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Editorial

Engineering the ecological mitigation of hillslope stability research into the scientific literature

1. Introduction

Over the last 50 years, alterations in land-use coupled with the consequences of climate change have led to severe degradation of mountainous and hilly regions around the world. Once a landslide has occurred or erosion processes are underway, the replacement of soil on a denuded slope may take hundreds or thousands of years through natural processes. In a world where the population is expected to reach 9 billion by 2040, agricultural soil is precious and hillslope stability is now a priority for governments in mountainous countries needing to feed rapidly increasing populations. Equally important are the effects of slope failure and soil erosion on community safety, infrastructures and downstream water quality and habitat. Therefore, the prevention of slope instability, the restoration of degraded slopes and the correct management of steep farmed slopes is of utmost importance. In response to the need for better mitigation strategies, there have been major advances in research and applications for using vegetation to improve slope stability in the last 20 years. These advances include the development of techniques and models for the study of root-soil interactions at different scales (e.g., Stokes et al., 2009; Bourrier et al., 2013; Briggs, 2013; Hubble et al., 2013; Im and Kim, 2013; Preti, 2013; Shiono et al., 2013; Tsai et al., 2013). These developments were presented and discussed at the 3rd International Conference on "Soil Bio- and Eco-engineering – The Use of Vegetation to Improve Slope Stability." Third in the series 'The Use of Vegetation to Improve Slope Stability,' this conference took place at the Department of Forest Sciences, University of British Columbia, Vancouver, Canada, 23–27 July, 2012. As in the preceding conferences, we brought together approximately 100 scientific researchers, practitioners, geotechnical and civil engineers, biologists, ecologists, geomorphologists and foresters to discuss current problems in slope stability research, and how to address those problems using soil bio- and eco-engineering techniques. Sessions focused on root-soil mechanics, vegetation on slopes over time and space, vegetation for reversing soil degradation and soil bioengineering case studies. A selection of papers from the conference is published in this special edition of 'Ecological Engineering,' as well as a special edition of the journal 'Plant and Soil' in 2013 (see Stokes et al., 2013).

Although land degradation through landslides, wind and water erosion causes several thousand deaths a year (Petley, 2012) and damage worth billions of US dollars (Reich et al., 2001; Dilley et al., 2005), surprisingly, a relatively small number of scientific papers are devoted to understanding the mechanisms behind land degradation and solutions for mitigation. In preparing this editorial, and to place the work presented in this special issue in context, we examined the evolution of peer-reviewed research that examines the interactions (adverse or beneficial) of vegetation on slope stability or water erosion. We did not examine the interactions between vegetation and wind erosion because these effects are smaller and more difficult to quantify. We focused on 3 questions: (1) in which countries are landslides and water erosion most prevalent; (2) where are the highest number of scientific articles produced; (3) in which peer reviewed journals is most work on this topic published. We conclude by suggesting how to increase the visibility of the emerging field of soil bio- and eco-engineering in the scientific literature.

2. Where are the world's landslide and soil erosion hotspots?

The global land area affected by deep seated and shallow landslides was calculated in 2005, as being approximately 3.7 million km^2, with approximately 300 million people (or 5% of the total world population) affected (Dilley et al., 2005). However, many landslides also occur as a result of human activities such as road building (Sidle and Ziegler, 2012), on riverbanks (Holzapfel et al., 2013) or on artificial slopes (Norris et al., 2008) and are not included in this dataset. Nadim et al. (2004) produced a global landslide hazard map based on a range of data including slope, soil and soil moisture conditions, precipitation, seismicity and temperature. However, this map did not take into account the human population hazard exposure, because population density was not considered. When the landslide hazard exposure was weighted by population density, the hazard to humans increased enormously (Fig. 1a). Compared to other natural hazards, (e.g. flooding, volcanoes, cyclones, drought), hazard exposure from landslides was highest, but was still lower than that of earthquakes (Dilley et al., 2005). To quantify the risk to human life, mortality from landslides in the period 2004–2010 was compiled into a database by Petley (2012). In that period, Petley (2012) recorded 32,322 deaths in 2620 landslides caused by non-seismic processes. The greatest number of deaths was recorded along the Himalayan Arc and the eastern edges of the Tibet-Qinghai Plateau. The number of landslides which caused fatalities in the same period was highest in India, China, Nepal, the Philippines and Indonesia (Fig. 2).

