

Eco-safe Rural Roads assessment

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Contributor: Sanjaya Devkota

Rural roads are important for the communities in the hilly areas of Nepal as they introduce livelihood opportunities at the local level, provide better access to the health care, education and resources. Yet, most of the rural roads in Nepal are unplanned and non-engineered, and these roads are often closed for many months during and after the monsoon. Such roads require huge investments, especially post-monsoon, to clear debris and to keep them operational. In parallel, there is evidence that such roads lead to large number of slope failures and accelerated sedimentation, which degrade the environment and ecosystem services. To remedy such roadside slope failures, eco-engineering practices were tested and demonstrated in partnership with three communities in the Panchase Region of the Nepal's Central-Western Middle Hills. Eco-engineering is a hybrid approach, combining civil engineering works for drainage and slope stability, with the plantation of deep-rooted vegetation. It is one activity contributing to Nature based Solutions (NbS) for the sustainable and long-term operation of the rural roads in the Panchase geographic region.

This paper describes the inter-disciplinary and community-based research, monitoring and evaluation methods applied, including, the establishment of onsite demonstration plots and Rhizotrons in which Key performance Indicators (KPI) analysis of plant species were performed. The results demonstrated the effectiveness of eco-engineering for reducing risk, while creating ecological co-benefits along rural roads (or eco-safe roads) in hilly areas. Based on this research, an 'Eco-safe Rural Road Assessment Framework' was developed, outlining the systematic process to be followed for the design of eco-safe rural roads for more sustainable road construction and maintenance. The ecological engineering practices which are being promoted by this framework have been accepted by communities and could be further implemented by local government bodies and up-scaled in other similar hilly areas around the country.

eco-safe rural roads, eco-engineering, Nepal

[1] 1. Eco-safe Rural Roads - Concept and Definition

Eco-engineering or soil bio-engineering measures encompass the use of vegetation, either alone or in combination with conventional civil engineering structures for control of soil erosion and shallow landslides ^[2]. In Eco-engineering systems, emphasis is given to the environment (e. g. soil, water, air, flora/fauna, society), inert and live construction materials ^[3] to stabilize soil slopes thereby avoiding disruptions. The plant species used in eco-engineering perform an engineering function proven to provide a combination of sustainability benefits such as protection against soil erosion in the short term and the long term stabilization due to the reinforcement effect of the roots on the soil ^{[4][5]}. There is now sufficient research to ^[3] demonstrate that eco-engineering measures are robust enough in many situations to constitute an alternative over civil engineering solutions. Often referred to as 'hybrid'

ecological engineering, soil bio-engineering techniques can be combined with civil engineering measures for the most optimal protection, when they do not cause harm to natural system.

The hypothesis of 'Eco-safe Rural Road' is that the roads should be operational year round to ensure economic activities at local level provide better access to the market, healthcare and education and increased the communities' resilience. While the use of eco-engineering is for safer rural roads, as faulty roads are also dangerous roads and sustainable mitigation of road side slope failures [6]. The eco-engineering approach, using either vegetative or hybrid techniques is a type of NbS [7] [1], which is gaining attention among scientists, professionals and policy makers around the globe. NbS, which includes 'Eco-safe road' approaches, provides sustainable and cost-effective solutions with multiple purposes: reducing environmental degradation and improving livelihoods, thereby addressing climate change adaptation (CCA), integrated water resources management (IWRM) disaster risk reduction (DRR), bio-diversity conservation and public-health. [2][4][5][8][9]

