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DAMAGE AND THE BUILT ENVIRONMENT

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Synonyms

Losses; Urban areas; Urban environment

Definition

Damage: Losses, injuries, failures, or troubles which may occur in a given area as a consequence of the impact of a hazard on exposed and vulnerable elements and systems. Types and amount of damage depend on the features of both hazards and exposed elements and systems.

Built environment: The areas most modified by human beings, where people and all man-made structures are concentrated. It is generally opposite to the natural environment, even though close relationships between the built and natural environments are largely recognized. Built environments can greatly differ, in terms of spatial and functional patterns. The various types of built environments respond differently to hazards: that is, a densely built up historical city and a recent low-density urban area have a different susceptibility to damage from a given hazard.

Introduction

The damage due to natural hazards in built environments generally refers to the physical destruction to man-made structures and to the impacts on people. These types of damages are generally defined as direct damages and occur at the onset of a disaster or shortly thereafter. Direct damages can be due both to a primary hazard or to its impact on exposed vulnerable elements which represent, in turn, further hazard sources: for example, damages to buildings or people due to fires following an earthquake which causes, in turn, breaks in gas pipelines. Such damages are very common in the built environment, as clearly highlighted by several disasters that have occurred in the recent past. Nevertheless, in many cases, official reports do not distinguish the damages in relation to the different hazard sources.

Besides direct damages, indirect ones may occur and can result from physical damages affecting the functioning of some elements or systems (hospitals, lifelines, etc.) or inducing economic consequences (temporary unemployment due to physical damages to industries). Indirect damages may even occur over a long period of time after the event, affecting broader areas than that directly hit by the hazard. Permanent or temporary losses in relevant economic activities at local scale can reverberate on macroeconomic variables.

By their nature, indirect damages are harder to quantify than physical ones. The amount of indirect damages may constitute the majority of the total losses in large disasters affecting urban areas. Nevertheless, long-term indirect damages are frequently neglected, mainly in official reports often designed to provide governments with estimates of the amount of funds required to address emergency and reconstruction needs.

The overall damage is quantified in terms of economic losses, generally including direct damages and the most relevant economic effects, as well as distinguishing the insured losses within the overall amount. It is worth noting that in many cases, the evaluation of indirect damages is made even more difficult by the “nonmarket effects.” Such effects are related to the loss in functioning of public equipment or infrastructure. Due to their public nature, such equipment provides services free of charge (Rose 2004); hence, damage cannot be easily assessed in economic terms.

Most of the available databases provide quantitative information related to damages to people (killed, injuries,

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homeless, missing, or evacuated) and to structures (number of damaged or destroyed buildings) and qualitative information highlighting the most affected sectors (industry, transport, etc.).

Typologies of damages

As previously mentioned, direct damages include physical damages and damages to people due to a primary hazardous event or to a secondary hazard triggered by the primary one. Since there is a close relation between hazard factors and physical damages, both the temporal and the geographical scale at which such damages generally occur are strictly related to the temporal and spatial scales of hazards themselves and may vary according to the type of hazard under consideration (earthquakes, landslides, or volcanic events induce different physical damages, over different temporal phases, and at different geographical scales).

A better understanding of the damages which can be classified as indirect requires a further distinction between "functional damages," meant as loss of efficiency or functioning affecting an element as a consequence of physical damages, and "systemic damages," meant as a loss of efficiency or functioning affecting an element or a system as a consequence of damages to other elements or systems.

Hence, systemic damages are generally due to the numerous interdependencies among elements or systems characterizing the built environment and are not directly related to the physical damages.

Given this distinction, functional damages are often taken into account due to their clear relationship to physical damage. For example, the most widespread methods for assessing damages have recently introduced parameters for the evaluation of functional damages linked to physical ones. In contrast, systemic ones are in many cases neglected, since they may reveal themselves in a medium or long term and can affect wide areas, even very far from the hazard source.

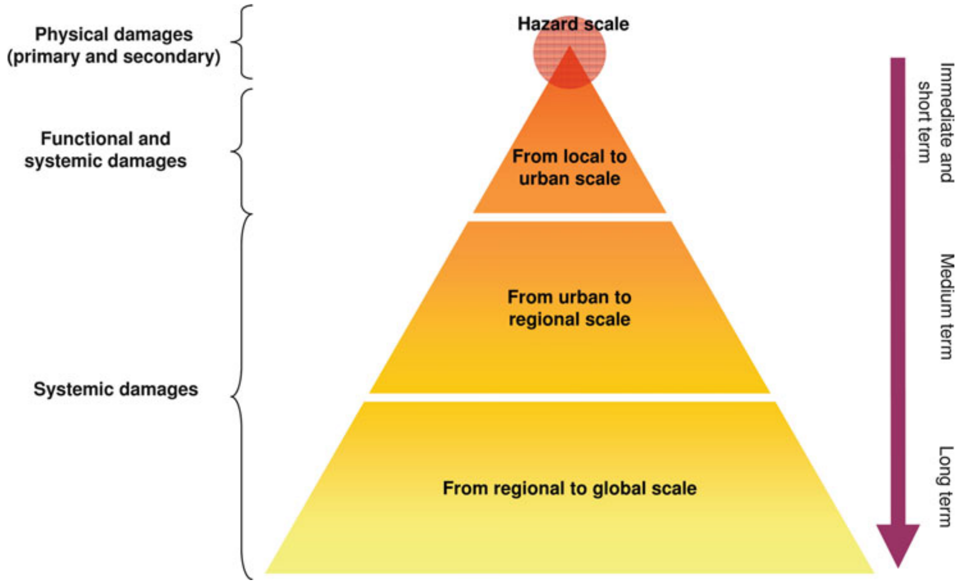
The pyramid of damages (Figure 1) shows the relationships among the different types of damages with respect to the spatial distribution of each type and to the time span in which they generally occur. The top of the pyramid represents the physical damages, occurring immediately after the hazardous event; the base represents the systemic damages. It is worth noting that there is a "fuzzy" boundary between functional and systemic damages, since functional damages are a direct consequence of physical ones and generally trigger ripple effects which reverberate on other elements, systems, or areas.

