Prospects of Using Geosynthetic Materials for Disaster Mitigation – A Case Study

S. Faiza Jamil[1] and S. Anbahan Ariadurai[2*]

[1]*Textile Research and Innovation Centre, Textile Institute of Pakistan, Karachi, Pakistan*
[2]*Department of Textile and Apparel Technology, The Open University of Sri Lanka, Nawala, Nugegoda, Sri Lanka*

*Corresponding Author: email: saari@ou.ac.lk, Tele: +94112881228

Abstract – *Natural disasters result in death, economic and environmental damages, and severe impediments to social development. They affect the economy immediately and directly, as well as having a long-term impact on the social life of the community. Some of the major natural disasters that have made severe damages with respect to loss of lives and property include floods, windstorms, earthquakes, and droughts. In the recent years geosynthetics have been successfully used, especially in the developed countries, for the mitigation of natural disasters such as floods, landslides, rock-falls, debris flows and avalanches. This paper discusses the possibility of using geosynthetics in mitigating natural disasters such as floods and earthquakes from a South Asian scenario with Pakistan as the case study. The work involves reviewing the nature and frequency of these natural disasters; identifying the areas where geosynthetics can play a vital role and juxtaposing the existing literature on geosynthetics for disaster mitigation with the risk situation. Conclusions are drawn emphasizing the seminal nature of the work and outlining the need for more focused studies on the use of geosynthetics for disaster mitigation in the South Asian context.*

Keywords: *Geosynthetics, Geotextiles, Natural disaster, Technical textiles, Disaster mitigation*

1 INTRODUCTION

Natural disasters lead to losses of human lives and property and adversely affect the national exchequer. Natural disasters are often frightening and difficult to understand, because humans have no control over when and where they would happen. What can be controlled is how prepared people are as communities and governments to deal with the dangers that natural disasters bring.

According to the International Disaster Database (EM-DAT), in the year 2012 alone 9330 people lost their lives due to natural disasters and some 106 million people were affected by disasters (Ferris, et al., 2013). Based on the statistics from the International Strategy for Disaster Reduction (ISDR), an organization headed by the United Nations Secretary for Humanitarian Affairs, between the years 1970 to 2005, the most common ten natural disasters are flooding (30.7%), windstorm (26.8%), epidemic (11.2%), earthquake (8.9%), drought (7.8%) landslide (5.1%), extreme temperature (3.5%), wild fire (3.4%), volcanoes (3.4%) and insect infection (1.0%) (Wayne, n.d.)

According to the statistics provided by the US Geological Survey between 2000 and 2012, around the world 813,856 have died due to earthquakes. According to a new study that has been published, it is predicted that 3.5 million people will have died in catastrophic earthquakes between 2001 and 2100 (Oskin, 2013). In a study published in 2009, scientists calculated that an earthquake with a million fatalities could be expected once a century if the world's population reaches 10 billion, as the United Nations predicts will happen in 2083 (Oskin, 2013). Four catastrophic quakes (those that kill 50,000 or more people) have already hit since 2001.

In many countries immediately after a natural disaster the authorities activate a Centralized Disaster Management System, where much of the work done is focused on disaster recovery and response and creation of awareness to deal with the disasters. Even though in some of the countries, certain amount of work is focused on reducing vulnerability through sustainable construction methods and materials, in only very rare occasions use of geosynthetics have been considered for disaster-proof infrastructure designs.

This paper intends to fill this void and introduce geosynthetics as a key material for mitigating natural disasters, with Pakistan as the case study. Since the subject is of a wide scope owing to the different types of disasters, the variety of damages caused by each and the multifarious functions of geosynthetics, the paper follows a short listing methodology to arrive at areas where geosynthetics can help reduce vulnerability.

The methodology of review is detailed below:

- Natural disasters are beyond human control and cannot be fully eliminated; the phenomenon can only be mitigated by manipulating a particular component of a natural disaster. This component is identified and highlighted for further exploration.
- Natural disasters inflicting the world are of various kinds. Only those that are highly frequented and have caused considerable damage lie within the scope of this paper.
- Frequently occurring natural disasters cause damage by destroying and disrupting a number of infrastructures and systems on which a country operates. Only those infrastructures that are essential and can be fortified with geosynthetics form the scope of this paper.
- Some explanation and details are provided of how the shortlisted infrastructures could be fortified with geosynthetics and hence reduce their susceptibility to natural disasters.