The European Union (EU) has endorsed NbS and is investing heavily in research on NbS through its Horizon 2020 [10] programme which focuses on various ecological engineering techniques, performance measures and policies for the sustainable development and DRR [11]. However, according to Neshover et al. (2017) [12], there is still debate on how to define NbS with questions on the scope of interventions. A review of the literature reveals two definitions conceptualized and elaborated by IUCN and the European Commission (EC). IUCN defines 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*" [13]. The IUCN definition adopted eight foundational principles of endorsement of nature conservation norms, consideration of local natural and cultural contexts, fairness and equity in delivering societal benefits, application at the landscape scale, and a forward-looking attitude in considering the evolution of ecosystems and associated benefits, while EC's define NbS as the cost-effective, locally adapted and resource efficient solutions that are "*inspired by, supported by or copied from nature*" and "*simultaneously provide environmental, social and economic benefits and help build resilience*" by bringing "*more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes*" [14]. Both definitions of NbS recognize nature as a common denominator that can play major role in addressing the societal challenges, CCA and DRR, whereas the IUCN definition is stricter in its definition of what constitutes a natural ecosystem. Both definitions characterized NbS as 'an umbrella' concept of other established ecosystem based approaches [12] such as eco-engineering, Ecosystem-based DRR or Ecosystem-based Adaptation that encompass cost-effectiveness, adaptability, and application of participatory processes, multidisciplinary and evidence-based strategy. [4][8][15][16]

2. Research Strategy

In order to establish the assessment framework specific to the use of eco-engineering for safer rural roads, or 'Eco-Safe Roads' in the Panchase region of Nepal, the research followed a pragmatic approach combining published research and existing best practices. Review of published articles and consultation with the concerned stakeholders such as community people, professionals working in the rural road sector, policy makers and researchers was contextualized through workshops, scoping visits, focused group discussions (FGDs), key

informants interviews (KII) and case studies. Nine semi-structured interviews with the range of stakeholders such as local authorities, engineers, conservation professionals, local non-governmental organizations (NGOs) and members of the community adjacent to the landslide susceptible road sides were conducted in 2013 and 2014 in the Panchase area of Central-Western Nepal. The FGDs and interviews were recorded and main themes and key words were analyzed in order to establish key principles for the development of an assessment framework for establishing 'Eco-Safe Roads'.

The scoping visits (November 15-17, 2013 and April 10-14, 2014) followed by the inception workshop provided useful information for identifying key issues related to landslides in the Panchase region. These included, that the region is highly susceptible to slope failure, not only due to the fragile landscape but also due to highly intense human activities, such as unplanned rural road construction. In conjunction to the scoping visits, the inception workshop identified three road side locations for establishing eco-engineering demonstration sites and locations for the Rhizotrons (Gharel in Kaski, Bhatkhola in Syangja and Tilahar in Parbat Districts). Rhizotron is a root monitoring device [17] established near vertical ($\sim 85^{\circ}$) excavated roadside slopes. The vertical part of the slope was fixed with transparent Plexi-glass and protected by three removable layers of insulating materials. On the upper slope of the Rhizotron, plant species were planted systematically dividing the Rhizotron length in equal divisions. The research was focused on perennial grass species as grasses can be established quickly, spread faster to give good ground cover and contain a high degree of tolerance [18]. The FGD identified seven local grass species: 1) Amriso (*Thysanotana maxima*), 2) Urlo-Khar (*Cymbopogon microtheca*), 3) Napier (*Pennisetum purpureum*), 4) Salim-Khar (*Chrysopogon gryllus*), 5) Kans (*Saccharum spontaneum*), 6) Kush (*Cannabis indica*), and 7) Babiyo (*Eulalioipsis binate*). Although not being a local species Vetiver (*Chrysopogon zizanioides*) grass was also chosen as this species has well known strong and deep root systems [19]. Plantations took place during the early pre-monsoon (April, 2014) to allow the seedlings to develop roots and survive during the intense monsoon rainfall. Plantations before the monsoon requires careful action to maximize the plant survival [20].

Various parameters such as species survivorship, canopy coverage, root-shoot (dry) biomass, root diameter and depth (shallow < 30 cm and deep ≥ 80 cm) followed by root contribution in soil cohesion were evaluated according to Wu et al. (1979) [21] while root mapping was performed as demonstrated by Bohm (1979) [22]. These parameters were considered to be the Key Performance Indicators (KPIs) of the plant species used. To quantify the KPIs of the species, well-established principles and norms such as Bohm (1979) [23] and Pohl et al. (2011) [24] were adopted. The KPIs were fitted into a Principal Component Analysis (PCA) model to better understand the species quality for the eco-engineering measures. PCA is a statistical procedure that uses an orthogonal transformation of a set of observations and explores the possible correlation among the linearly uncorrelated variables [25].