Finally, it is clear that since damages are "displaced, geographically and temporally, the narrower the time-space focus, the greater the likelihood that losses will be underestimated" (Cochrane 2004:39).

Chains of damages

A relevant challenge in analyzing and assessing damages derives both from potential chains of hazards and from physical damages inducing functional and/or systemic ones. Very often, it is difficult to distinguish in available databases such complex chains of causes and damages which characterize most of the large-scale disasters affecting urban areas.

As largely recognized in the current literature, disasters in the built environment are more and more "complex." According to McEntire et al. (2002), their growing complexity is due to changes of hazards, exposure, and



Damage and the Built Environment, Figure 1 The pyramid of damages highlights the correspondence among the types of damage, the geographical scales and the temporal spans at which they generally occur.

vulnerability of territorial systems and to the interactive mix of such changes.

As concerns hazard chains, they can have different levels of complexity, since a natural event can trigger one or more technological accidents and, in the interim, other secondary natural events. Additionally, a triggered technological event may induce, in turn, domino effects. In these cases, the phenomena have different features and the affected areas and targets will not necessarily overlap. Therefore, the damages may be due both to the effect of each hazard and to the synergies and overlapping among their impacts. Moreover, physical damages can result in losses of efficiency in different elements or systems which in turn, due to the interdependencies among them, may induce systemic damages.

Relationships between damage and built environment

Past disasters clearly highlight how much physical and functional characteristics of the built environment may affect the type and the amount of damage resulting from a hazardous event. The influence of physical features of the built environment on damages can be highlighted looking at the Kobe (1995) and the Northridge (1994) earthquakes. The two events had similar characteristics but very different outcomes. They had approximately the same magnitude; both of them occurred before the sunrise and affected metropolitan areas with high population density. However, the Northridge earthquake resulted in 57 dead, 1,500 injured, and 12,500 buildings seriously damaged, whereas the Kobe event caused about 5,500 deaths, 35,000 injured, and 180,000 buildings damaged. The overall damage caused by the Northridge earthquake was estimated at about 15 billion dollars, whereas the Japanese disaster cost approximately 147 billion dollars. Such a disproportion was due to several factors. First of all, the Northridge urban fabrics were regular and with high levels of accessibility, whereas in Kobe they were irregular and mostly developed along the coast. Moreover, the Japanese city is constrained between the sea and the mountains, with scarce cross-sectional roads and access from the outside. Consequently, the different urban morphologies created different conditions of accessibility for the rescuers in the emergency phase. For Kobe, the direct damages were significantly increased by fires due to breaks in gas pipelines caused by the earthquake. Such fires spread over a large area due to the structural typology of many old houses (wooden houses) as well as the interruptions in water supply which made the situation worse, thereby highlighting the role of systemic damages in large disasters.

Concerning the influence of functional features on damage, it is worth noting that areas characterized by social, economic, and functional weaknesses generally show high levels of physical damages. In contrast, large urban contexts, characterized by relevant activities (productive activities, mobility hubs, etc.), may show low levels of physical damages and high levels of functional and systemic ones which can expand over large areas.

Coupled human-natural environments

Even though damages induced by natural disasters on natural resources are in many cases negligible in the built environment, it is worth highlighting the need for taking into account the “vulnerability of coupled human-environment systems” (Turner et al. 2003: 8074) for a complete assessment of damage. Natural resources often represent the main target of secondary hazard due to the impact of the events on industrial plants or laboratories handling hazardous materials, gas pipelines, and so on. On the other hand, the everyday perturbations on natural resources due to human activities and to urbanization processes can cause or accelerate natural hazards or amplify their effects.

The twofold role played by natural resources was clearly highlighted during the Katrina hurricane, which impacted the city of New Orleans in 2005. In that case, the alteration of natural ecosystems before the hurricane contributed to the occurrence of the flood event, and the multiple damages due to the impact of flood on industrial plants induced relevant damages on natural resources, which had, in turn, short and long term repercussions on the social and economic systems. Moreover, in the Katrina event also the inadequate interventions undertaken during the emergency phase increased overall damage on environmental resources.

Measuring damages

The assessment of damage can be carried out after the hazardous event, to evaluate the dimension of the disaster, or before the event, to assess expected damage which represents a measure of the risk which a territory is prone to, with respect to a given hazard.

In both cases, the assessment is generally expressed in monetary or economic terms. For example, the European Union Solidarity Fund, established in 2002, is activated in cases of “major natural disasters,” when the estimated cost of the direct damage is over three billion Euros or over the 0.6% of the GDP of the affected state. Such thresholds are defined taking into account only the cost of direct damages. The economic amount of the disaster is determined by the total amount of exposed assets.

Consequently, the lower values of damages reported for less developed or poor countries, if compared with those occurring in more developed nations, are ineffective and sometimes hide significant damage, although not in economic terms, for exposed people.

The damage assessment before or after the event is generally referred to populations, buildings, and infrastructures including economic and productive activities, taking into account all the direct and some of the indirect damages.

Concerning population, in pre-event damage assessment methods, damage is generally expressed in quantitative terms, through the number of dead and injured people determined as a percentage of the total involved population. At urban and territorial scales, this percentage is generally obtained through statistical techniques, whereas at local scale it is specifically related to the expected damage level of building stock.

In the medium and long terms, the impact of the event on the population is expressed through the number of individuals that become homeless.

