; World Bank 2019a).

It is expected that the guidelines document will be open-source, hence available to a wider audience, and will serve as a reference document for those interested in undertaking NbS in landslide risk mitigation. It will also help in sustaining the capacity built through the project.

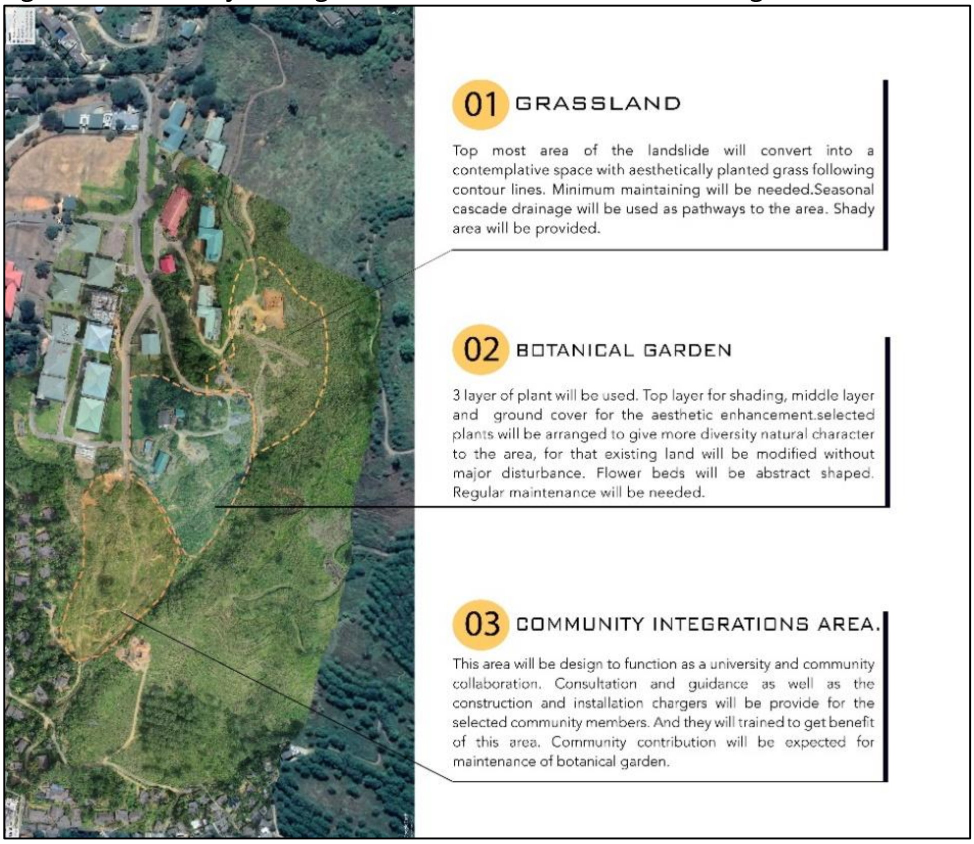
- *Undertake Pilot Projects Covering NbS and Hybrid Techniques to Demonstrate Success*

NbS cannot mitigate risk in all cases of landslides. Some solutions may become technically unsuitable and pose limitations in obtaining expected results. In other cases, it is essential to consider other aspects (such as cost-effectiveness, socioeconomic conditions, the risk environment, and so on) before selecting NbS as the most appropriate mitigation option. Therefore, specific situations must consider the most appropriate candidate sites for application of NbS for mitigation of landslide risk (World Bank 2019a).

The project team, in consultation with the NBRO, selected two sites for pilot demonstration and for developing a comprehensive landslide risk management plan (World Bank 2019b). The two selected sites had the most favorable conditions for application of NbS, and therefore comprehensive landslide risk management plans were prepared for both: Badulusirigama in Badulla District (figure 3) and Galaboda in Ratnapura District.

These two pilot projects helped to demonstrate the site selection process; planning process; numerical modeling to quantify the contributions of vegetation cover to overall stability; selection of suitable plant species for different areas depending on SWOT (strengths, weaknesses, opportunities, threats) analysis of different zones covering the slope; design of mitigation plans using soil bioengineering and hybrid solutions; and implementation aspects such as preparation of the BOQ, work plan, and budget.

Figure 3 Preliminary Zoning Plan for NbS Pilot Site in Badulusirigama, Badulla District, Sri Lanka



Source: World Bank 2019b.

Note: NbS = Nature-based Solutions.

- *Promote Community Projects to Encourage Community Involvement and Assistance in Maintenance to Reduce Cost*

When any application of NbS is discussed, the postimplementation maintenance issue often comes up as a major concern, which also adds to the challenge of limited resource availability. Usually plants need a certain maintenance period, and during dry weather periods, survival will depend on the availability of a conducive environment for the plants. In some economies—such as Hong Kong, China; Nepal; and Thailand—these challenges are often addressed through active community participation in maintenance work, usually as a voluntary contribution. In return, the community is given an opportunity to grow commercial crops or is allowed to recover costs through different community programs using raw materials obtained from the project site.

