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Geomorphology, natural hazards, vulnerability and prevention of natural disasters in developing countries

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Abstract

The significance of the prevention of natural disasters is made evident by the commemoration of the *I*nternational *D*ecade for *N*atural *D*isaster *R*eduction (IDNDR). This paper focuses on the role of geomorphology in the prevention of natural disasters in developing countries, where their impact has devastating consequences. Concepts such as natural hazards, natural disasters and vulnerability have a broad range of definitions; however, the most significant elements are associated with the vulnerability concept. The latter is further explored and considered as a key factor in understanding the occurrence of natural disasters, and consequently, in developing and applying adequate strategies for prevention. Terms such as natural and human vulnerabilities are introduce and explained as target aspects to be taken into account in the reduction of vulnerability and for prevention and mitigation of natural disasters. The importance of the incorporation not only of geomorphological research, but also of geomorphologists in risk assessment and management programs in the poorest countries is emphasized.

Keywords: Geomorphology; Natural hazards; Natural disasters; Vulnerability; Prevention; Developing countries

1. Introduction

Before the appearance of *Homo sapiens* on Earth, the purely natural system ruled our planet. Many geophysical events such as earthquakes, volcanic eruptions, landsliding, and/or flooding took place threatening only the prevailing flora and fauna. Millions of years later, the human presence transformed the geophysical events into natural disasters.

The transformation of these geophysical events into natural disasters occurred simultaneously with the appearance of the human system, when human beings began to interact with nature, when fire was discovered and tools were made from the offerings of the natural habitats. The evolution of humans left behind the age in which only nature existed. It provided the starting point of the interrelation of the human system with nature.

The human system itself was subjected to significant transformations, where the concept of work and hence of social division of work, production relations and economical–political systems appeared. These transformations and their links to the natural system

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have served as templates of the dynamics of natural hazards and therefore, of natural disasters.

Natural hazards are indeed geophysical events, such as earthquakes, landsliding, volcanic activity and flooding. They have the characteristic of posing danger to the different social entities of our planet, nevertheless, this danger is not only the result of the process per se (natural vulnerability), it is the result of the human systems and their associated vulnerabilities towards them (human vulnerability). When both types of vulnerability have the same coordinates in space and time, natural disasters can occur.

Natural disasters occur worldwide; however, their impact is greater in developing countries, where they occur very often. In most cases, the occurrence of natural disasters in these countries is due to two main factors. First, there is a relation with geographical location and geological–geomorphological settings. Developing or poor countries are located to a great extent in zones largely affected by volcanic activity, seismicity, flooding, etc. The second reason is linked to the historical development of these poor countries, where the economic, social, political and cultural conditions are not good, and consequently act as factors of high vulnerability to natural disasters (economic, social political and cultural vulnerability).

Recently, attention has been paid to the prevention, reduction and mitigation of natural disasters by creating a Scientific and Technical Committee of the International Decade for Natural Disaster Reduction (IDNDR). Efforts within this international framework have been taken worldwide; however, since natural disasters continue to devastate developing countries (e.g. Hurricane Mitch in Central America), a major emphasis on prevention should be addressed [or undertaken] by institutions at all levels, namely international, national, regional, local, etc. Strategies for prevention of natural disasters are universal, yet, their applicability needs to take into account the particular characteristics of the threatened entity, in such a way that a better understanding of the vulnerability of a specified social entity (natural + human) could lead to the development of adequate disaster prevention strategies.

Understanding and reducing vulnerability is undoubtedly the task of multi-disciplinary teams. Amongst geoscientists, geomorphologists with a geography background might be best equipped to undertake research related to the prevention of natural disasters given the understanding not only of the natural processes, but also of their interactions with the human system. In this sense, geomorphology has contributed enormously to the understanding and assessment of different natural hazards (such as flooding, landslides, volcanic activity and seismicity), and to a lesser extent, geomorphologists have started moving into the natural disaster field.

This paper addresses the significance of the incorporation of geomorphologists into the national/regional/local groups of experts to establish adequate strategies of risk assessment and management. These strategies should be based on an understanding of the necessities derived from the vulnerability, both natural and human of the threatened social entities. Given the existence of differential vulnerabilities, this task is even more relevant in developing countries, located in areas prone to natural hazards and where the character of marginalization, and economical, political, social and cultural issues reduce the opportunities to prevent and cope with natural disasters.

2. Natural hazards and geomorphology

The term natural hazard implies the occurrence of a natural condition or phenomenon, which threatens or acts hazardously in a defined space and time. Different conceptualizations of natural hazards have not only evolved in time, they also reflect the approach of the different disciplines involved in their study. In this sense, a natural hazard has been expressed as the elements in the physical environment harmful to man (Burton and Kates, 1964); an interaction of people and nature (White, 1973); the probability of occurrence of a potentially damaging phenomenon (UNDRO, 1982); and as a physical event which makes an impact on human beings and their environment (Alexander, 1993).

Natural hazards are threatening events, capable of producing damage to the physical and social space where they take place not only at the moment of their occurrence, but on a long-term basis due to their associated consequences. When these consequences have a major impact on society and/or infrastructure, they become natural disasters.

The term hazard is often associated with different agents or processes. Some of those include atmospheric, hydrologic, geologic, biologic and technologic. Specifically, natural hazards are considered within a geological and hydrometeorological conception, where earthquakes, volcanoes, floods, landslides, storms, droughts and tsunamis are the main types. These hazards are strongly related to geomorphology since they are important ingredients of the Earth's surface dynamics. Hazards are the result of sudden changes in long-term behavior caused by minute changes in the initial conditions (Scheidegger, 1994). In this sense, geomorphic hazards can be categorized as endogenous (volcanism and neotectonics), exogenous (floods, karst collapse, snow avalanche, channel erosion, sedimentation, mass movement, tsunamis, coastal erosion), and those induced by climate and land-use change (desertification, permafrost, degradation, soil erosion, salinization, floods) (Slaymaker, 1996).

According to Gares et al. (1994) geomorphic hazards can be regarded as the group of threats to human resources resulting from the instability of the Earth's surface features. The importance of these features is concentrated on the response of the landforms to the processes, rather than on their original source. Notwithstanding the lack of the use of the concept geomorphic hazard (Gares et al., 1994; Slaymaker, 1996), geomorphology has an important task to fulfill in terms of natural hazards research. Magnitude and frequency, as well as temporal and spatial scale, are key geomorphic concepts strongly correlated to natural hazards.