Compared to soil loss from landslides, the annual potential yield of sediment through water erosion was much higher, and estimated to be 130 billion metric tonnes from 72.5 million km^2 of global land area (Reich et al., 2001). Approximately half of that sediment

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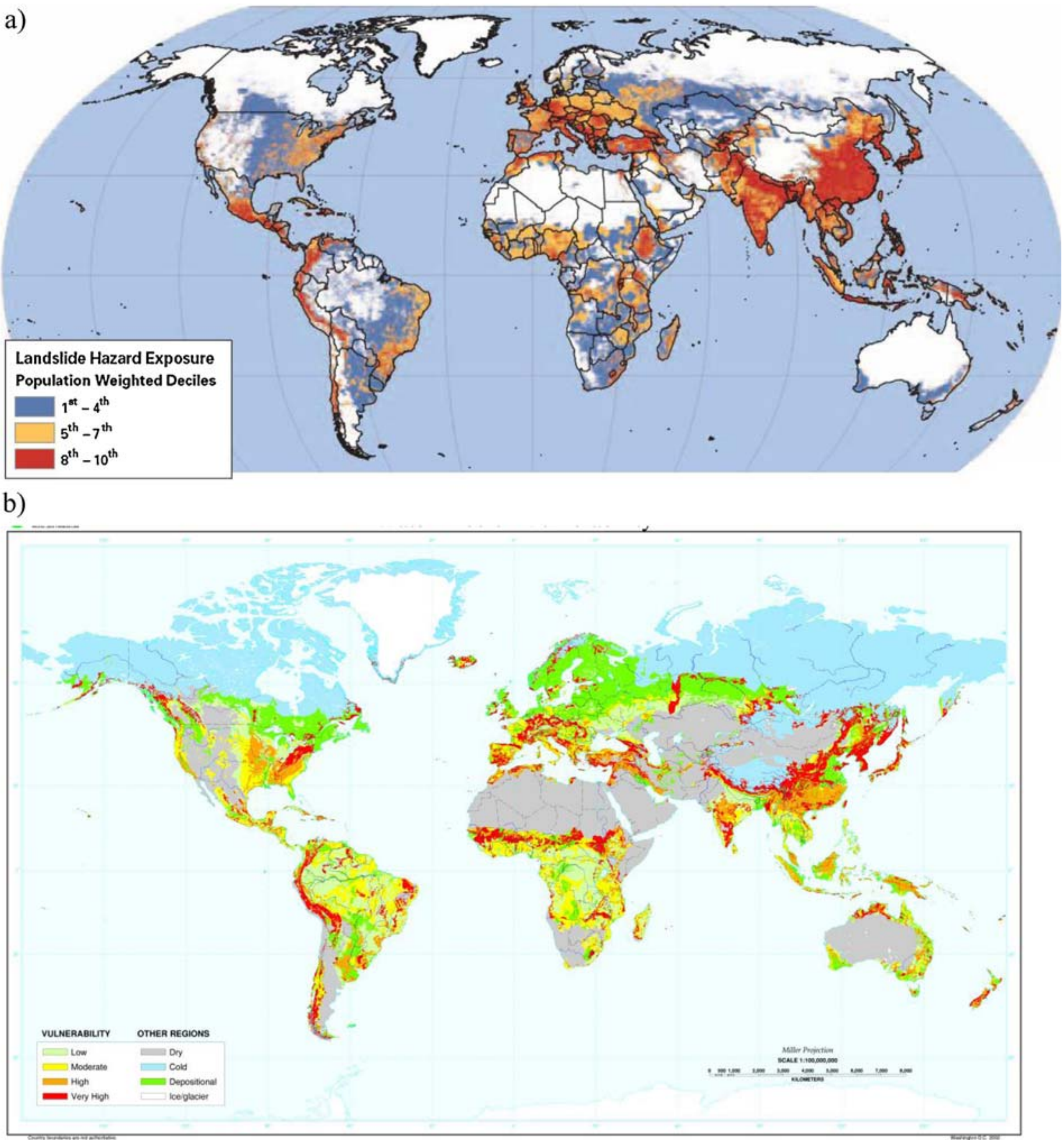

Fig. 1. (a) Landslide hazard exposure after weighting by population density. Grid cells were divided into deciles based on population density and the resulting index was used to weight the landslide hazard (Dilley et al., 2005). Population hazard exposure are highest in the areas coloured red and lowest in the areas coloured blue. Reproduced with kind permission from Dilley et al. (2005). (b) Map showing world regions most vulnerable to water erosion (reproduced with kind permission from Reich et al. (2001)).

production comes from arable lands alone. As with the landslide hazard map (Fig. 1a), it can be seen that the semiarid regions of Asia (in particular, the eastern edges of the Tibet-Qinghai Plateau, the southern Himalayan Arc), the chains of mountains extending down the western coast of South America as well as the southern Sahel in Africa are the hotspots most susceptible to water erosion (Fig. 1b).