2 INTRODUCTION TO NATURAL DISASTERS

United Nations defines disaster as a natural or manmade event that disrupts a society to an extent that it cannot reestablish or resume its functions with the existing resources (Department of Humanitarian Affairs, 1992).

Not every natural occurrence such as a flood or an earthquake can be termed as a disaster. For an event to be a "disaster" it has to incur "losses" be it of financial, human or environmental nature. The following equation illustrates this (Cyr, 2005).

Hazard + Vulnerability = Disaster

Hazard is an event that is *potentially* harmful to life, property or ecology but may not necessarily cause such losses. (Khan & Khan, 2008). These may be classified under three main heads:

1- Hydrological hazard: Floods, limnic eruptions, tsunamis
2- Meteorological hazards: Billiards, cyclones, droughts, heat waves, hailstorms, tornadoes
3- Geological hazards: Volcanic eruptions, earthquakes, avalanches

Vulnerability of a group of people refers to its extent of preparedness or otherwise against hazards (Guzman, 2003).

There are several factors that results in a populations' increased level of vulnerability. These include poor construction practices, inadequate disaster warning and monitoring systems, lack of awareness, proximity to hazardous terrains etc. (World Bank, 2009). In other words, a disaster occurs only when a natural hazard meets vulnerability; and since it is beyond the control of the human beings to effectively limit a geological, meteorological or hydrological activity (hazard), what humans can do is only mitigate disasters by limiting the vulnerability.

The role of geosynthetics in limiting vulnerability to failures in soil structures is well established. Here, the primary function performed by the geosynthetic is reinforcement. As a reinforcement agent, geosynthetics work in conjunction with a soil mass to improve its tensile strength and elasticity properties as compared to the corresponding properties of an unreinforced mass (Bathurst, n.d.). With reference to disaster mitigation, geosynthetics can be used in the construction of sustainable structures, thus reducing the vulnerability towards natural disasters. This is graphically illustrated in Fig. 1.

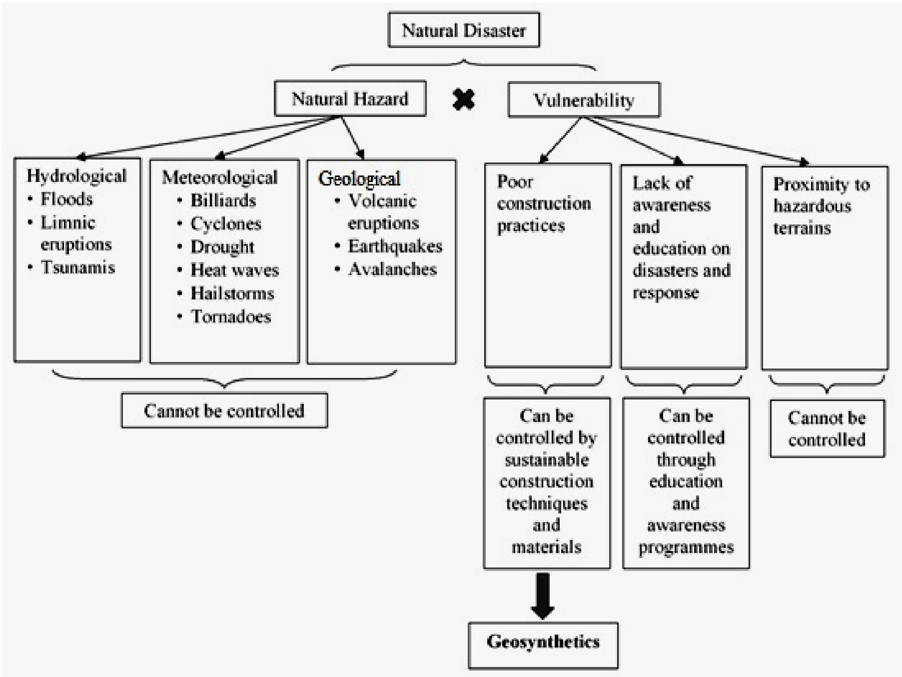

Fig. 1 Role of geosynthetics in disaster mitigation

3 THE PAKISTAN SCENARIO

Pakistan has an area of about 796,096 Sq. Km. Its topography consists of coastal beaches, sandy deserts, plateaus, plains, mountains, and snow covered peaks. The population is around 170 million of which 34% reside in urban areas and the rest in the rural areas. Like many other regions of the world, the areas comprising Pakistan are not free from the risk of natural disasters. It is highly susceptible to floods and, due to its closeness to the tectonic plates of Indo-Australia and Eurasia, is also at great risk of earthquakes (World Bank, 2009).