According to the close relationship between type and intensity of hazards and physical damages, natural hazard scales are based on the measure of damages produced in the built environment. For example, the Fujita Tornado Damage Scale was created to classify size and intensity of tornadoes in respect to the damages caused to man-made structures. Further examples are the Mercalli scale and the Parameterless Scale of Intensity (PSI) (Spence et al. 1991). Whereas the former is a discrete and subjective scale, the latter is a continuous one, based on curves which relate observed damage level in a given area to the intensity of the earthquake, for each structural type of building.

Generally, a damage scale classifies buildings into categories, ranging from complete destruction to no apparent damage. The scale of damage used by FEMA's HAZUS for earthquake, floods, and hurricane represents a widespread standard for post-event damage surveys. The HAZUS' damage models take into account both direct damages and some typologies of indirect ones, such as impacts on economic sectors over time, beds lost in hospitals, users not served by network services, and so on. The outputs are different for each type of hazard; for example, in case of earthquakes, direct losses in terms of repair costs, income losses, casualties, and shelter needs and indirect losses related to supply shortages, sales decline, or economic losses can be evaluated.

In the aftermath of disasters, damage assessment has been traditionally carried out through in-field surveys. Such surveys have some disadvantages, since the access to the affected areas is generally difficult in the immediate post event. Moreover, they require a long time to be applied, and although determined through analytic assessment forms, they can be influenced by the subjective judgments of the technicians. Some of the mentioned gaps can be overcome through remote-sensing damage assessment based on satellite and aerial images. These techniques allow the evaluation of the damage levels through quantitative methodologies based on remote-sensing characteristics observed from high-resolution optical imagery collected by satellites.

Furthermore, some techniques specifically addressed to evaluate functional damage have been developed, even though they are still in the early stages. These techniques are based on the assessment of the demand for activities and services arising after a hazardous event and the available supply in the impacted area. The balance between such components allows one to define the unsatisfied demand, which represents a measure of the functional damage (Galderisi and Ceudech 2009). These techniques can be helpful both for post- and pre-event assessment, mainly in relation to the loss in functioning of public equipments and infrastructures which, as mentioned above, is difficult to quantify in economic terms.

Conclusions

In summary, the different types of damages resulting from natural disasters in the built environment are at present largely recognized in scientific literature. Nevertheless, official reports and available databases generally focus on direct damages, whereas functional and systemic ones are mostly neglected. Furthermore, available techniques for the post-event assessment of physical damages are still mainly based on in-field surveys; damage assessment models based on remote-sensing techniques are however in development. With respect to medium and long-term systemic damages, data and standard assessment models are not currently available, even though some models are available in scientific literature.

Finally, the need for shifting from the couple hazard/physical damages towards the complex chains of hazards/physical, functional, and systemic damages, as well as for taking into account the role of the environmental resources into reports and data-bases on damage has to be emphasized.

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Cross-references

Costs (Economic) of Natural Hazards and Disasters
Disaster
Earthquake Damage
Fujita Tornado Scale
Mercalli, Giuseppe
Remote Sensing of Natural Hazards and Disasters
Risk
Urban Environments and Natural Hazards

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Synonyms

Rock avalanche; Sturzstroms

Definition

A debris avalanche is a large volume, extremely rapid, and, therefore, highly destructive *mass movement* involving unconsolidated material.

Introduction

Historical occurrence of catastrophic landslides in the European Alps during the nineteenth century animated early popular interest in *natural hazard* phenomena and fostered the development of scientific studies on *slope stability.* Thanks to eyewitness accounts and precise landslide reports, well-known Swiss *sturzstroms* of Rossberg (A.D. 1806) and Elm (A.D. 1881) described by Heim (1932) offered some basic knowledge for interpreting previous historical cases (such as Piuro; Figure 1) and identifying distinctive characteristics of these sudden failures of mountain slopes: the large dimensions of the displaced mass (volume $> 10^6$ m^3), the long runout (L = horizontal movement: up to 20–30 times greater than H = vertical drop), and high velocity (up to 100 m/s). Later comparisons between historic and prehistoric case studies (Eisbacher and Clague, 1984) allowed for a better distinction between *sturzstroms* of granular or rocky materials (i.e., distinction between *debris* and *rock-avalanches*). Recurrent geomorphic features and sedimentological characteristics of debris avalanches were then used for characterizing slope instabilities throughout the world, either in mountain environments (Hsü, 1975) or volcanoes (Siebert, 1984), and even the submarine environment. Recent advances in planetary science reveal debris avalanches also affect other bodies in our solar system (Shaller and Komatsu, 1994).

Geo-environmental contexts and typology

Debris avalanches, as defined by past and present classifications of slope instabilities (Sharpe, 1938; Varnes, 1958, 1978; Cruden and Varnes, 1996), are large, extremely rapid, and often open-slope (non-channelized) landslides. They act as important agents in geomorphological landscape evolution of both mountain ranges and volcanic areas, where they may result either from earthquakes, volcanic activity, heavy rainfall, or snow melting.

Rugged mountains, like the Alps, are prone to large slope instabilities because of the widespread occurrence of oversteepened slopes, particularly where rock masses and surficial deposits are unstable due to recent glacier debuttressing and retreat, and to *permafrost* degradation. Debris avalanches are also frequently and extensively activated by gravity-induced slope failures in active volcanic areas where they can be related to magmatic or phreatic eruptions, or also can be triggered by earthquakes or precipitation.

Due to the broad environmental distribution, and, therefore, different expertise and approaches being applied in their study, debris avalanches have sometimes undergone inconsistent classifications with respect to distinctive features, styles of movement, and to rheologic behavior of involved material. So far, major apparent discrepancies are related to the thickness of deposits and the water content of debris avalanches, which have been defined either as “shallow flows of partially or fully saturated debris (. . .) without confinement in an established channel” (Hungr, 2005), or as “the products of large scale collapses of a sector of a volcanic edifice under water-undersaturated conditions” (Ui et al., 2000). The following geomorphological and sedimentological notes are useful to describe distinctive features of debris avalanches deposits of both volcanic and nonvolcanic contexts and to interpret their characteristic transport mechanisms as flows or complex slides according to the categories of Cruden and Varnes (1996).