During the process of mitigation planning and design, the project team had discussions with Uva Wellassa University and members of the community living below the landslide area. The idea was to explain the planned activities and the reasons for mitigation interventions while also obtaining the views of the university and the members of the community. The university representatives felt that, if they are allowed, they are willing to engage in monitoring activities and related research. During the meetings, the community members were provided with certain options for community projects. For example, they are familiar with lemongrass cultivation and extraction of natural lemongrass oil. Hence, during zoning, the project team realized that some areas can be allocated for community projects involving lemongrass oil production—an idea supported by the university.

Each application of NbS brings the potential of such innovative approaches to fulfill the maintenance requirement and make it a cost-effective operation. These opportunities need to be explored and experimented with.

- *Increase Donor Attention to Meeting the Resource Gaps*

There is a belief that healthy and diverse ecosystems are also more resilient to extreme events because they act as natural buffers to climate-related shocks and stresses. In so doing, they help to build the climate resilience of the most vulnerable and contribute to the sustainable reduction of poverty and food insecurity. NbS thus play a vital role in building resilient communities, ecosystems, and economies by protecting, sustainably managing, and restoring natural or modified ecosystems.

The worldwide donor community is making positive contributions by implementing projects to promote climate change adaptation, and it should be encouraged to support application of NbS as a proactive, cost-effective, and sustainable mechanism for reducing climate change impacts and disaster risk.

- *Create Awareness of NbS Advantages*

Unpredictable extreme weather events associated with rising global temperatures and changing precipitation patterns—coupled with both gradual and nonlinear changes to ecosystems—compel a renewed focus on the planning of disaster risk reduction and adaptation measures. Rather than creating or maintaining a risk environment that exacerbates disasters, governments can use disaster risk reduction and adaptation strategies to create an environment that promotes human well-being and security. The application of NbS, as a proactive measure as well as a mitigation tool, is useful for improving the risk environment and is one of the ways to support more favorable coexistence of the natural and built environments.

While targeted capacity-building programs on NbS application for risk management serve the professionals, programs to raise awareness can help drastically in reaching nonprofessional stakeholders. These stakeholders need to have a good understanding of the ways of coping with and adapting to the rapid changes, complex situations, and challenges associated with considerable uncertainty about the future. Hence it is useful to present the positive aspects and long-term benefits of NbS, using conventional media channels as well as unconventional mediums such as social media to reach them effectively and efficiently.

- *Promote Collaborative Research Programs (with Like-Minded Institutions)*

The project team assessed existing policies and the relevant legal, regulatory, and institutional frameworks to understand the degree of relevance and applicability of NbS for landslide risk management. The policy study revealed a number of relevant laws, regulations, and policies that the government of Sri Lanka has introduced, dating from the colonial era to the present. Most of these laws, regulations, and policies are connected with overlapping responsibilities and approaches to address the issues of environmental protection and conservation. Under the current legal, regulatory, and institutional frameworks, multiple government institutions bear the responsibility of protecting and conserving different environmental resources in Sri Lanka and are currently undertaking NbS for different purposes (Basnayake et al. 2019).

The study also revealed that it is appropriate to undertake a collaborative approach to the application of NbS as one of the options for landslide risk management. Such a strategy suggests that the mandated agency for landslide risk management, the NBRO, collaborate with like-minded institutions on joint research programs, capacity building, and awareness raising and promotion of NbS.

- *Integrate NbS into Program Budgets and Donor Appeals to Meet Resource Constraints*

NbS are known to be cost-effective and environmentally friendly landslide risk management practices. They can be successfully applied, both with conventional engineering measures and as alternatives to such measures in selected locations where vegetation can improve slope stability. In addition to the cost advantages, the long-term effectiveness of NbS in mitigating landslide risk, possible application in larger vulnerable areas, social benefits, and environmental contributions to ecosystem resilience building and maintenance are of high importance to the country.

Such facts favor promotion of NbS as a good practice for climate change adaptation and disaster risk reduction. Therefore, the cost aspect can easily be managed, and resource constraints could be overcome through integration of NbS into new or existing landslide risk management programs.

The government of Sri Lanka is making considerable effort to get donor assistance and to allocate necessary resources for mitigation of landslide risk associated with transport infrastructure, health facilities, and the education system—and NbS can be integrated into such projects as a viable alternative to complement current risk mitigation practices. The government is planning to implement larger landslide risk management programs and to collaborate with donors such as the World Bank, the Asian Development Bank (ADB), the Asian Infrastructure Investment Bank (AIIB), and others. To that end, it is essential that donors show positive engagement in supporting NbS for landslide risk mitigation. It would be useful to allocate considerable resources for implementation of demonstration projects and pilot initiatives to promote NbS and boost the confidence of landslide professionals. In addition, some resources can be allocated toward enhancing the knowledge and resource base associated with NbS applications, supporting new research and development programs, and strengthening capacity-building efforts.

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