Table 1 shows the frequency of the top five frequented natural disasters that have inflicted Pakistan from the year 1954 - 2004.

Table 1 Frequency of natural disasters in Pakistan (%)

Natural Disaster	Frequency (%)
Floods	33
Earthquakes	18
Cyclones	16
Extreme Temperature	12
Landslides	10

Source: World Bank (World Bank, 2009)

Though Table 1 clearly points out floods and earthquakes as the top two frequently occurring disasters in Pakistan, the statistics do not include two of the worst catastrophes of recent years; the earthquake of 2005 (GLIDE number: EQ-2005-000174-PAK) and the floods of 2010 (GLIDE Number: FL-2010-000141-PAK).

3.1 Earthquake of 2005 (EQ-2005-000174-PAK)

The earthquake that happened on 8th October 2005 in Northern region of Pakistan measured 7.6 on Richter scale and covered a total area of some 30,000 square kilometers. The number of people killed due to this earthquake was 73,330 (Idris, 2007). Two aspects of material and environmental damage that took place during this earthquake, namely destruction of buildings and failure of lands, are discussed below as a background to the later discussion of the use of geosynthetics as a disaster mitigation material.

It is estimated that 780,000 buildings were destroyed or damaged beyond repair due to the earthquake, majority of which were of unreinforced masonry (URM) (Earthquake Engineering Research Institute, 2006).

The earthquake also set off numerous landslides. Owen et al. (Owen, et al., 2008) have classified the failures resulting in these landslides as being largely located in six geomorphic–geologic–anthropogenic settings, one of which is associated with road construction. In fact, landslides largely occurred on the roads that were built along the slopes exceeding 50 degrees (Owen, et al., 2008). This also supports the earlier findings that road construction on slopes triggers landslides (Barnard, et al., 2001) (Keefer, 1984).

3.2 Floods of 2010 (FL-2010-000141-PAK)

The monsoon of 2010 brought unprecedentedly heavy rainfall in Pakistan. The rains caused unprecedented floods in Khyber Pakhtunkhwa province, followed by Punjab and Sindh provinces. The damages and losses due to the rains resulted in 1985 deaths with further 1.7 million houses being damaged and 20 million people getting affected (Pakistan Disaster Management Authority, n.d.).

The damages were even more exacerbated due to major failures in river embankments, prominently along the course of the main Indus river. These failures of embankments occurred in the left marginal bund of Taunsa barrage, Rangpur canal, Muzaffargarh canal, Jampur flood bund in Punjab, Tori flood bund, Ghouspur bund, Beghari Sindh feeder bund, old Ghora Ghat bund, Haibat loop bund, MNV drain, Khirther canal, Moolchand Shahbundar bund and Manchar lake in Guddu – Kotri downstream reach (Sindh) of Indus river (Pakistan Disaster Management Authority, n.d.).

Due to these breaches and failures nearby towns and villages were inundated killing people, destroying crops and causing enormous infrastructure damage. Such failures of embankments are unfortunately not new to Pakistan. For example, during the floods of 2005 (GLIDE Number: FL-2005-000158-PAK) a total of five dams gave way with the biggest of these being the 35 metre Shadikor dam (McCully, 2005), which failed and drowned the nearby areas (United Nations Institute for Training and Research, 2005). This dam was built in the year 2003 with a cost of 45 million Pakistan Rupees., but it failed because of overtopping, which is a condition where the water is so abundant that it overflows from the dam and then causes it to collapse.

4 GEOSYNTHETICS IN SUSTAINABLE CONSTRUCTION AND DISASTER MITIGATION

Geosynthetics hold immense potential for sustainable construction and disaster-proof infrastructure. Their ability to bond with earthen / soil structures and yet retain flexibility make them a viable choice for reinforcement purposes.