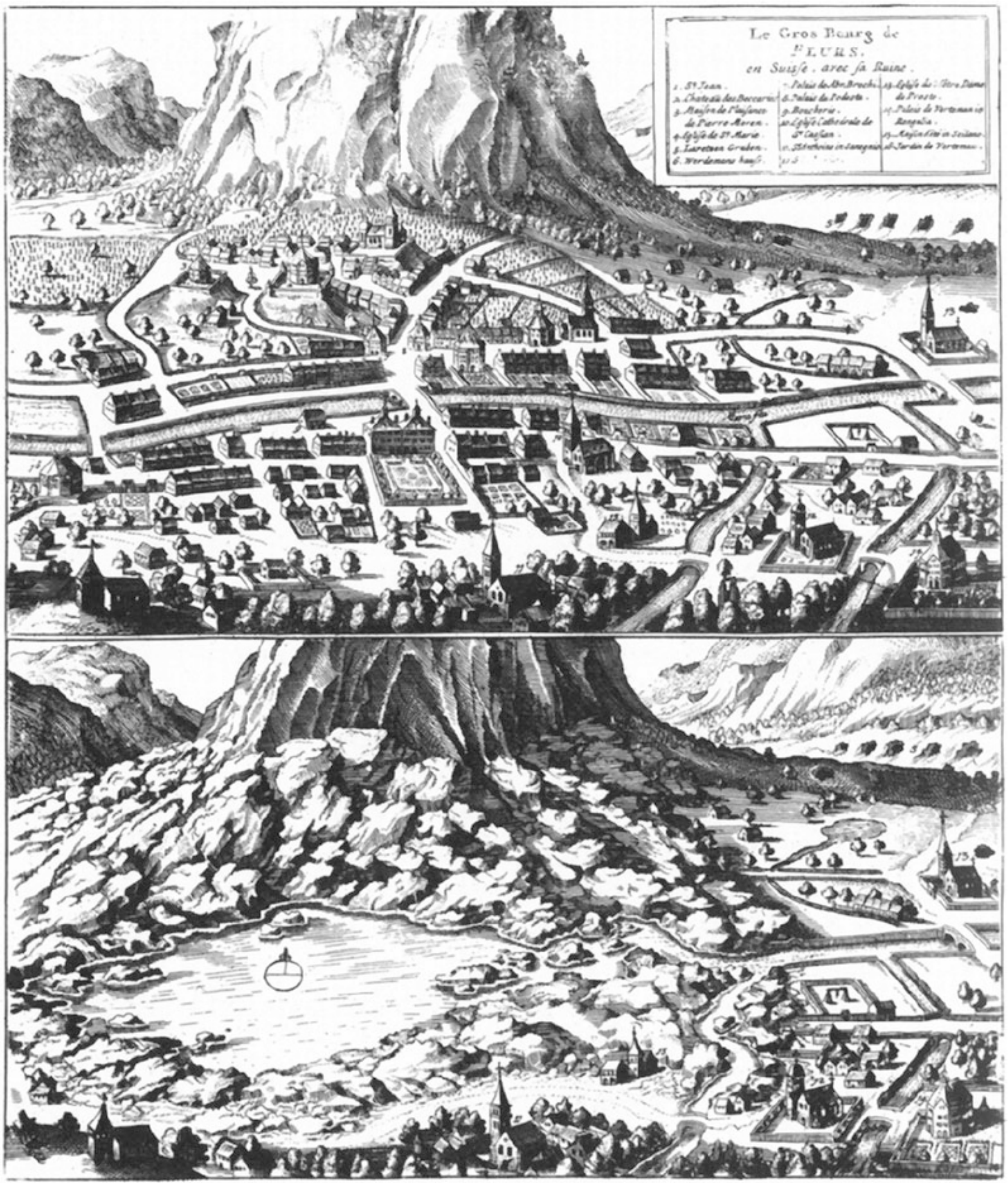
Geomorphological and sedimentological characteristics

Analysis of erosional and depositional features along the depletion, transport, and accumulation zones of debris avalanches allows outlining similarities and differences between types of volcanic and nonvolcanic environments (Figure 2).

As a general scheme, depletion zones of both types of slope instabilities are characterized by concave landforms, volcanic detachment scarps (“amphitheaters”) being more arcuate in plan and gentler in profile than the nonvolcanic ones (“headscarps”). Arm-chair shaped volcanic amphitheaters can be strongly remodeled either by magmatic processes (i.e., new lava dome growth) or later gravitational instabilities. In all cases, initial detachment scarp height and slope steepness can be reduced by debris fall and accumulation.

Debris avalanche deposits from both types of environments are characterized by a hummocky topography, with hills and depressions, discontinuous drainage, steep-sided distal and lateral edges. If compared to the area covered by debris, thickness of the displaced mass is relatively shallow, but dimensions differ largely between different environments. It is a matter of scale: Volcanic debris avalanches may reach magnitude orders of 1 km^3 in subaerial conditions and > 10 km^3 in submarine conditions, maximum thickness of deposits exceeding 100 m. Debris avalanches in nonvolcanic mountain environments have been reported at smaller dimensions, up to 0.1 km^3. These relatively shallower deposits (average 10 m) can spread over the slope with no established channels.