3. Where is most peer-reviewed scientific research on the interactions between vegetation and landslides or water erosion published?

A literature search was performed using the Web of Science (WoS) database. We chose several sets of terms present in either the title, list of keywords or abstract. These terms were to reflect the mass wasting processes i.e. shallow landslides or soil erosion, and how vegetation affects those processes. In order to focus on this relationship, we used the terms 'plant + vegetation,' so that plant individuals were considered, rather than just the presence of 'vegetation' or not at a site. When analyzing publications by year or country, we selected the terms 'slope + (stabil*) + plant + vegetation + (landslide OR riverbank OR bioengineering OR cohesion)' or 'soil + erosion + plant + vegetation.' When analyzing scientific production by journal type, we expanded our search, and included the terms remote sensing, bioengineering and riverbank. We searched only for peer-reviewed articles in international journals, as these journals are the most accessible to

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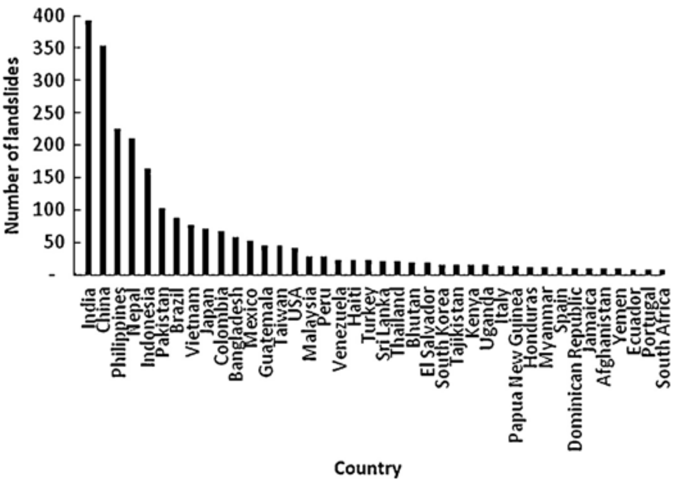

Fig. 2. Number of non-seismic landslides occurring in each of the key landslide countries worldwide, causing fatalities in the period 2004–2010. Data from Petley (2012) and http://ihrrblog.org/2012/08/16/global-patterns-of-loss-of-life-from-landslides/.

Fig. 3. Number of papers (peer reviewed articles) published in the Web of Science database between 1991 and 2012, which include the terms 'slope + stabil* + plant + vegetation + (landslide OR riverbank OR bioengineering OR cohesion)' (137 papers, black line and white diamonds) or 'soil + erosion + plant + vegetation' (1012 papers, black line and squares) in the title or abstract.

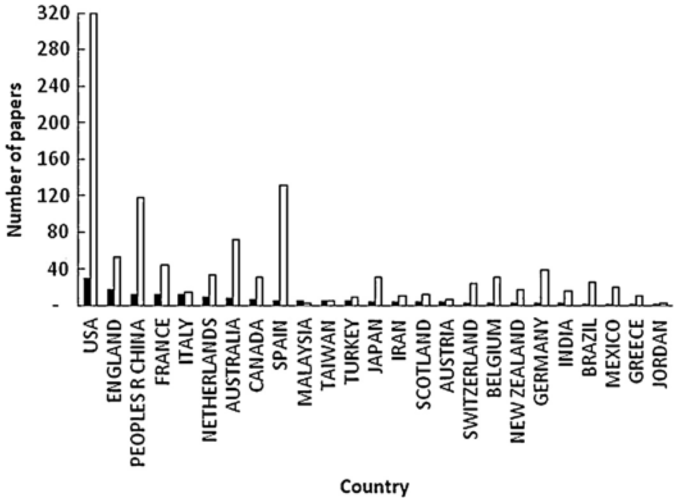

Fig. 4. Number of papers (peer reviewed articles), per country, published in the Web of Science database between 1991 and 2012, which include the terms 'slope + stabil* + plant + vegetation + (landslide OR riverbank OR bioengineering OR cohesion)' (137 papers, black bars) or 'soil + erosion + plant + vegetation' (1012 papers, white bars) in the title or abstract. Only countries which have published >2 papers on both slope stabil* AND soil erosion are shown. The order of countries is descending with regard to the number of articles published with the terms 'slope + stabil* + plant + vegetation + (landslide OR riverbank OR bioengineering OR cohesion)'.

a global audience, and peer-reviewed work is more scientifically respected.