The inventories of rural roads and landslides in the Phewa Lake watershed were prepared firstly from the Remote Sensing (RS) images and secondly verified through the field survey. To better understand the slope stability and underlying causes, the research was designed to implement physically based infinite slope stability model according to Chae et al. (2015) [26]. For this purpose, a sub-set of Panchase mountain region, the Phewa Lake watershed ($\sim 111.5\text{km}^2$) was modelled utilizing the soil properties, topographical variables derived from the 12.5 meter resolution Digital Elevation Model (DEM) and rainfall intensity, the Landslide Susceptibility Model (LSM) was

established. The LSM was verified adopting Receiver Operating Characteristics (ROC) curve [27][28] utilizing the inventory maps. The research followed a pragmatic approach based on a regional rainfall Intensity-Duration-Frequency (IDF) model, published by Devkota et al. (2018) [29] and the soil depth to bed rock (SDTB) [30] of the Phewa Lake watershed; saturation depth of the soil profile at watershed scale was estimated adopting Green-Ampt (GA) model according to Dingman (2002) [31] while soil physical and hydrological properties were derived either in the field or in the laboratory. The initial moisture content of the soil in the watershed was considered to be 80% due to the antecedent rain water.

As part of the capacity development, a two-day long community-based soil bioengineering training was conducted for the road users adjacent to the demonstration sites. The community participation in the training was gender balanced with nearly equal participation of male and female members. During the training, a dialogue was established with community representatives to discuss the objectives of the demonstration sites and the research. A local road user's group (RUG) was formed for each demonstration site while the RUG adjacent to the road were given to the role of determining which areas to rehabilitate, which area to select for the Rhizotron, which plant (grass) species to select and they were responsible for the seedling collection, plantation, and routine maintenance and weeding. In parallel, expert knowledge was used to design eco-engineering measures and quality control of the construction activities adopted from Devkota et al. (2014) [32]; Howell (1999a) [33]; Howell (1999b) [34] and Gray and Sotri (1996) [4] where applicable. Community people were also engaged and compensated for other construction activities such as roadside drainage, stone wall construction, and stone-rip-rap surface drainage, while local government officials and technical experts were assigned to design and co-monitor the work quality and progress with the community leaders.

In order to address the sustainability of the eco-engineering measures implemented at the demonstration sites, this research attempted to establish knowledge transfer partnership (KTP) as suggested by Raymond et al. [35] among the key stakeholders such as researcher, academician, local government representative and local people. The integration of local knowledge and physical science adopted in the research established the foundation and the conceptualization for the proposed assessment framework. The case studies provided data and experiences for establishing and testing the eco-engineering concept, and its complexities and challenges.

3. Rural Road and Landslides in Phewa Lake Watershed of Panchase Region

Analysis of RS image and field mapping revealed the total length of the rural roads in the watershed was about 305 km through the end of August 2016, with a road density of about 2.74 km/km². The unplanned and non-engineered construction of rural roads is one of the major causes of soil losses [36][37] in the region. There were 373 field validated slope failures events during the period of 2013 to 2016 out of which 199 events were caused by the roads, while the triggering factor was rain. The smallest and largest unit of mapped landslide was ~19 m² and ~0.24 km² respectively. Figure 1, presents the landslides (DMG 2002 and 2013-16) and the rural roads till the end of August 2016 in the Phewa Lake watershed. As of Vuillez et al. (2018) [38] the older landslides were observed

mostly on natural slopes (e. g. forest and cultivated terraces) whereas most of the recent failures were along the roads.