Texture of debris avalanche deposits can be defined as that of a diamicton, whose unsorted materials include (coarse) clasts and (fine) matrix. Dimensional separation between these two phases is related to the size of debris avalanches: Clasts of large volcanic debris avalanches may reach hundreds of meters in diameter, average size of nonvolcanic ones being metric. As for the height of

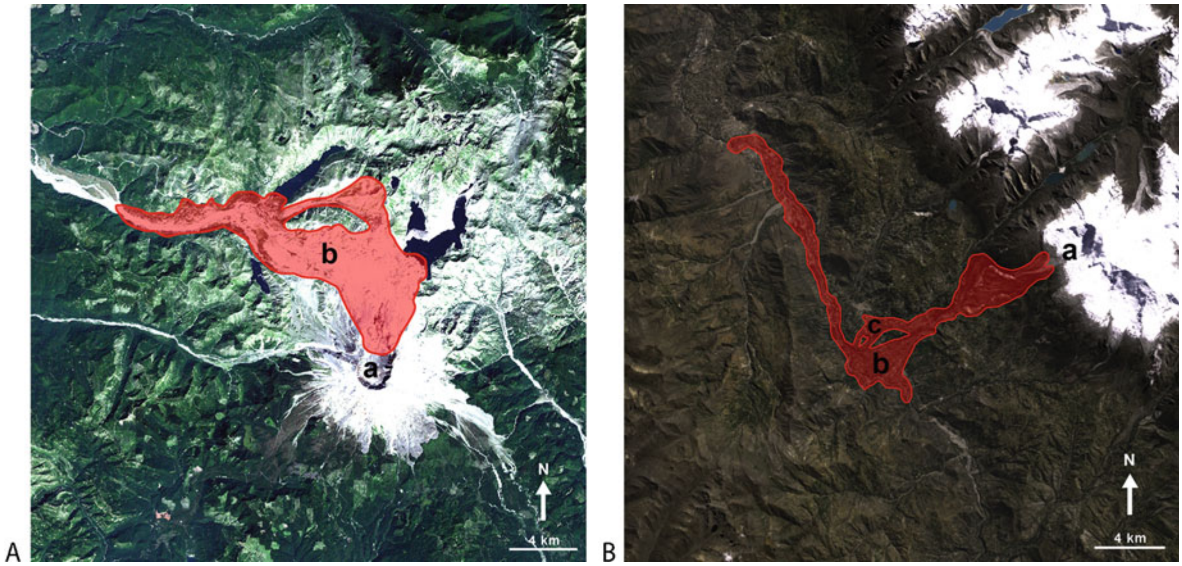


Debris Avalanche, Figure 1 Historical illustration of an ancient sturzstrom: pre- and post-event of the Piuro landslide (September 4th, 1618; Central Alps, Italy; modified from the original illustration by J.J. Scheuchzer, Itinera per Helvetiae alpinas regions, Lugduni Batavorum, 1723).

hummocks, the size of volcanic debris avalanches clasts ("blocks") tend to decrease toward the distal part of the deposit. Internal structure of blocks often shows distinctive irregular fracture patterns (jigsaw cracks), a common characteristic also reported in nonvolcanic case studies. Debris avalanche matrix includes relatively finer deposits: usually sand or finer, but also gravel or larger, when smaller than the average dimension of clasts.

Granulometric heterogeneities and their distribution throughout the accumulation zones are distinctive features for interpreting overall kinematic characteristics of debris avalanches. Matrix abundance is larger at the base of the deposit, close to the contact with not-displaced material. Surficial abundance of highly fractured blocks, larger clasts concentrations along hummocks, and their topographical contrasts with flat, matrix-rich areas indicate progressive disintegration of materials during flow-like motion of debris avalanches.

Deposits are usually chaotic and heterometric, and usually do not display well-organized internal fabric. On the contrary, the deposits of the sturzstrom of Flims (Grisons, Swiss Alps) in the Rhine valley upstream of Chur show



Debris Avalanche, Figure 2 Outlines of debris avalanche runout: (**A**) the Mount St. Helens debris avalanche (WA, USA; May 18, 1980). a) volcanic detachment scarp ("amphitheater"); b) area of hummocky topography. (**B**) Huascaran debris avalanches (Perù; (May 31, 1970). a) detachment headscarp; b) area of hummocky topography at Ranrayrca; c) devastated site of Yungay (see pictures in Figure 3).

the presence of a well-preserved fabric in areas that were not disorganized during the transport.

Type of movement

Used by itself, the term "avalanche" to describe landslide movements does not make specific reference to a particular material type or a single transport mechanism. It only relates to the overall kinematics of the displaced mass. Several dynamic emplacement models of debris avalanches have been proposed for interpreting different characteristics and distributions of the movement of loose materials through involved slopes.

Some authors invoked "air fluidization" phenomena to explain the long runout of debris avalanches of the coherent type and their peculiar features, such as frontal and lateral bulldozed edges, and internal preserved primary stratigraphy. A "hovercraft"-like mechanism was first proposed by Shreve (1968) in the case of Sherman Glacier, Alaska, where the rock/debris avalanche was interpreted to move over a cushion of trapped air. As an alternative view, progressive incorporation of air in the avalanching debris was postulated by Kent (1966). Also mechanisms of "pore fluid vaporization" due to frictional heating are able to increase gas pore pressure at the base of the debris avalanche, thus lowering the angle of friction and enhancing velocity. This is the case of Flims, Switzerland, where CO_2 gas, dissociated from carbonate rocks, provided lubricant for early movement of the landslide mass. The "air-controlled" emplacement modes appear to be not applicable to extraterrestrial and subaqueous debris avalanches, for which other mechanisms should be invoked.

The emplacement models by "mechanical fluidization" (Davies, 1982) refer to momentum exchanges between the particles of the debris avalanche, due to their collision. Cruden and Varnes (1996) interpreted the debris motion to be dependent on turbulent granular flow with dispersive stresses. Hsü (1975) pointed out the role of interstitial dust suspension in lowering effective normal pressure between flowing blocks, therefore reducing frictional resistance of dry debris. Also snow and ice can be incorporated into the debris avalanche to enhance fluidization, thus contributing to mobility of the displaced mass, such as in the case of Huascaran, Peru (May 31, 1970), where peak velocities over 100 m/s were reached (Plafker and Ericksen, 1978).