Results from the literature search showed that although there is an increasing trend in the publication of articles with 'slope + (stabil*) + plant + vegetation + (landslide OR riverbank OR bioengineering OR cohesion)' in the title or abstract, the total number of articles is low (Fig. 3). Between 1991 and 2012, only 137 papers have been published, with a peak year occurring in 2010 (corresponding to the publication of a special issue on the subject in the journal Ecological Engineering, see Stokes et al., 2010). However, the number of articles using the terms 'soil + erosion + plant + vegetation' is much greater, with 1012 papers published between 1991 and 2012. Peak years were in 2010 (107 papers) and 2012 (101 papers) and since 2003, at least 50 papers a year were published using these terms. Only 8 articles have the terms 'landslide + bioengineering' and 13 papers have the terms 'riverbank + vegetation + plant + (bioengineering OR stabil*).'

The number of peer reviewed articles published per country and which included the terms 'slope + stabil* + plant + vegetation,' revealed that researchers from the USA have published the most papers (30) since 1991 followed by those from England (18), China (13) and France (12) (Fig. 4). Similarly, researchers from the USA have also published the most papers using the terms 'soil + erosion + plant + vegetation' (320 papers, Fig. 4) followed by those from Spain (131) and China (117). Only researchers from Australia and England have published > 50 papers using these terms, since 1991.

Considering journals registered in the WoS database, which published peer-reviewed articles using the terms (slope + stabil* + vegetation + plant) or (landslide + vegetation + plant) between 1991 and 2012, Ecological Engineering or Plant and Soil dominated (Table 1). Catena published a small number of papers in the subject area, but was the top journal for articles including the terms (soil + erosion + vegetation + plant), followed by Plant and Soil and the Journal of Arid Environments (Table 1). The dominant journal changed when the terms (remote + sensing) were included, with the majority of papers published in the International Journal of Remote Sensing and Sensors (Table 1). The terms (landslide + bioengineering) were only found in seven journals, with most articles appearing in Plant and Soil (Table 1). The journals Earth Surface Processes and Landforms, Ecological Engineering and Environmental Management were most likely to publish papers on (riverbank + stabil* + vegetation + plant).

4. Where should we focus in the future?

There is of course much more information and existing data on slope processes and bio- and ecological engineering than that included in the articles discussed here. This includes information in books, conference proceedings and publications not listed in the peer-reviewed article pages of WoS. In order to improve dissemination of findings, and raise the profile of this emerging field, scientists and practitioners should consider publishing more in peer-reviewed open access journals, or choosing the open access option in regular journals. Open access papers can be freely consulted worldwide, and are particularly appreciated by (i) practitioners not having subscriptions to academic journals

Table 1
Journals registered in the ISI Web of Science database, which publish either >2 papers, or >2% of peer-reviewed articles using the following terms in the title, abstract or keywords: slope + stabil* + vegetation + plant; landslide + vegetation + plant; soil + erosion + vegetation + plant; landslide + vegetation + remote + sensing; landslide + bioengineering or riverbank + stabil* + vegetation + plant (years 1991–2012).

Journals publishing >2% of papers or >2 articles												
Terms used in search												
	Slope + stabil* + vegetation + plant	%	Landslide + vegetation + plant	%	Soil + erosion + vegetation + plant	%	Landslide + vegetation + remote + sensing	%	Landslide + bioengineering	%	Riverbank + stabil* + vegetation + plant	%
Total number of papers	122		76		1012		66		8		13	
	Ecological Engineering	9.3	Ecological Engineering	8.2	Catena	5.5	International Journal of Remote Sensing	9.1	Plant and Soil	25.0	Earth Surface Processes and Landforms	15.4
	Plant and Soil	5.6	Plant and Soil	5.9	Plant and Soil	3.5	Sensors	7.6	Ecological Engineering	12.5	Ecological Engineering	15.4
	Catena	5.6	Biotropica	4.7	Journal of Arid Environments	3.1	IEEE Transactions on Geoscience and Remote Sensing	4.5	Environmental Modelling Software	12.5	Environmental management	15.4
	Earth Surface Processes and Landforms	2.7	Catena	4.7	Ecological Engineering	2.4	Natural Hazards	4.5	Hydrology and Earth System Sciences	12.5		
	Ecology	2.2	Forest Ecology and Management	4.7	Restoration Ecology	2.2	Advances in Space Research	3.0	International Journal of the Physical Sciences	12.5		
	Journal of Arid Environments	2.2	Plant Ecology	4.7	Land Degradation Development	2.0	Arabian Journal of Geosciences	3.0	Natural Hazards Review	12.5		
	Journal of Vegetation Science	2.2					Computers Geosciences	3.0	Proceedings of the Institution of Civil Engineers Water Maritime and Energy	12.5		
							Disaster Advances	3.0				
							Earth Surface Processes and Landforms	3.0				
							Ecological Research	3.0				
							Environmental Earth Sciences	3.0				
							Environmental Geology	3.0				
							Journal of Applied Remote Sensing	3.0				
							Landslides	3.0				