Indeed, many contributions by geomorphologists or within the geomorphology field have been directed towards the analysis and understanding of natural hazards. Based on their observations of fluvial processes, Wolman and Miller (1960) introduced the importance of magnitude and frequency of different events and their significance on the landscape as a result of the total work performed by them. Therefore, the importance of both extreme events and high-frequency, low-magnitude events within geomorphic processes is determined by the relation of the work done on the landscape to the particular landforms resulting from it. For a given event, such as a natural hazard, magnitude and frequency exert a very important control on the impact of geomorphic processes since they have an influence on landform change and therefore, on the dynamic equilibrium in geomorphological systems.

The concepts of magnitude and frequency are essential for the assessment of natural hazards. For example, the consequences of a flood are measured using return periods, giving an idea of the characteristics the flood may have (magnitude) and how often it is likely to occur (frequency). Although flooding can be regarded as the typical example to represent the magnitude and frequency duality, it also can be well typified by processes such as mass movement, volcanic activity, neotectonics and erosion. For instance, the significance of magnitude and frequency on mass movement has been demonstrated by the occurrence of slope failures under different conditions and on a great variety of materials. These events included storms with 50 years of recurrence intervals in Scotland (Jenkins et al., 1988), winter floods and their associated failures in humid temperate catchments (Dowdeswell et al., 1988), in the Pyrenees (Corominas and Moya, 1996), in Mediterranean environments (Montgomery and Dietrich, 1994; Thornes and Alcántara-Ayala, 1998) and in Colombia (Terlien, 1996) to mention a few.

The dynamism of the Earth's surface is enclosed within a temporal and spatial scale. The response of the landform to the changes caused by the processes corresponds to the magnitude and frequency of the events, the resistance of the involved materials and the size of the concerned landform (Summerfield, 1991). Natural hazards take place in a certain place and during a specific time, but their occurrence is not instantaneous. Time is always involved in the development of such phenomena. For example, flooding triggered by hurricanes or tropical storms is developed on a time basis. Atmospheric perturbations lead to the formation of tropical storms, which may evolve into hurricanes, taking from a few hours to some days. Hence, the intensity and duration of rainfall in conjunction with the nature of the fluvial system, developed also on a time basis, would determine the characteristics of the flooding.

3. Natural disasters

3.1. Defining natural disasters

Several definitions of natural disasters emphasize the character of this term. During the 1960s disasters

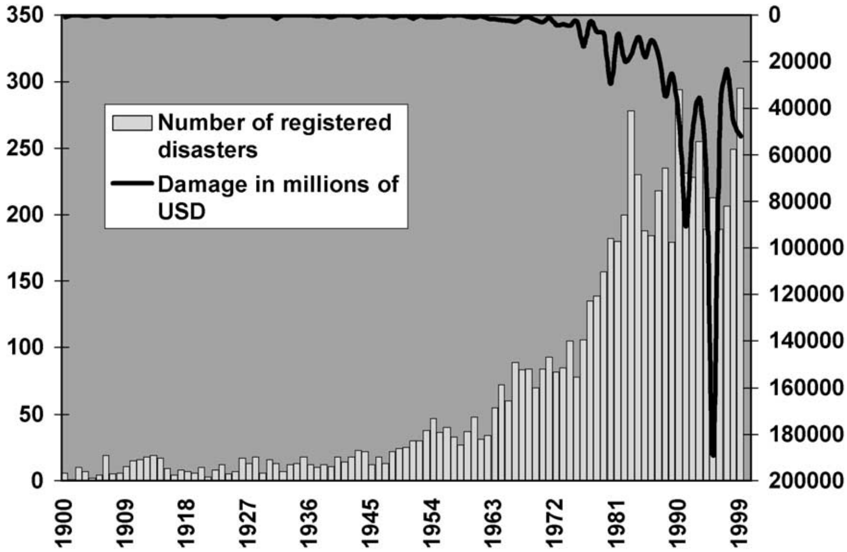

Fig. 1. Number of disasters and associated damage worldwide between 1900 and 1999 (Source: EM-DAT database).

were understood as uncontrollable events in which a society undergoes severe danger, disrupting all or some of the essential functions of the society (Fritz, 1961). The idea of a defenseless society clearly damaged by a powerful natural force is expressed in a definition where a disaster is a severe, sudden and frequently disruption of normal structural arrangements within a social system, over which the social system has no control (Barkun, 1974).

Westgate and O'Keefe (1976) were among the first to recognize the importance of vulnerability by defining disaster as the interaction between extreme physical or natural phenomena and a vulnerable human group, resulting in general disruption and destruction, loss of life, and livelihood and injury. IDNDR (1992) defined a disaster as "a serious disruption of the functioning of a society, causing widespread human, material, or environmental losses which exceed the

Fig. 2. People killed and affected as a result of the natural disasters occurring in the world between 1950 and 1999 (Source: EM-DAT database).

Table 1
Some of the major geomorphology related natural disasters of the world from 1900 to 1999 (Data source: EM-DAT and * the Office of US Foreign Disaster Assistance)