Furthermore, they are inert and environmental friendly. They are also inexpensive as compared to other reinforcing materials such as steel. This section deals with the possibility of deploying geosynthetics for preventing some of the damages / failures caused by floods and earthquakes. Table 2 gives a shortlist of some of the damages caused by earthquakes and floods.

Table 2 Damages caused by earthquakes and floods

Disaster	Damage
Earthquakes	Collapse of masonry structures and mud houses Seismic-induced landslides
Floods	Failure of levees and dams Overtopping of dams

4.1 Collapse of masonry structures

Masonry constructions are primarily designed to support vertical loads such as their own self-weight and that of their contents. They are weak against complex seismic forces. Seismic retrofitting refers to the concept of modifying the existing masonry structures to enable them to withstand seismic loads (Nanda, et al., 2011). Two ways in which geosynthetics can be employed for retrofitting are *isolation of the base* and *textile reinforcement of the walls*.

4.1.1 Foundation isolation

In conventional designs the buildings are fixed to the ground. The seismic forces due to ground shaking are transferred to the superstructure. The seismic forces then induce lateral forces in the building and cause a part of it to shear off. The probability of this failure mechanism can be greatly reduced by introducing 'foundation isolators' at the plinth level to separate the superstructure from the ground. A foundation isolator works by shifting the natural period of the building away from that of the earthquake and providing additional damping to absorb the energy (Yegian, et al., 1999).

Several studies (Nanda, et al., 2011) (Yegian, et al., 1999) (Yegian & Kadakal, 2004) (Kevazanjian, et al., 1991) (Xiao, et al., 2004) (Yegian & Catan, 2004) have demonstrated the effectiveness of geotextile and geosynthetics as base isolators for seismic hazard mitigation. Though the existence of other base isolators are all too well known, they pose problems that can be avoided with the use of geosynthetics. For example, steel sheets are expensive and lead to construction complications; graphite, grease, screened sand, dry and weight sand cannot be used for a long term as graphite can be affected by chemical, grease can be contaminated by debris, dirt etc., and sand gets crushed after the shock which will increase the frictional characteristics (Nanda, et al., 2011). There are different ways by which the geotextiles and geosynthetics have been applied as base isolators in building constructions. In one of the studies (Thurston, 2007), the proposed base isolation system consisted of 40mm thick sheet of polystyrene followed by two slip layers of Ultra High Molecular Weight Polyethylene (UHMWPE) and Typar™ geotextile. As there could be a slurry seep through the geotextile, another layer of polyethylene sheet is placed on top of the geotextile. On top of this polyethylene sheet the concrete is casted in-situ and clearances are provided around the slab perimeter to prevent soil passive pressure from resisting slab movement.

4.1.2 Textile reinforcement of the walls

Poly-functional Technical Textiles (against natural hazards) (Polytect, 2008) is an EU funded research project under 6th Framework Programme (Yegian, et al., 1999). The aim of the project was to produce multifunctional sensor-embedded textiles that would provide both reinforcing strengths and monitoring capabilities for masonry structures and geotechnical applications.

One such research product is *Seismic Wall Paper*. It consists of a textile interface between outer mortar / cement / plaster layer and the inner URM (stone or brick) (Zangani, 2010).

There are several advantages of using sensor embedded textiles for reinforcing masonry structures. These include high strength to weight ratio, ease of handling and speed of installation. At the same time, monitoring the structure during its lifetime (strain, cracks, temperature, etc.) is very important, in order to predict possible anomalous situations, such as diffused cracking caused by additional unexpected loads or seismic events, soil subsiding, etc. In this way, the real-time monitoring of the structure allows repairing in the early stage, avoiding possible successive retrofitting and reducing maintenance costs (Coricciati, et al., 2010).

4.2 Collapse of mud houses

While foundation isolation and textile reinforcement of walls could make masonry structures resistant to damage by earthquakes, the fact remains that a large majority of housing sector in Pakistan is composed of *katcha* house rather than the *pucca* house. *Katcha* house is made of dry stone walls, and mud walls. Earth, which is compacted dry or mud plaster is used in floor and roof (UN Habitat, 2010). The resistance of mud house against earthquake is very low. Over 200 mud houses collapsed in Dalbandin, Baluchistan in the earthquake of January 2011 (Kassim, et al., 2011). A similar incident had taken place three years earlier when in 2008 an earthquake of magnitude 6.4 in Baluchistan destroyed more than 15,000 mud-walled and timber homes because of their low resistance to earthquakes (Karwal, 2008) (Maqsood & Schwarz, 2010).