Mountain debris avalanches are mainly generated under water-undersaturated conditions. Greater mobility and larger volumes of debris avalanches in volcanic areas seem to be related to more frequent and widespread conditions of altered and water-saturated materials. In such an environment, larger spreading debris avalanches are generated due to direct proportional relationships between volume of the displaced mass, area covered by the debris, and runout length. Bingham plastic flow models have been proposed for several debris avalanches on volcanoes. They are comparable to viscoplastic materials behaving as rigid bodies at low stresses. By increasing stress they approximate a threshold to a viscous fluid behavior. The sequence of activated movements usually starts with sliding phenomena followed by plug flow.

When the behavior of a rock/debris avalanche during transport is not homogeneously characterized by strong interactions between particles, the granular flow can approximate a nonturbulent type. Here, clasts can be very angular in shape and original fabric of slope material

Debris Avalanche, Figure 3 Effects of the Huascaran debris avalanches (Perù), event of May 31, 1970. (**a**) hummocky topography; (**b**) devastated buildings and (**c**) bus at Yungay; (**d**) damaged tree stump, and debris avalanche deposits (photo by W. Alberto, 2008).

somehow preserved, as suggested by Schneider et al. (1999) for the cases of Flims, Switzerland, and Blackhawk, California. In other cases, grain-size segregation during granular flow causes pseudo-stratification of debris avalanches deposits (Fineberg, 1997). Flow transformations are particularly evident in distal and lateral parts of the deposits, where the internal structures of debris accumulation disappear.

The role of basal lubricant for debris avalanches also can be achieved by other fluidized materials; sand or finer materials can be "trapped" beneath the avalanche debris after having been eroded by the moving landslide mass.

Hazards and risks

Spatial and temporal occurrences, and magnitude of instability events, are key factors controlling hazards and risks derived from debris avalanches. Hazards assessment studies should also address the recognition of possible emplacement modes and triggering mechanisms related to specific environmental contexts. As shown elsewhere large-scale volcanic debris avalanches are of higher magnitude than nonvolcanic ones. Larger mobility and volume of mobilized materials lead to wider affected areas that can be assessed by using H/L diagrams, showing the relationships between the maximum collapse height and the runout distance. By analyzing volcanic instabilities, attention has to be paid also to the evidence of transformed flows, that is, from debris avalanches to debris/mud flows or to lahars. The collapse of the north side of the volcanic edifice of Mount St. Helens during the cataclysmic eruption of the May 18, 1980, caused a massive 2.8 km^3 rock-slide/debris avalanche that traveled 28 km from its source (Voight et al., 1985). Associated debris flows (*lahars*) and muddy stream flows traveled farther, extending the damaged area northwestward, when the water-saturated parts of the massive debris avalanche deposits began to slump and flow.

Other intensity parameters, such as velocity and flow depths, should be also estimated in order to assess derived parameters such as run-up of mass from instable slopes and area of possible impacts on structures. In the case of the Huascaran debris avalanches (Perù), a first event (January 10, 1961) had limited damaging impacts due to lower magnitude and thanks to the protective effect of a 240 m-high ridge near Yungay; the subsequent event (May 31, 1970) of higher magnitude (3,800-m total height, 16-km runout; Figure 1b), overtopped the ridge, and Yungay and Ranrayrca were devastated (Figure 3a–d). Casualties were up to 18,000 people, associated debris flows filled Rio Santa and flowed 160 km downstream to the Pacific Ocean.

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Cross-references

Debris Flow
Landslide
Landslide Types
Mass Movement
Nuee Ardente
Rockfall
Slide and Slump
Slope Stability

DEBRIS FLOW

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Definition

Debris flow is an extremely rapid, flow-like mass movement, traveling in a steep, established channel and involving a saturated, unsorted mixture of granular soils, organics, and other debris (Hungr et al., 2001).

Most steep natural slopes are mantled by varying thickness of colluvial soils, disturbed by surficial phenomena known collectively as soil creep, as well as small-scale landslides. Colluvium naturally accumulates in depressions and near the thalweg of steep low-order drainage channels, where it is likely to become saturated during high infiltration periods. During the same period of high near-surface groundwater pressures, a local slope instability such as a debris slide from a steep gully headwall or an erosion-undercut side slope above the channel can occur. The moving debris impacts the steep floor of the channel, instantly increasing total stresses on the saturated colluvium, or poorly sorted channel deposits accumulated there. Given the rapid occurrence of such loading, even pervious granular materials cannot drain quickly enough, and excess pore pressures are generated. As a result of this "rapid undrained loading" mechanism, the colluvium on the gully floor is destabilized. It joins material already in motion, and a translating wave of liquefied debris continues downslope (e.g., Johnson, 1970; Sassa, 1985).

In addition to debris slides, initiation can occur as a result of rock fall impact, or by the spontaneous shear failure of the steep bed of the channel, carrying heavy flood flow. Because the initiation typically occurs during a period of unusually intensive precipitation or snowmelt, multiple, near-simultaneous initiation in several branches of a steep drainage system often takes place (Figure 1).

As the resulting flow-like mass movement progresses downslope, the rapid loading cycle is continuously repeated, as long as the slope remains sufficiently steep

Debris Flow, Figure 1 Multiple debris flow initiation points and converging channels in a Rocky Mountains, Alberta, Canada, mountain drainage.

and loose saturated material is available. Often, the entire length of the steep segments of zero and first- or second-order channel is scoured of loose material, and the debris flow "surge" grows to a volume far exceeding that of the initial slide (Hungr et al., 2005). While entraining saturated solid material, the debris flow surge also overtakes and incorporates surface flow from the channel, becoming progressively more diluted.