Disaster	Year	Country	Killed	Affected
Flood	Jul-1931	People's Republic of China	3,700,000	28,500,000
Flood	Jul-1959	People's Republic of China	2,000,000	–
Flood	Oct-1949	Guatemala	40,000	–
Flood/mudslides *	Dec-1999	Venezuela	30,000	600,000
Flood	Aug-1998	People's Republic of China	3656	238,973,000
Flood	10-Aug-1998	India	1811	29,227,200
Flood	06-Aug-1998	Sudan	1393	338,000
Flood	09-Sep-1998	Mexico	1256	400,000
Flood	7-Jul-1993	India	827	128,000,000
Flood *	28-Feb-1999	Mozambique	23	177,000
Cyclone *	18-Oct-1999	India	9465	15,000,000
Cyclone	2-Oct-1963	Grenada, Trinidad y Tobago, Dominican Republic, Haiti, Jamaica, Cuba, Bahamas	7258	–
Cyclone	Nov-1964	Vietnam	7000	700,000
Cyclone	3-Sep-1930	Dominica/Dominic Republic	6500	20,000
Cyclone	8-Sep-1900	United States	6000	–
Cyclone (Mitch)	26-Oct-1998	Honduras	5657	2,100,000
Cyclone	09-Jun-1998	India	3000	4,600,000
Cyclone (Mitch)	26-Oct-1998	Nicaragua	2447	868,000
Cyclone (Mitch)	26-Oct-1998	Guatemala	263	105,700
Cyclone (Mitch)	26-Oct-1998	El Salvador	240	84,000
Storm	25-Nov-1998	Bangladesh	200	121,000
Earthquake	5-Oct-1948	Soviet Union	110,000	–
Earthquake	28-Dec-1908	Italy	75,000	150,000
Earthquake/debris avalanche	31-May-1970	Peru	66,794	3,216,240
Earthquake	6-Dec-1939	Turkey	32,962	–
Earthquake	24-Jan-1939	Chile	30,000	58,500
Earthquake	13-Jan-1915	Italy	30,000	–
Earthquake	4-Feb-1976	Guatemala	23,000	4,993,000
Earthquake *	17-Aug-1999	Turkey	15,466	23,954
Earthquake	21-Jan-1917	Indonesia	15,000	–
Earthquake	28-Feb-1960	Morocco	12,000	25,000
Earthquake	23-Dec-1972	Nicaragua	10,000	720,000
Earthquake	21-Jan-1944	Argentina	10,000	155,000
Earthquake	19-Sep-1985	Mexico	8776	130,204
Earthquake	16-Aug-1976	Philippines	6000	181,348
Earthquake	29-Apr-1903	Turkey	6000	–
Earthquake	18-Feb-1951	Papua New Guinea	3000	–
Earthquake *	26-Sep-1999	Taiwan	2084	100,000
Earthquake *	25-Jan-1999	Colombia	1171	745,000
Volcano	8-May-1902	Martinique	40,000	–
Volcano	13-Nov-1985	Colombia	21,800	12,700
Volcano	1909	Indonesia	5500	–
Volcano/mudflows	1919	Indonesia	5000	–
Volcano	15-Jan-1951	Papua New Guinea	3000	–
Volcano	21-Aug-1986	Cameroon	1734	4634
Avalanche	13-Dec-1916	Italy/Austria	10,000	–
Tsunami	17-Jul-1998	Papua New Guinea	2182	9199

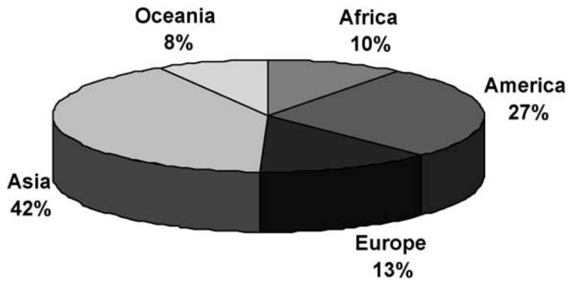

Fig. 3. Percentage of the number of disasters registered from 1900 until 1999 by regions of the world (Source: EM-DAT database).

ability of affected society to cope using only its own resources. Disasters are often classified according to their speed of onset (sudden or slow), or according to their cause (natural or man-made)''.

The dual character of natural disasters has been addressed by considering not only the natural character, but also the social and economic systems. As a result, a natural disaster can be defined as some rapid, instantaneous or profound impact of the natural environment upon the socio-economic system (Alexander, 1993), or as a suddenly disequilibrium of the balance between the forces released by the natural system and the counteracting forces of the social system. The severity of such disequilibrium depends on the relation between the magnitude of the natural event and the tolerance of human settlements to such an event (Albala-Bertrand, 1993). As explained by Tobin and Montz (1997), a disaster is an event that has a big impact on society. It is a hazardous event that disrupts the workings of society. It may or may not lead to deaths, but it typically has severe economic impacts.

By reviewing definitions of natural disasters it is clear that there is a tendency to include either the physical events as cause of the disaster, or to acknowl-

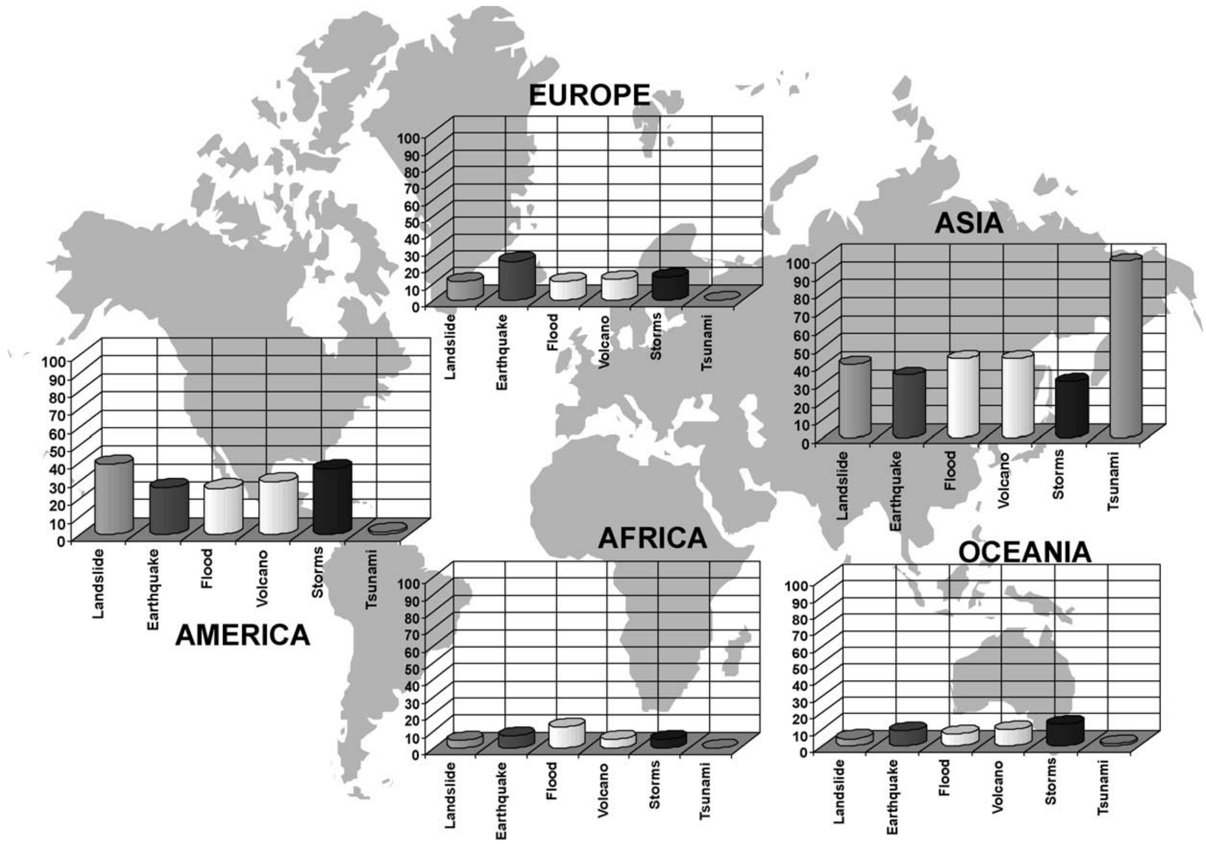

Fig. 4. Occurrence of different types of disasters by regions of the globe. Cylinder bars show the percentage of each particular disaster in a given region in relation to the whole world (Source: EM-DAT database).

edge that the social and economic systems take part as well as nature. In some cases, the possible consequences of the natural disasters are stated, whereas the reason why they occur is frequently omitted.