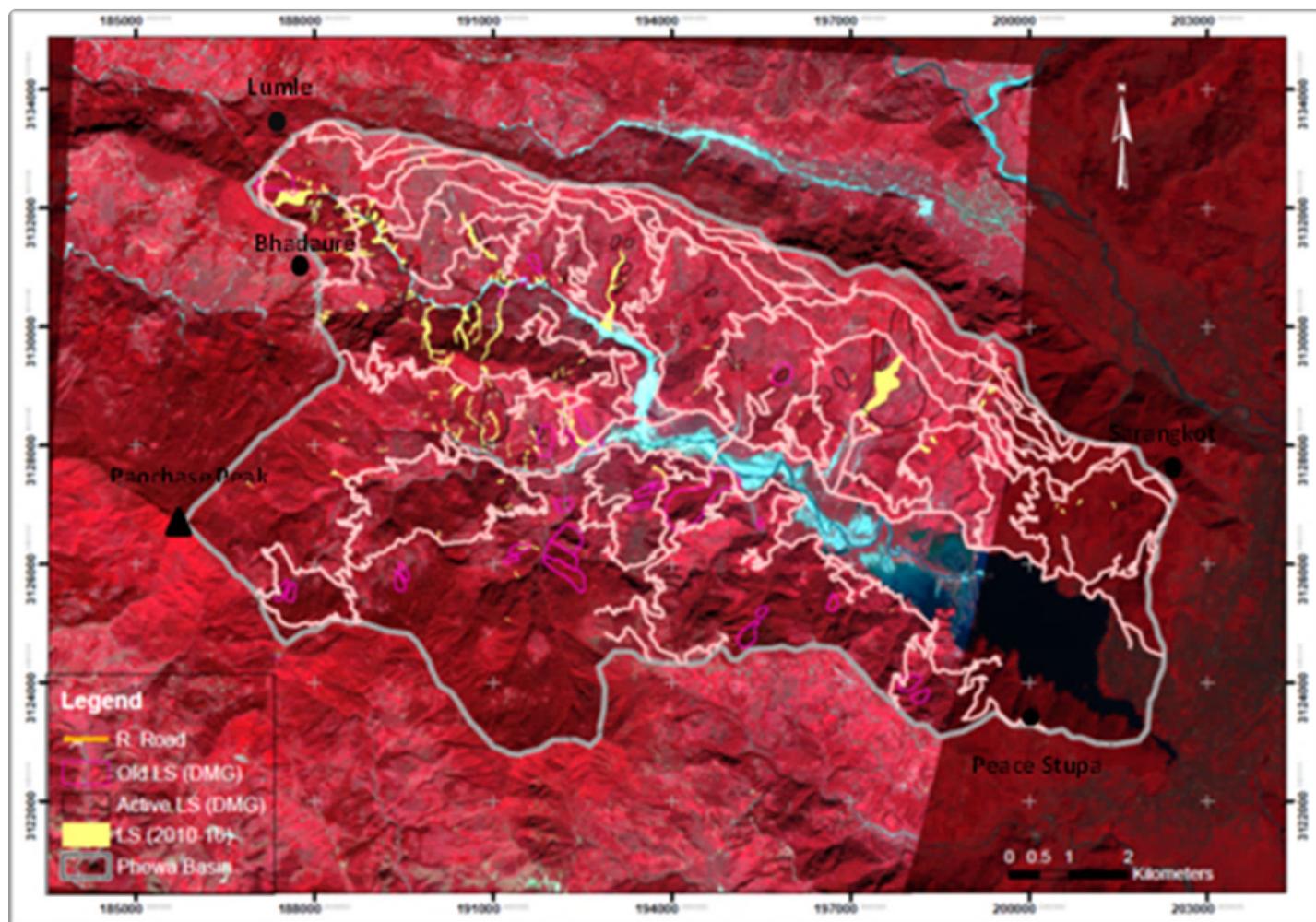


Figure 1. Inventory map (combined) rural roads, landslides (2013-16) and DMG 2002 [39], in the background false-color composite Rapid Eye image (5m x 5m) taken in 5 Oct 2015.

An infinite slope stability model was implemented under two different rainfall intensity scenarios (scenario 1: 4.65 cm/hr, 100 year return period; scenario 2: 5.70 cm/hr, 500 year return period). The model results indicated that 4.84% and 7.26% of the watershed area was susceptible to failure ($FS \frac{1}{1} < 1$) while 20.10% and 22.55% area was depicted to be critical ($FS = 1-1.5$) respectively for scenario 1 and 2. The ROC depicted that the scenario 1 (Figure 2) was better because of its higher AUC over the scenario 2 (scenario 1: AUC [14] = 76.4%, scenario 2: AUC= 71.5%). Despite the model result, the LSM also indicated that the majority of the rural roads in the watershed were either passing through the landslides or in landslide susceptible areas for which eco-engineering measures offer the most cost effective and sustainable solutions.