Flow of saturated liquid debris in a steep channel is not a stable process. Surges form either by longitudinal sorting and accumulation of coarse clasts (Iverson, 1997) or by increasing turbulence where the flow depth is large (Davies, 1986). Either process leads to the development of "surges," characterized by a steep front consisting either of a concentration of boulders ("a moving dam") or a zone of highly turbulent flow. The passage of a bouldery front often creates a ridge-like "levee" deposit along the margins of the channel (Figure 2). Behind the front, the surge attains a shorter or longer region of maximum depth, containing fairly dense liquefied material and often flowing in a macroscopically laminar regime and a tapering "tail" or "intersurge flow," where the flow becomes more highly diluted and turbulent (Pierson, 1980).

Debris Flow, Figure 2 Bouldery levee created by a debris flow surge in Kyrghistan. The boulders in the center of the photo are approximately one meter in diameter.

The surge building process is the most important aspect of debris flows, as it magnifies the flow depth and thereby peak discharge. While a debris flow surge may not travel much faster than an extreme water flood flow in the same steep channel, its peak discharge may be several tens of times greater than the peak discharge of a flood. Typical flow parameters of debris surges in the coastal region of British Columbia are peak discharge of 300–500 m^3/s, velocity of 10–15 m/s, and flow depth of 2–5 m. Thus, debris surges are capable of vastly greater impact and potential damage than even the most extreme water floods.

Due to the presence of multiple initiation points and contributing channels, as well as the erratic time development process of surge building, many debris flow "events" consist of multiple and sometimes periodic surges, separated by periods of flood flow.

Heavy water floods in steep channels can also transport large quantities of sediment, often in the form of bulk channel instability driven by the tractive forces of overflowing water. Some writers suggested using peak discharge as a criterion to distinguish between a "debris flood" and "debris flow" (Aulitzky, 1980; Hungr, 2005). A debris flood has a peak discharge of the same order as a hydrologic flood wave. It may transport large quantities of sediment but is limited in its ability to transport very large boulders and inflicting damaging impacts on trees and structures. A debris flow at peak discharge is much deeper, can transport boulders several meters in diameter, and destroys objects in its path (Figure 3). Many events contain individual surges that can be classified as debris floods, in addition to those that are true debris flow surges. Usually, the latter dominate in terms of resulting damage.

Debris surges traverse and erode material from steep channels and then gradually deposit on "debris fans." Debris fans can be recognized and distinguished from alluvial fans by high steepness, extremely poor channel stability, and the presence of very large clasts in the deposits (Figure 4).

Debris flows are ubiquitous in mountain drainages and on steep slopes everywhere, particularly where concentrated periods of high precipitation occur and good supply

Debris Flow, Figure 3 A large boulder deposited by a debris flow in Taiwan.

Debris Flow, Figure 4 A debris fan in the Coast Ranges, British Columbia, Canada.

of unconsolidated colluvium exists. Because it is such a common process, debris flow is responsible for considerable losses in terms of fatalities, destruction of structures, and, most often, interruption and damage to infrastructure such as roads and railways. This type of damage exacts a steady toll in all regions with steep slopes. Sometimes, juncture of unfavorable circumstances, especially in terms of extreme rainfall, creates clusters of debris flows that can devastate an entire region. For example, the 1999 debris flows on the northern slopes of the Aquila Range in the Venezuelan state Vargas claimed approximately 30,000 fatalities among the inhabitants of several debris fans in the area (Larsen and Wieczorek, 2006).

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Cross-references

Creep
Debris Avalanche
Landslide (Mass Movement)
Landslide Types
Mass Movement
Mudflow
Pore-Water Pressure
Quick Clay
Rockfall

DEEP-SEATED GRAVITATIONAL SLOPE DEFORMATION

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Definition

A deep-seated gravitational slope deformation (DGSD) is a gravity-induced process affecting large portions of slopes evolving over very long periods of time. A DGSD may displace rock volumes of up to hundreds of millions of cubic meters, with thicknesses of up to a few hundred meters.

Introduction

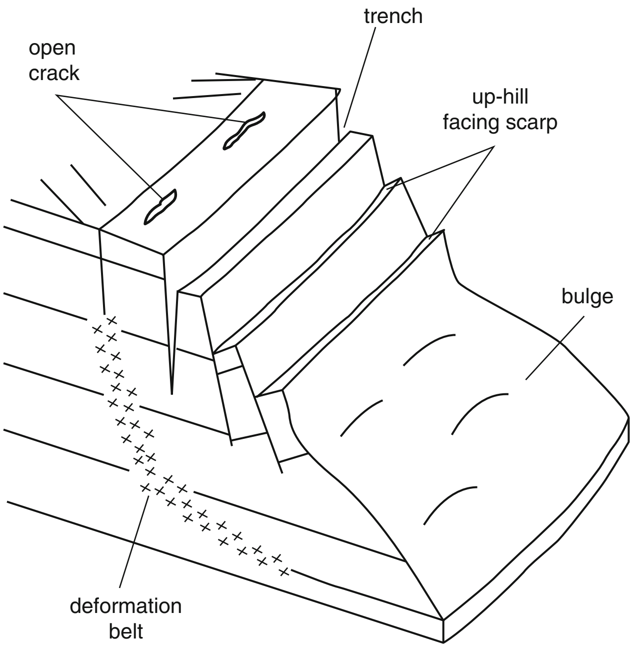
Deep-seated gravitational slope deformations (DGSDs) are not considered hazardous phenomena because they evolve very slowly. However, they must not be neglected when defining slope instability in a territory and the related hazard implications. Despite their slow deformation rates, DGSDs may cause damage to surface and underground (e.g., tunnels) structures. In addition, they may evolve into faster mass movements or favor collateral landslide processes.