3.2. Where do natural disasters occur?

Natural disasters are a global issue as they occur all over the world (Figs. 1 and 2). Even though they may have a considerable impact in countries such as Japan, USA, France or Switzerland, their significance in countries such as Bangladesh, India, China, Guatemala, Colombia or Mexico is by far greater (Table 1). The global death toll due to natural disasters is concentrated in developing countries (also called Third World Countries), and it can be as high as 95% of the total toll (Alexander, 1993).

Most of the developing countries are located in areas especially prone to natural hazards. Volcanism is associated with specific areas such as the Circum-Pacific Volcanic Belt, where approximately 80% of the total activity takes place (Anderson and Decker, 1992). Many Latin American and Asian countries are located within this area, and the effect volcanism and its associated risks may cause to the population living in close proximity is observed in disasters such as the catastrophe of Nevado del Ruiz in Colombia (21,800 people killed).

Asia and Latin America share the highest concentration of flooding and associated risks due to hurricanes, cyclones, tropical storms, typhoons, and monsoons. They are also the areas most susceptible to earthquakes. According to the registered natural disasters which occurred between 1900 and 1999 (Fig. 3), 42% of the total number took place in Asia, whereas America had 27%, Europe 13% and Oceania and Africa, 8% and 10%, respectively (EM-DAT database, Office of US Foreign Disaster Assistance and the Centre for Research on the Epidemiology of Disasters OFDA/CRED). The spatial distribution of natural disasters (Fig. 4) shows a clear tendency to occur in developing countries. In addition, their impact is reflected given the cost the consequences have in relation to the GNP, GDP and the time needed for partial or total recovery. For instance, more than 9000 people lost their lives and about 11% (3.2 million people) of the total population in Central America was affected by the consequences of Hurricane Mitch. The impact was not homogeneous in all the countries. In Honduras the losses were equivalent to 80% of the 1997 GDP, whereas those in Nicaragua were almost 49% of GDP. The total losses of the whole region were estimated at US$6 billion (Table 2), having a slightly larger concentration of direct (51.5%) than the indirect (48.5%) damage. Furthermore, the damage to the population (Table 3) can be barely evaluated in financial terms and in relation to the post-disaster recovery time (CEPAL, 1999).

The case of Hurricane Mitch in Central America shows that even though the susceptibility of these

Table 2
Summary of damage in millions of dollars caused by Hurricane Mitch in Central America (Source: CEPAL, 1999, based on official figures and their own estimates)

	Total	Direct damage	Indirect damage	Replacement cost
Total sectors	6018.3	3100.3	2918.0	4477.3
Social sectors	798.5	551.8	246.6	975.1
Housing	590.9	436.3	154.6	746.3
Health	132.7	53.8	78.9	117.0
Education	74.9	61.8	13.1	111.8
Infrastructure	1245.5	656.9	588.6	1756.5
Roads, bridges and railways	1069.5	528.1	541.5	1427.9
Energy	58.7	28.6	30.1	60.6
Water and sewerage systems	91.4	74.6	16.8	224.4
Irrigation and drainage	25.8	25.6	0.2	43.6
Productive sectors	3906.9	1824.1	2082.8	1635.2
Farming, fishing and forestry	2946.5	1701.9	1244.6	1302.0
Manufacturing industry	608.0	32.8	575.2	69.9
Trade, restaurants and hotels	352.4	89.4	263.0	263.3
Environment	67.4	67.4	0.0	110.5

Table 3
Population affected by Hurricane Mitch in Central America (Source: CEPAL, 1999, based on official figures)

Item	Total	Costa Rica	El Salvador	Guatemala	Honduras	Nicaragua
(1) Dead	9214	4	240	268	5657	3045
(2) Missing	9171	3	19	121	8058	970
(3) Injured	12,842	–	–	280	12,275	287
(4) In shelters	466,271	5411	55,864	54,725	285,000	65,271
(5) Total evacuated and direct victims	1,191,908	16,500	84,316	105,000	617,831	368,261
(6) Population directly affected	3,464,662	20,000	346,910	730,000	1,500,000	867,752
(7) Children under five	1,801,624	10,400	180,393	379,600	780,000	451,231
(8) Total population	31,648,907	3,270,700	6,075,536	11,645,900	6,203,188	4,453,583
(9) Percentage affected	10.9	0.6	5.7	6.3	24.2	19.5

countries to natural disasters is high due to the environmental setting (in a non-deterministic sense), issues related to the social, economic, political and cultural aspects of any social entity play a great role as factors of vulnerability to natural disasters. Although poverty and natural disasters should not be considered as synonyms, it is certain that some characteristics, resulting from the economic–social–political–cultural system reduce or eliminate equal access to opportunities, and therefore to development. These characteristics increase vulnerability. Therefore, the occurrence of natural disasters in developing countries is not only linked to the susceptibility of natural hazards due to geological–geomorphological features and geographical location, but also, due to the vulnerability of the system where they exist.

An example of the coupling of natural and human vulnerability by analyzing the 1985 earthquake of Mexico City was presented by Blaikie et al. (1994). The city was erected on the bed of an ancient lake, making the soil highly vulnerable to earthquakes and associated processes such as liquefaction (natural vulnerability). Construction of buildings within the zone was performed using materials of diverse type and quality, during different periods of time. High population density, low-income jobs and poverty contributed to poor housing standards (social and economic vulnerability). All the elements derived from the particular natural, social, and economic vulnerability of the area were combined at the time of the earthquake producing zones of disaster. This case and the consequences of hurricane Mitch underpin the need of both types of vulnerability analysis to better understand and prevent natural disasters.

4. Natural disasters and geomorphology

Little has been done to associate geomorphology and natural disasters directly. Few publications in geomorphology deal specifically with this issue (e.g. Okuda, 1970; Verstappen, 1989; Rosenfeld, 1994). However, innumerable works related to natural hazards have represented the significance of geomorphology to the natural disaster field. Geomorphologists have been concerned with the understanding, analysis and forecast of hazards such as flooding, mass movement, earthquakes and volcanism.