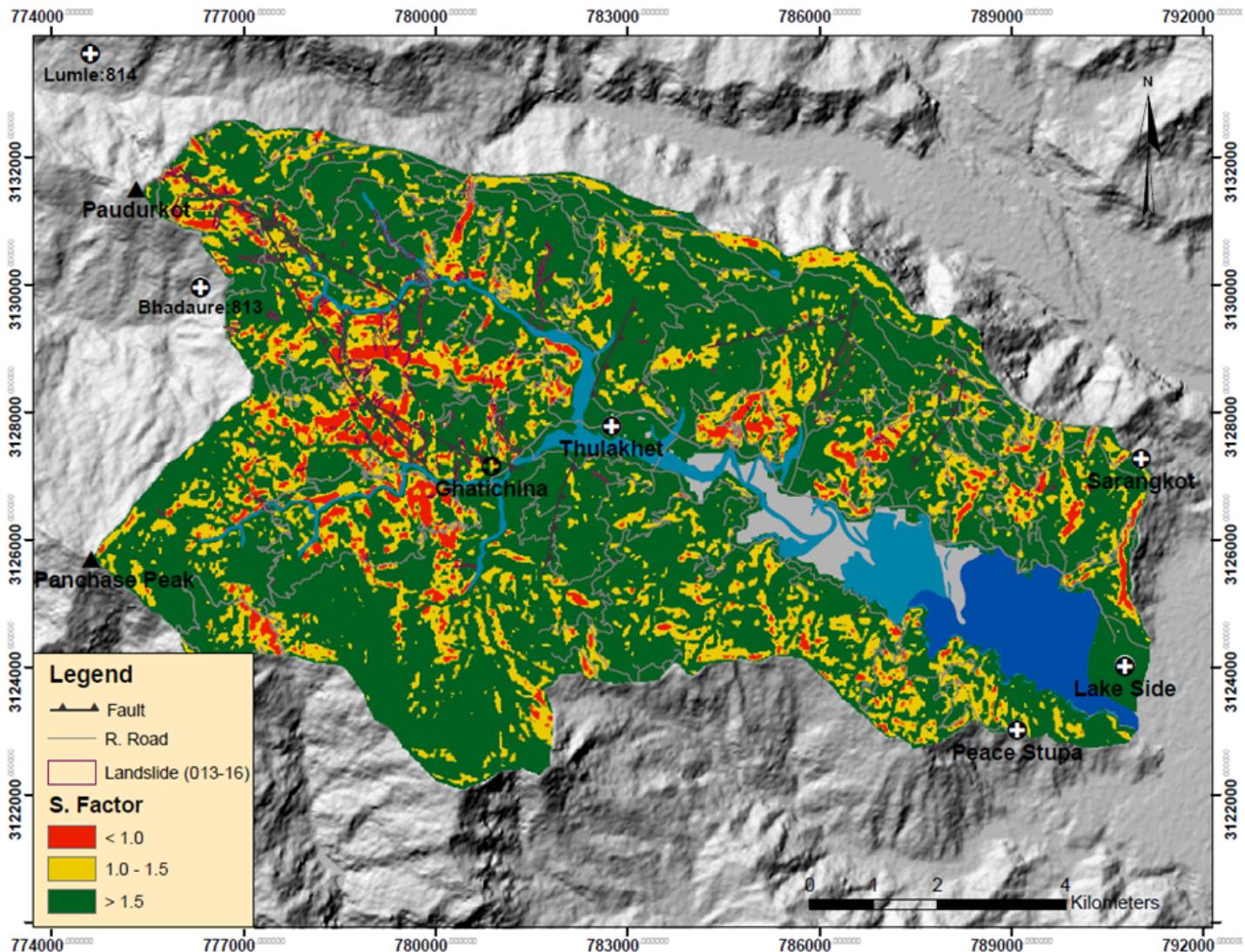


Figure 2. LSM of Phewa Lake watershed (scenario 1) indicating the rural roads, fault line and landslides inventory of 2013-2016.