An easy way to increase the compressive strength and hence the earthquake resistance of the mud houses is to reinforce the mud with fibres. The flexibility of the reinforced structures is also greater than the unreinforced ones (Akinmusuru & Adebayo, 1981) (Binici, et al., 2005). The fibres that can be used are easily available fibres such as straw, coir, jute, wheat, maize and bamboo.

Natural fibres cause an overall reduction in weight and density of the material. Also, as the composite mass dries, the stresses are distributed across the entire mass of the material reducing chances of breakage (Becker, 2010).

4.3 Seismic-induced landslides in areas of road construction

Road construction is done by cutting large areas of earth/soil from the upside of the slope, and then using the cut mass as a fill on the downside.

Owen at al (Owen, et al., 2008) have stated that in 2005 Kashmir earthquake, landslides occurred in almost every section of the road that was built on slopes with an angle greater than fifty degrees. Furthermore, the fill sides of many of the roads failed because the soil mass was not integrated enough during the construction.

The failures of road embankment occur due to non provision of slope strengthening works. One of the techniques suggested for slope stabilization by Bukhari et al (Bukhari, et al., 2006) is the provision of geosynthetic liner technology. Geogrids are spread out horizontally on the fills and then hooked to the walls by means of pins.

In cases where landslides are induced by excessive rains or inadequate drainage, and in areas where soils are susceptible to spontaneous liquefaction or quick clay, the non-woven fabric helps mitigate landslide by not only generating the tension forces to enhance the overall stability of slopes, but also preventing the development of pore water trapped in clayey soils by providing horizontal drainage through the fabric (Choobbasti, et al., 2009).

4.4 Failure of levees and dikes

Levees fail because of poor design, substandard construction, poor maintenance, or the reduction of their channel capacity because of sedimentation of the riverbed. Levees also fail because their “design flood” is exceeded. Any flood larger than the design flood will most likely overwhelm the levee (McCully, 2007). However, this is not the case with geosynthetic-reinforced levees. They are known to hold their ground during severe overtopping and storm conditions resisting scour and erosion. The procedure is simple and involves placing geotextile tubes horizontally, end-to-end and then pumping them with sand slurry. The tubes are then covered with sand forming the core of artificial dune structure. Such levees have proven their worth in the past; the most notable example of their integrity is from the Katrina storm that inundated the town of New Orleans in 2005.

It was revealed in the post-Katrina analysis that the geosynthetic reinforced levees (St. Charles and Jefferson) remained intact in the face of severe storm, while all other levees were breached (Dendurent & Woodward, 2009) (Dendurent & Woodward, 2009).

4.5 Overtopping of Dams

Studies on the reasons of overtopping of dams show that the failure occurs due to such factors as the area on which the dam is constructed, the type and capacity of dam, properties of construction material etc. Interestingly, all these failures start in the downstream side of the dam and then proceed to affect the entire dam body. It is therefore obvious that to arrest dam failure at an early stage, protection of its downstream face is very important (Cazzuffi, 2000).

Geosynthetics are widely used to prevent erosion caused by over topping of the dam. They are a good reinforcement option since they are inexpensive and are easy to install as compared to concrete slabs. They are also durable, flexible and provide good aesthetic appeal.

Geotextiles and geosynthetics have been used for reinforcement of downstream face for protection from overtopping in the earthen dam, Lake-in-the-Sky, in United States (turf biomat), Maraval dam in France (PET Woven geotextile) and in Bass Lake dam, Trout Lake dam and Price Lake dam in USA again.

Based on the discussions, it can be deduced that geosynthetics can be successfully used in Pakistan and other countries with similar economic and social backgrounds, for various disaster mitigation applications. Figure 2 summarizes these areas through a flow chart diagram.