Flooding associated with hydrometeorological phenomenon namely tropical storms, hurricanes, monsoons (Kale et al., 1994), El Niño or La Niña is regarded as one of the most dangerous natural hazards and principal trigger of disasters. Fluvial geomorphologists have paid considerable, attention to flooding. Approaches to understand this process include the study of past events or palaeoflood geomorphology and flood hydrology (Enzel et al., 1993; Baker, 1994; Kale et al., 1997). Furthermore, flood simulations (Enzel and Wells, 1997; Bates and De Roo, 2000; Chang et al., 2000), forecasting (Chowdhury, 2000) and flood maps elaborated by using Geographical Information Systems (GIS) (Merzi and Aktas, 2000), radar imagery (Zhou et al., 2000) and remote sensing (Islam and Sado, 2000; Siegel and Gerth, 2000) have been a crucial aspect in the development of hazard and risk assessment and management.

Based on different approaches such as mapping (Canuti et al., 1987; Leroi, 1997; Yin, 1994), the elaboration of inventories (Al-Homoud and Tubeileh, 1997; Chacón et al., 1996; Guzzetti et al., 1994), analysis of historical archives (Brunsden, 1993; Ibsen and Brunsden, 1996; Domínguez-Cuesta et al., 1999), field observations, sampling, laboratory testing, monitoring (Gili et al., 2000), modeling (Brunsden, 1999; Sousa and Voight, 1992), the use of photogrammetry (Chandler and Cooper, 1989; Chandler and Moore, 1989; Chandler and Brunsden, 1995), GIS (Carrara et al., 1990; Dikau and Jaeger, 1993; Dikau et al., 1992; Proske, 1996) and remote sensing (Mantovani et al., 1996; Singhroy et al., 1998), geomorphologists have focused on the different aspects of mass movement, including landslide hazard analysis (Hansen, 1984) and assessment (Hutchinson, 1992; Petley, 1998). In addition, there is a tendency to integrate hydrological modeling into mass movement investigations (Anderson et al., 1996; Brooks and Collison, 1996; Collison et al., 1995; Collison and Anderson, 1996; Montgomery and Dietrich, 1994; Van Asch and Buma, 1997). This integrative approach, where hydrological models are coupled to mass failure models, has improved the understanding of mass movement and yield better and more precise predictions of mass failure.

Geomorphology has also contributed in the fields of volcanic (Thouret, 1999) and seismic hazards (Panizza, 1991). Geomorphologic surveys have been used as the base for volcanic hazard zoning (Verstappen, 1988, 1992), risk (Pareschi et al., 2000), volcanic management crisis (Gómez-Fernández, 2000), and to promote natural disaster reduction (Elsinga and Verstappen, 1988). Furthermore, the analysis of tectonic activity has been used as a key element for seismic hazard assessment (Galadini and Galli, 2000), and such earthquake assessment has also been applied to environmental planning (Panizza, 1981). Earthquake hazard zonation of the most vulnerable areas such as Mexico (Ordaz and Reyes, 1999) and Turkey (Erdik et al., 1999) has been performed to have a better

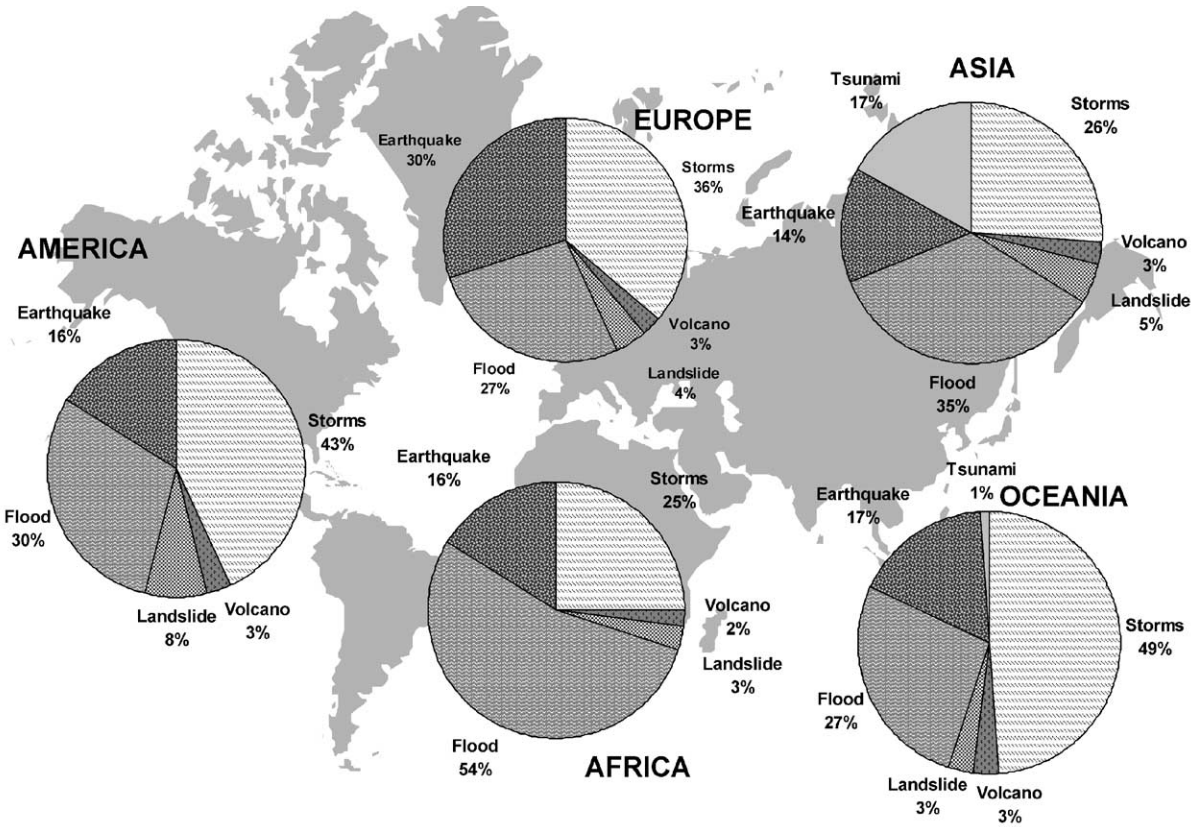

Fig. 5. Percentage of geomorphology related disasters by type and region from 1900 to 1999 (Source: EM-DAT database).