4. KPI of the Plant Species

The perennial grass species that were recommended by the community, were also recommended by Devkota et al. (2006) [40] and Howell (1999a) [39], implying that the species selection through the local knowledge is useful. Altogether nine indicators were quantified to evaluate the performance of the eight model plant species (Table 3). Among the model species Babiyo (*P. purpureum*) and Kans (*D. bipinnata*) respectively demonstrated highest and lowest survivorship of 81.33% and 65.33% and the same is valid for the canopy cover. Vetiver (*C. zizanioides*) followed by Babiyo (*P. purpureum*) respectively demonstrated the highest shoot and root dry biomass among others. This research concluded that the model plant species can be divided into three classes as per the root depth: 1) deep, 2) moderately deep and 3) shallow according to which Vetiver (*C. zizanioides*) and Amriso (*T. maxima*) were the most deep rooted species followed by Urlo-Khar (*C. microtheca*) and Salim-Khar (*E. binata*) moderately deep rooted (≤ 50 cm) whilst Babiyo (*P. purpureum*), Nepiyar (*C. gryllus*), Kans (*D. bipinnata*), and

Kush (*S. spontaneum*) were the shallow (≤ 30 cm) rooted species. The measurement depicted that the root density is higher in the depth range of 0-10 cm followed by 10 cm – 30cm. As the rooting depth increases, the root density decreased. For entire mapping, the largest root (2.07 mm) measured in the Rhizotron profile was from Amriso (*T. maxima*) at the depth range of 0-10 cm. The root tensile strength is one of the important indicators that contribute to increasing the soil cohesion, known as root cohesion. Vetiver (*C. zizanioides*) demonstrated highest tensile strength (T_r) by the root cohesion (c_r), which was followed by Amriso (*T. maxima*) among others. The Table presents the summary of all the nine KPIs of the model plant species.

Species Local Name	L-Name	Survival (%)	Canopy Cover (%)	Biom-s-dry (kg)	Biom-r-dry (kg)	RAR-deep	RAR-shallow	Rooting Depth (cm)	T_r (MPa)	c_r (kPa)
Vetiver	<i>C. zizanioides</i>	80.00	70.57	0.83	0.32	0.0018	0.0241	0-100	45.4	14.08
Urlo-Khar	<i>C. microtheca</i>	78.67	48.33	0.63	0.33	0.0018	0.0092	0-50	24.11	7.48
Babiyo	<i>P. purpureum</i>	81.33	86.67	0.78	0.54	0.0001	0.0128	0-30	18.25	5.66
Nepiyar	<i>C. gryllus</i>	76.00	60.27	0.39	0.28	0.0004	0.0082	0-30	25.28	7.84
Salim-Khar	<i>E. binata</i>	66.67	51.43	0.18	0.19	0.0003	0.0104	0-50	23.1	7.17
Kans	<i>D. bipinnata</i>	65.33	29.70	0.26	0.19	0.0006	0.0119	0-30	20.24	6.28
Kush	<i>S. spontaneum</i>	72.00	41.10	0.33	0.15	0.0010	0.0084	0-30	21.53	6.68

Species Local Name	L-Name	Survival (%)	Canopy Cover (%)	Biom-s-dry (kg)	Biom-r-dry (kg)	RAR-deep	RAR-shallow	Rooting Depth (cm)	T_r (MPa)	c_r (kPa)
Amriso	<i>T. maxima</i>	70.67	78.63	0.62	0.30	0.0099	0.0657	0-80	26.65	8.27

L-name = Latin Name, Biom-s-dry= dry biomass of shoot, Biom-r-dry=dry biomass of root, RAR deep = Root area Ratio of deep roots, RAR shallow = Root area ratio of shallow roots, T_r = tensile strength, c_r = root cohesion

PCA model was developed utilizing the nine KPIs of the model species to test the quality of plant for eco-engineering measures. The model demonstrated the performance of Amriso (*T. maxima*) was better for soil depth of about 80 cm among the seven local species whilst Vetiver (*C. zizanioides*) was the best among all for the soil depth of 100 cm. Urlo-Khar (*C. microtheca*) and Salim-Khar (*E. binata*) are useful for the landscape where the soil depth is below 50 cm. Other species are useful where the landscape soil depth is lower than 30 cm.