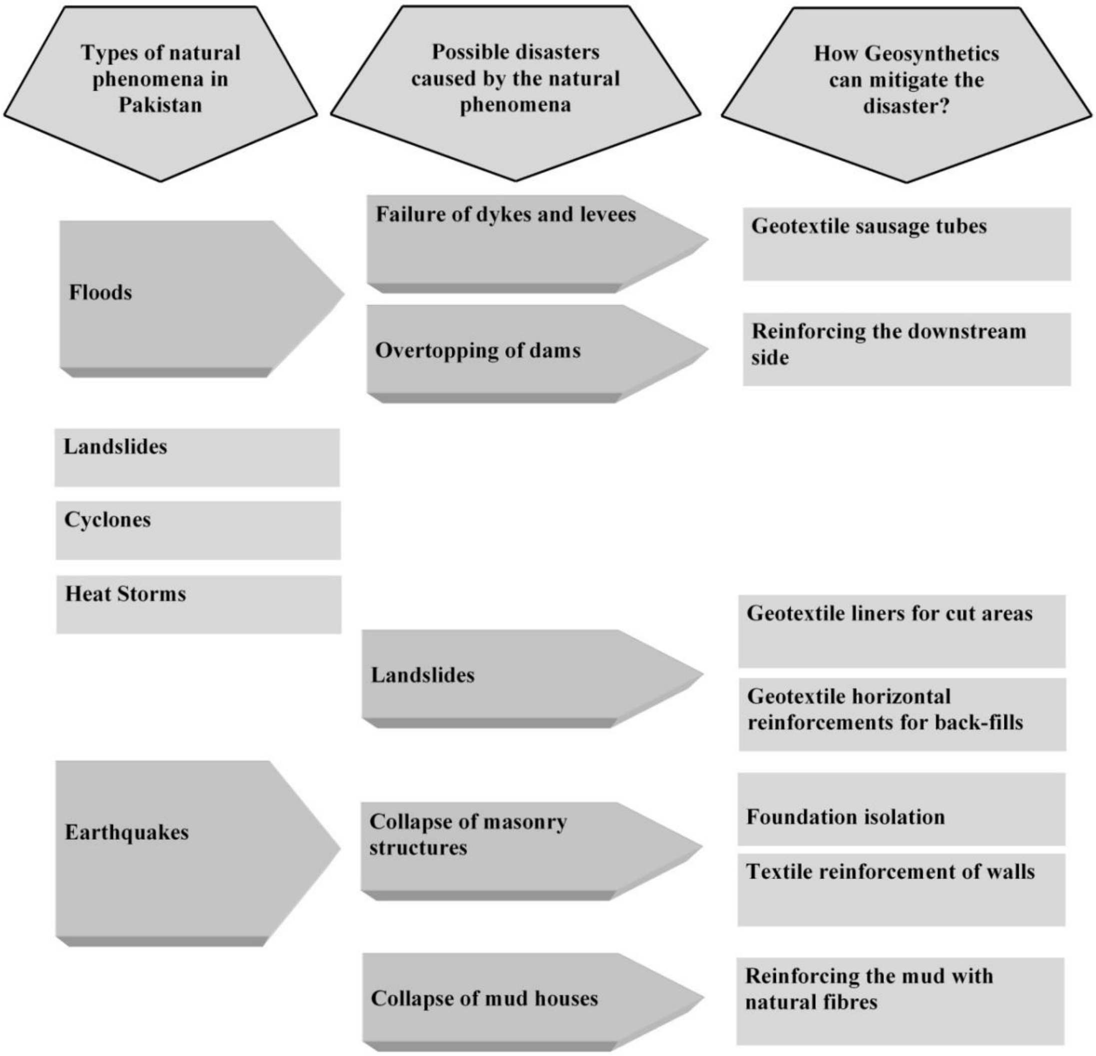

Fig. 2 Role of geosynthetics in disaster mitigation in Pakistan

5 CONCLUSIONS

Unfortunately many of the countries in the world, including those in the South Asian region are prone to natural hazards of various kinds including earthquake and floods. However the positive aspect is the fact that a natural disaster, as mentioned earlier, is a product of natural hazard and vulnerability. Therefore, it is apparent that if measures are taken to decrease the vulnerability by seeking and employing sustainable and affordable building construction and technologies for disaster-resistant infrastructure and design the disaster resulting out of the hazards can be greatly reduced. Geosynthetics have long been known as durable and easy to use reinforcement material. Their importance, in the wake of increasing susceptibility of the region to natural disasters, is more than ever before.

This article summarizes some of the areas in which geosynthetics and geotextiles could be used to mitigate the damage caused by natural disasters. Further focused studies need to be done in each of the specific areas discussed to accrue benefits by geosynthetics for a disaster-resistant South Asia.

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