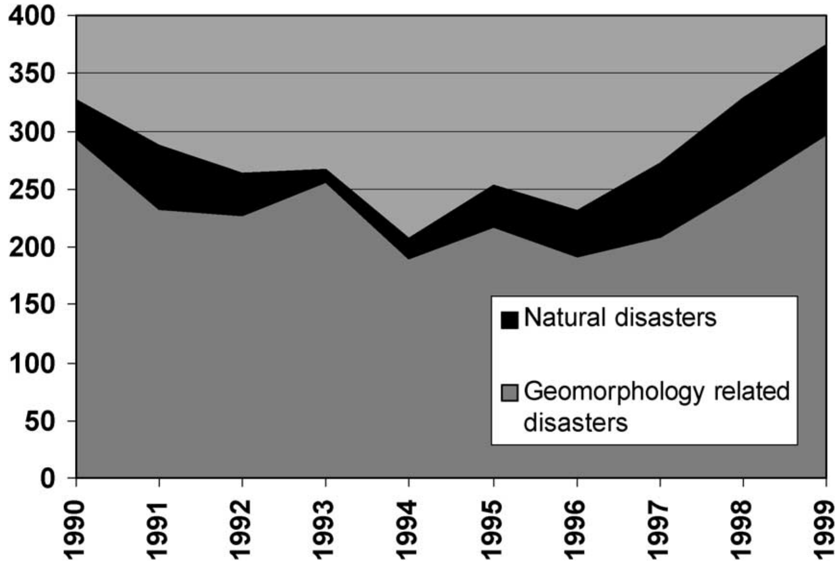

Fig. 6. Natural and geomorphology related disasters registered from 1990 to 1999 worldwide (Source: EM-DAT database).

panorama of the occurrence of such events and their consequences.

In the geomorphological dimensions of natural disasters, Rosenfeld (1994) examined the contributions of different geomorphological projects to interdisciplinary research, including rainfall-induced landsliding, cyclonic storms, flooding, etc. Certainly, the use of remote sensing, Global Positioning System (GPS) and GIS, has led to the incorporation of geomorphologists into the mapping, analysis and modeling of such geophysical, hydrological and geomorphological processes within the natural and human hazards approach. Rosenfeld illustrated the relationship between the natural and human sides of the

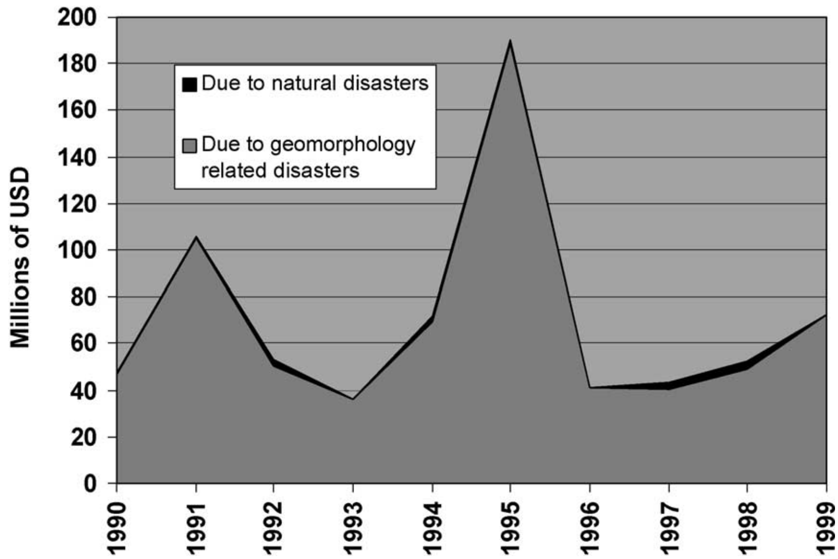

Fig. 7. Estimated damage due to natural and geomorphology related disasters from 1990 to 1999 (Source: EM-DAT database).

Table 4
Total number of people reported killed, by continent and by type of phenomenon from 1990 to 1999 (Source: EM-DAT database)

	Africa	Americas	Asia	Europe	Oceania	Total
Slides	225	2010	5500	644	279	8658
Droughts	12	0	2680	0	98	2790
Earthquakes	816	3519	91,878	2395	70	98,678
Floods	9487	35,598	55,916	2839	30	103,870
Wind Storms	1612	13,264	185,739	913	262	201,790
Volcanoes	0	77	994	0	9	1080
Total	12,152	54,468	342,707	6791	748	416,866

extent of natural hazards by using a pyramid-form graph, where the faces represent the duration and areal extents of different hazards in terms of casualties and hazard severity according to the different degree of development of the countries, and based on the level response needed to cope with the disasters as a function of economic development.

By analyzing the EM-DAT database, which includes phenomena such as slides, floods, earthquakes, volcanoes, wind storms, extreme temperatures, droughts, wild fires, and epidemics as natural disasters, it can be noticed that with exception of extreme temperatures and epidemics, all the other phenomena are geomorphology related. Fig. 5 presents the percentage of those disasters related to geomorphology by type and region from 1900 to 1999. Between 1990 and 1999, 2808 disasters were recorded worldwide. Eighty four percent of them were related to geomorphology (Fig. 6). The total amount of estimated damage (Fig. 7) in relation to the global natural disasters registered within the same period of time, and the number of people reported killed (Table 4) and affected (Fig. 8) give a good indication of the significance of geomorphology for the prevention of natural disasters.

The contribution of geomorphology to the field of natural disasters is mainly through the elaboration of hazard assessments. In general, such assessments comprise stages like mapping, modeling, prediction and management proposals, using field observations, photogrammetry, geographical information systems and remote sensing the zonation and mapping of different hazards is done. Modeling approaches consider not only the understanding of present, but past events, leading to accurate predictions of the consequences a geomorphic hazard may have on a determined landscape under a given conditions.