5. Proposed Eco-safe Rural Road assessment Framework

Based on the case study and review of the available research materials 'Eco-safe Rural Road assessment Framework' was contextualized. The framework that outlines the issues to be addressed through appropriate technique with the pre-defined objectives, and guides to understand, design, development, implementation and assessment of eco-engineering that deals with the NbS for the road side slope protection measures. The proposed framework consists of the following seven steps. All the below steps need to be implemented together with the relevant stakeholders, ensuring full gender-balanced community participation from the very beginning through the final monitoring and evaluation

1. Define the problems to be addressed(baseline);
2. Establish the NbS objectives;
3. Identify NbS measures and alternatives for safe and sustainable rural roads;
4. Implement the NbS plan for Eco-safe Rural Road;
5. Establish an awareness and communication plan;
6. Mobilize the community for implementation and Up-scaling;
7. Establish monitoring and Evaluation Plan and follow-up.

The framework also discussed the issues to be addressed at different stages of the eco-engineering implementation process in the Panchase region suitable for other similar geographical area of Nepal.

6. Conclusions

Roads are important infrastructures that bring livelihood opportunities and improve the quality of life. However unplanned and non-engineered rural roads are the cause of disasters such as landslides [41]. In Nepal, the problem of unplanned and non-engineered rural roads is pervasive as such roads are often nonoperational for 4-6 months during and after monsoon (June-Nov.) [42][43]. These roads are causal factors for landslide and soil erosion, while intense monsoonal rain is known to be the triggering factor damaging the lives and livelihoods, degrading the environment and ecosystem services [44]. In parallel, landslides cause human suffering and wastes economic resources by damaging and blocking roads, restricting rural communities in accessing health-care, education, and resources. At the present time, the government is not to adequately address this widespread problem due to limited resources and capacities. It is now important to bring the Nature based Solutions (NbS) in the mainstream development activities for which eco-engineering approach can be a sustainable solution. Eco-engineering is a type of the NbS, used to mitigate a range of roadside slope failures, in which deep rooted plant species are used alone or in combination with civil engineering measures.

Although soil bioengineering is popular in Nepal and many useful manuals and handbooks were developed in the past three decades, yet in practice soil bioengineering is not mainstreamed, especially for local community built roads. Importantly, there is no comprehensive assessment framework for the sustainable rural road side slope protection. The proposed 'Eco-safe road' framework demonstrated the underlying causes of slope failure and outlined the process to be followed while undertaking eco-engineering measures for the safer and sustainable rural roads in the hills of Nepal. Data and information required for defining the underlying problems of rural road side slope failure were also discussed through the research and case study described in this article. The 'Eco-safe Rural Road' approach demonstrated in the three locations (Gharel in Kaski, Tilahar in Parbat and Bhatkhola in Syangja Districts) has been accepted by the local communities, because of the depicted results and co-benefits. Whereas, the local government representatives showed their interest as the techniques which were demonstrated are cost effective and sustainable. The eco-engineering approaches described through this research can be expanded to other similar geographic regions of the country for which this framework can be used as guideline for the successful implementation of eco-engineering measures.

The upscaling of NbS for the 'Eco-safe Rural Road' can be possible during the demonstration stage as well as during the mainstreaming phase when teams learn from the project demonstrations [40]. During the demonstration phase, upscaling can contribute to strengthening government, stakeholders and investors' confidence [45] and increase the number of NbS implementation projects and co-benefits. Upscaling of NbS requires multi-actor partnerships [46]. Scientists can provide the evidence base to predict the benefits of NbS while the societal stakeholders can be instrumental in informing key implementation issues; for example, finding suitable locations for NbS [47]. Planners can contribute to develop innovative ways to systematically incorporate NbS into governance instruments and regulations.

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