and (ii) researchers and practitioners in developing or transitional countries, where fatal landslides are most common. Social media and blog sites are also extremely useful for providing information e.g. the Landslide Blog (http://blogs.agu.org/landslideblog/). For a scientific paper to be picked up by search engines and have as wide an audience as possible, it is necessary to choose the correct keywords. If the focus of the paper is soil bioengineering, eco-engineering, protection/restoration of a site subject to gravitational mass movement, the terms slope + stabil* or erosion should be included in the title, abstract or keywords.

The number of articles focusing on water erosion and vegetation was much greater than those focusing on landslides. As the land mass affected by water erosion is significantly higher than that degraded by landslides, this result is not surprising. Water erosion also occurs outside mountainous and hilly areas, and often on arable land. Therefore, the economic impacts are more immediate and easily quantified. However, water erosion rarely causes fatalities, because it is usually a slow mechanism, unless e.g., an erosion event turns into a flow event and torrential rains causing flooding, resulting in increased slope/bank erosion and damage to properties and people living adjacent to shorelines. Landslide-induced mortality is much higher than previously thought (Petley, 2012), yet the trend in the number of publications by country does not reflect the number of landslides causing fatalities. The highest number of fatal landslides between 2004 and 2010 occurred in India (Petley, 2012). The type of landslide e.g. deep-seated or shallow, was not specified in these statistics, but these landslides did not occur through seismic events. Although vegetation cannot play a major role in stabilizing deep-seated landslides, the sheer magnitude of landslides occurring in India suggests that this is a country where future research must be performed. India also has many top class Universities and Engineering Schools, where such studies could be carried out. Other countries with a high number of landslides include China, the Philippines, Nepal and Indonesia. Although Chinese researchers published 13 papers on slope/riverbank stability and vegetation during our sample period, several studies were in collaboration with foreign researchers working in China. Nevertheless, research in this field has been declared a priority in China (Stokes et al., 2010) and it is expected that the number of publications will increase enormously in the next decade. The Philippines, Nepal and Indonesia did not figure prominently in the results of our literature search, indicating a lack of peer-reviewed scientific production. The lack of WoS listed articles does not mean that excellent studies are not performed in these countries. For example, farmers and scientists in the Philippines have developed a system called Sloping Agricultural Land Technology (SALT) (Tacio, 1993). Through agroforest and mixed crop farming, SALT reduces soil erosion and restores moderately degraded hilly lands to a profitable farming system. Similarly, scientists in Indonesia are examining agroforestry systems as a means to reduce soil erosion (Verbist et al., 2009). Soil bioengineering techniques are also widespread in Nepal, in particular along roadsides (Howell, 1999; Rai, 2010; Dhital et al., 2013). Local engineers and communities have a great deal of hands-on experience, which is accessible outside the country through online books and guidelines. The international scientific community should assist in the dissemination of results from such operational studies, by working with local engineers and stakeholders in joint projects and cooperative actions (Stokes et al., 2013).

In the last five years, the number of articles focusing on slope stability and vegetation is similar to those published in the field of soil erosion in the mid 1990s. If this increasing trend continues, we can expect several hundred peer reviewed papers by the mid 2020s. Nevertheless, communication through publications, teaching and outreach must continue, so that awareness and acceptance of vegetation management for slope stability augments. More case studies are needed, particularly in the countries most exposed to the risks of soil loss. Scientists and engineers need to invest time and money in the developing and transitional countries highlighted in this paper, so that knowledge of scientific procedures and developed technical standards are exchanged with expertise and hands on experience. With regard to peer-reviewed scientific production, efforts must increase, and special issues such as this issue in Ecological Engineering, or Plant and Soil (see Stokes et al., 2013), will add improve the impact of lectures and posters presented at conferences and meetings such as the series 'The Use of Vegetation to Improve Slope Stability.' The fourth conference in this series will be hosted by the University of Sydney, Australia, in July 2016. For further details, please contact Prof. Tom Hubble (hubble@mail.usyd.edu.au).

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