Hazard assessment is a key part within the risk analysis process. Certainly, geomorphologists have contributed enormously on this matter. Nevertheless,

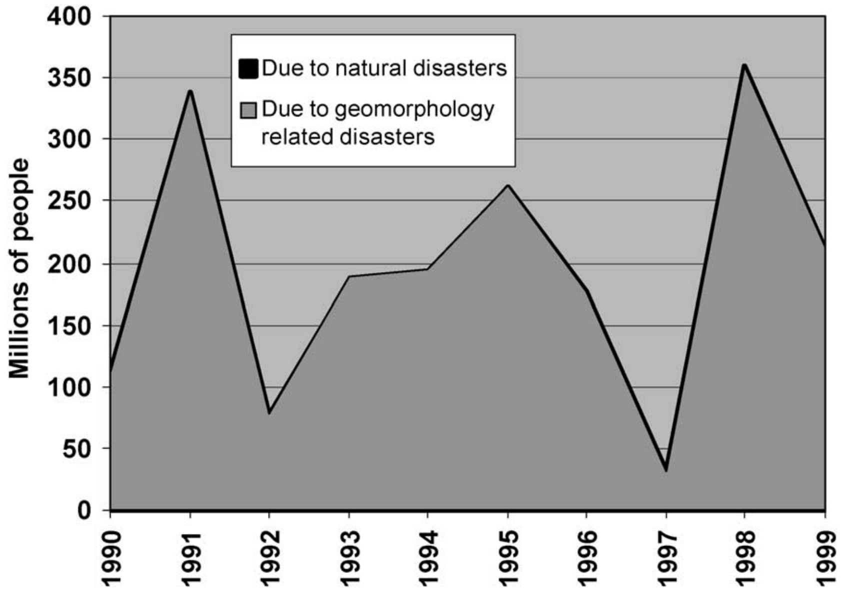

Fig. 8. People affected due to natural and geomorphology related disasters from 1990 to 1999 (Source: EM-DAT database).

a greater progress would be achieved if vulnerability analysis were also taken into account.

5. Geomorphology, vulnerability and disasters

By examining the different definitions of natural hazards and natural disasters, it is clear that the conceptualization has changed from a perspective of a merely physical or natural event, towards the integration of the human system. Initially, the uncontrollable character of natural hazards directed efforts towards coping with their impacts and also towards the prediction of these events. Technological advances and the development of prediction models for volcanic activity, hurricanes, tsunamis, flooding, landsliding, etc. were developed seeking a better understanding of the phenomena and to some extent to offer possibilities to cope with the impact of natural hazards, but mainly in ‘developed countries’.

Later, in the 1960s, the idea of the devastation by natural disasters as a result of the social and economic characteristics of the regions where natural hazards took place was introduced (White, 1961, 1964; Kates, 1962; Burton et al., 1968; Hewitt and Burton, 1971). However, it was not until the 1970s that the role of economic and social conditions as factors of vulnerability to natural disasters was acknowledged.

The interest of understanding not only the natural events per se, but the characteristics of risk in the areas prone to these phenomena, has moved the attention of many social scientists towards the study of risk and vulnerability (e.g., Albala-Bertrand, 1993; Blaikie et al., 1994; Cannon, 1993; Varley, 1991; Winchester, 1992). Previous investigations have shown the need for defining and measuring hazard events in a non-scientific (physical) view. This includes the description and analyses of different perceptions of hazard (Burton et al., 1968) based on the concept of differential perception of risk, a very important factor in the development of risk management approaches.

At the present time, not only social scientists but geoscientists are considering the socio-economic character of some regions prone to natural hazards, as one of the main factors of vulnerability to natural disasters. For instance, Cardona (1997) considered the social, economic and institutional aspects within the management of the crisis of Galeras volcano in Colombia. Dibben and Chester (1999) proposed a framework to analyze human vulnerability in the case of Furnas volcano in the Azores. They recognized that people’s vulnerability to volcanic hazards implies an interaction of different elements related to the social context and the corresponding physiological and psychological characteristics. In his overview of volcanic geomorphology, Thouret (1999) pointed out that in order to cope with the consequences of natural hazards and their interaction with people living around the volcanoes, geomorphology is an essential part to undertake risk assessment based on geomorphic hazard and risk zonation.

5.1. A closer look to vulnerability

The study of vulnerability related to natural disasters has been the focus of different investigations and hence, of several definitions. Westgate and O’Keefe (1976) defined vulnerability as the degree to which a community is at risk from the occurrence of extreme physical or natural phenomena, where risk refers to the probability of occurrence and the degree to which socio-economic and socio-political factors affect the community’s capacity to absorb and recover from extreme phenomena. For Varley (1991), vulnerability is a function of the degree of social and self-protection available to potential victims. It is clearly related to the ability of households or communities to cope with and recover from outside events and particularly to shocks and sudden changes (Maskey, 1993). It also concerns the predisposition of a society to experience substantial damage as a result of natural hazards (Clarke and Munasinghe, 1995). These definitions imply that vulnerability is the result of the socio-economic and political systems of the entity in danger. However, it is the definition of Cannon (1993), which considers different factors affecting or producing the vulnerability of individuals or groups, that is most germane. According to him, vulnerability “is a characteristic of individuals and groups of people who inhabit a given natural, social and economic space, within which they are differentiated according to their varying position in society into more or less vulnerable individuals and groups. It is a complex characteristics produced by a combination of factors derived especially (but not entirely) from class, gender, or ethnicity.” Cannon divided vulnerability into three parts: (1) Livelihood resilience: the degree of resilience of the particular livelihood system of an individual or group, and their capacity for resisting the impact of hazard. (2) Health: including both the robustness of individuals, and the operation of various social measures. (3) Preparedness: determined by the protection available for a given hazard, something that depends on people acting on their own behalf, and social factors.

These three aspects cover a great proportion of the different kinds of vulnerabilities. Nevertheless, each aspect has different components and the combinations of them can be so numerous that it is necessary to specify the particular types of vulnerability of each threatened entity. The latter will provide an adequate understanding of the total vulnerability to natural disasters so that prevention can be effectively accomplished. This insight strengthens the contribution of Aysan (1993), who recognizes different kinds of vulnerability, as follows:

- Lack of access to resources (materials/economic vulnerability)
- Disintegration of social patterns (social vulnerability)
- Lack of strong national and local institutional structures (organizational vulnerability)
- Lack of access to information and knowledge (educational vulnerability)
- Lack of public awareness (attitudinal and motivational vulnerability)
- Limited access to political power and representation (political vulnerability)
- Certain beliefs and customs (cultural vulnerability)
- Weak buildings of weak individuals (physical vulnerability)

There are indeed many other kinds of vulnerability. However, all of them can be inserted within four main types of vulnerability: social, economic, political and cultural. This classification indicates that each social entity has different types of vulnerability, and it is not only the result of the human actions, decisions and choices, it is the result of the interaction of the natural, economic, social, cultural and political contexts where people live. Vulnerability cannot be treated as a homogeneous and general term; its dynamism is given by each society, and it is both a universal and particular concept. There is certainly a differential character of vulnerability. Vulnerability is given by the coupling between the natural and human systems (Fig. 9). In this sense, vulnerability can be divided into natural vulnerability and human vulnerability. Natural vulnerability depends on the threatening natural hazard (very much related to geographical location), thus, there is volcanic vulnerability, flooding vulnerability, landsliding vulnerability, tsunamis vulnerability, hurricane vulnerability and so on. On contrast, human vulnerability is based on the social, economical, political and cultural systems.

Hence, vulnerability can be defined as the propensity of an endangered element due to any kind of natural hazard to suffer different degrees of loss or amount of damage depending on its particular social, economic, cultural, and political weaknesses. Total vulnerability is a function of the individual types of vulnerability present in a given area. Such vulnerability determines the magnitude of the disaster, the level of resilience and the recovery process.

5.2. A step forward into the prevention of natural disasters: applied geomorphology

The reduction of natural vulnerability could be obtained from an equal access to scientific informational resources and methodologies for the understanding and prediction of natural hazards (e.g. state-of-art predicting models) and to international training programs. Natural hazards cannot be prevented, but the understanding of the process and scientific methodologies to predict patterns of behavior of such processes can be powerful tools to help reduce natural vulnerability.

Geomorphological research can provide theoretical and applied approaches to the prevention of natural disasters in terms of origin and dynamism of the physical processes. Furthermore, geomorphologists could also offer important contributions based on the understanding of the interaction between natural hazards (natural vulnerability) and the societies (human vulnerability). Consequently, they should be involved to a greater extent in such tasks, as is the case of the contributions of D. Alexander, M. Panizza and H.T. Verstappen—to mention the most familiar examples—who not only have shed light on understanding geo-

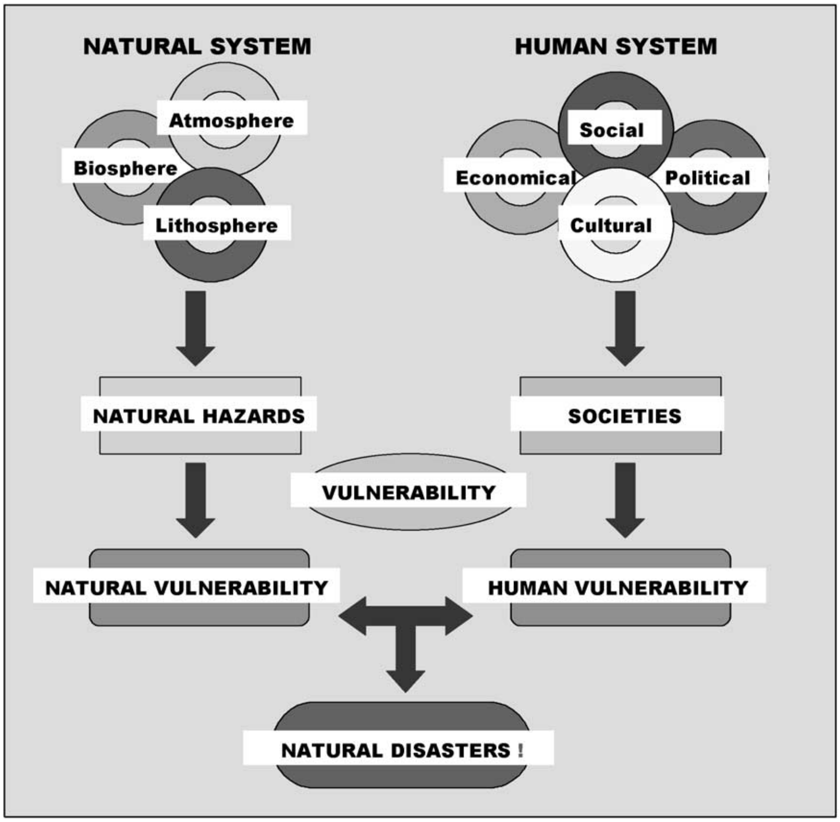

Fig. 9. The ingredients of natural disasters.

morphological processes, but also on the strong link between the processes and society.

Geomorphology can be considered a strategic discipline in the reduction of both human and natural vulnerabilities. By contributing to the understanding of endogenetic and exogenetic processes, methodologies to predict patterns of occurrence of hazardous events can be developed and applied. Geomorphologists assist in the reduction of natural vulnerability in three different ways: first, by enriching the theoretical knowledge of geomorphology, which is the base of the application of our discipline; second by developing prediction models for different processes such as landsliding, flooding, volcanism, among others; and finally, through diversified approaches of applied geomorphology for the prevention of natural disasters. Indeed geomorphology is a powerful field that must play a role in the interdisciplinary efforts to develop adequate strategies for prevention and mitigation of natural disasters. Nonetheless, contributions of geomorphology would be even more significant if research applications were directed towards the understanding and coupling of human and natural vulnerabilities. Reduction of natural disasters is a complex task by nature; however, it is now clear that a combination not only of social and scientific knowledge, but also, of attitudes towards the elaboration of adequate strategies based on vulnerability analysis of the particular social entities is urgently required.

6. Conclusions

Natural hazards are threatening events, capable of producing damage to the physical and social space in which they take place not only at the moment of their occurrence, but in the long-term, due to their associated consequences. When these consequences have an impact on society and/or infrastructure, they become natural disasters. These can be considered as sudden but expected (we all know that they occur) natural events, which impact the human and natural systems. The degree of their impact in space and time is a function of the exposure to and the magnitude of the natural phenomena (natural vulnerability) and the human vulnerability of the threatened entity.

Natural disasters occur all over the world; however, their impact in developing countries is greater due to the geographical location in zones highly susceptible to natural hazards (natural vulnerability), and also due to the different types of economic, social, political and cultural vulnerabilities that exist. These vulnerabilities are indeed the result of their historical development and their social, political, economic and cultural contexts. The rich get richer, the poor, poorer and the access to opportunities within the social entity are unequal and indirectly proportional to the occurrence of natural disasters (the less opportunities, the more vulnerability, the more affected by natural disasters).

The International Decade for Natural Disaster Reduction (IDNDR) has achieved several goals such as the organization of international groups to provide advice on the prevention of natural disasters on regional and national bases. Events such as Hurricane Mitch in Central America (October 1998), the earthquake in Turkey (August 1999) and their devastating consequences demonstrated that natural disasters occur in places where the geographical coordinates of natural and human vulnerabilities converge. An effort must be made to promote the elaboration of vulnerability analysis within a risk assessment and management framework, where not only geomorphology, but also geomorphologists play a key role for the prevention of natural disasters. The latter needs indeed to be more rapidly implemented in developing countries.

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