Causes

Deep-seated gravitational slope deformations are often recognized in formerly glaciated valleys and in seismically active mountain regions. The occurrence of DGSD is generally related to tensional stresses induced by gravity in steep-sided valleys which can be linked to (1) unloading of oversteepened slopes due to glacier retreat or fluvial downcutting, (2) presence of discontinuities of tectonic origin (joints, fractures, etc.), and (3) seismic activity (Kostak and Avramova-Taceva, 1981; Dramis and Sorriso-Valvo, 1983, 1994; Bisci et al., 1996; Pasuto and Soldati, 1996; Agliardi et al., 2001; Gutiérrez et al., 2008). Displacements related to DGSDs occur due to the presence of deformation belts at depth, where the rock mass is affected by micro-fractures (Radbruch-Hall, 1978). The main feature that distinguishes DGSDs from landslides s.s. is the absence of a continuous or well-defined sliding surface.

The term "deep-seated gravitational slope deformation" was firstly used by Malgot (1977). Alternative definitions for DGSD include *sackung* (Zischinsky, 1966), *gravity faulting* (Beck, 1968), *depth creep of slopes* (Ter-Stepanian, 1966, 1977), *gravitational slope deformations* (Nemčok, 1972), *deep-seated creep deformations* (Mahr and Nemčok, 1977), *gravitational block-type movements* (Pasek, 1974), or *gravitational spreading* and *gravitational creep* (Radbruch-Hall, 1978).

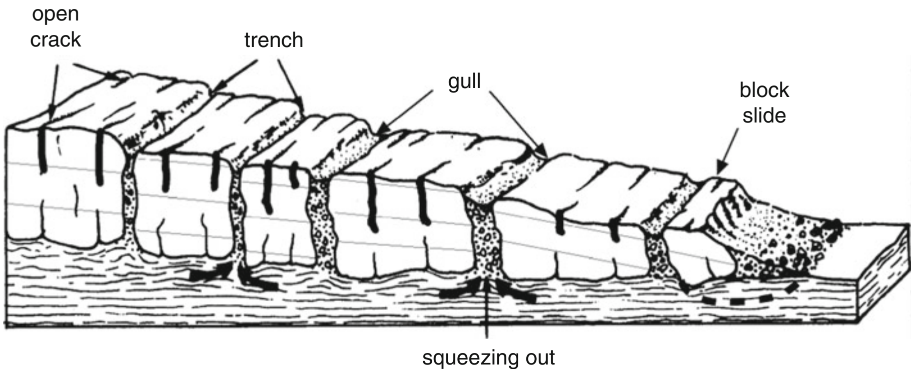
It is worth mentioning an earlier contribution to the definition of the processes involved in DGSDs by Terzaghi (1950), who showed the difference between "landslide" and "creep." According to Terzaghi, a "landslide" occurs along a well-defined sliding plane when the stress conditions for failure are satisfied, whereas "creep" is a continuous process characterized by undefined boundaries between stationary and moving material. This implies that the deformation/creep phase may be naturally followed by a sliding and much quicker phase. Though the temporal evolution from a deformation phase to a sliding phase is generally hard to predict, and possibly extremely long, the hazard implications become clear. Furthermore, as far as hazard is concerned, it should be noted that the presence of deep-seated gravitational deformations within a rock mass also favors the onset of collateral slope movements (e.g., rock falls, rock topples, block slides, etc.), which are likely to occur suddenly. If this takes place in inhabited areas, risk issues may have to be faced.



Deep-seated Gravitational Slope Deformation, Figure 1 Sackung (After Bisci et al., 1996; modified).

Types

Two main types of DGSDs can be outlined: *sackung* and *lateral spreading*. Sackung (or rock flow, according to the landslide classification by Cruden and Varnes, 1996) refers to the sagging of high and steep slopes due to visco-plastic deformation occurring at depth (Zischinsky, 1969; Bisci et al., 1996). Homogeneous and jointed or stratified rock masses, characterized by a brittle mechanical behavior, are generally affected by this type of DGSD. As a result of the deformation, typical sackung morphological features are twin ridges, trenches, gulls, and uphill-facing scarps in the upper part of the slopes as well as bulges in the medium and lower parts of the slopes (Figure 1). In addition, subhorizontal joints can be found at the lower edge of the slopes. In spite of a general agreement on the morphological features which characterize a sackung, there is still some uncertainty and dispute on the kinematics of the process. However, the development of deep-seated deformations is generally referred to the rock mass behavior at depth which is different from that at surface, owing to the higher confining pressure. Two main displacement models have been proposed. One the one hand, it is assumed that a high confining pressure does not allow the formation of well-defined shear surfaces at depth (Mahr, 1977), enabling only viscous deformations to take place (nonshearing model). This generally occurs



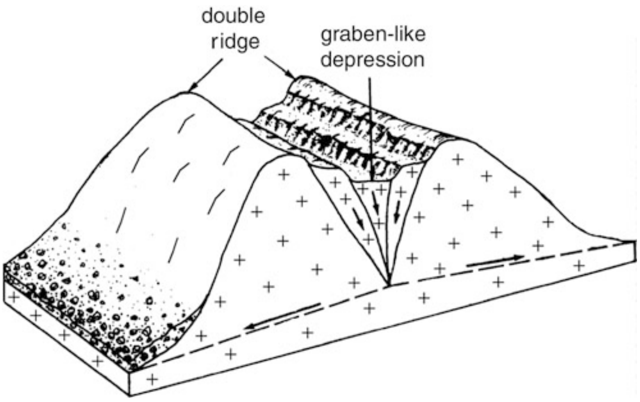
Deep-seated Gravitational Slope Deformation, Figure 2 Lateral spreading affecting brittle rock masses overlying ductile terrains (After Pasuto and Soldati, 1996; modified).

at the central parts of the slope, whereas at the top and toe of the slope, shear surfaces may still develop due to lower confining pressures. On the other hand, it is stated that the deformation zone is indeed interrupted along a shear surface located at the base of the unstable rock mass (plastic failure model) (Savage and Varnes, 1987).

Lateral spreading (or rock spreading) consists of lateral expansions of rock masses occurring along shear or tensile fractures. Two types of rock spreading can be distinguished which occur in different geological conditions (Pasuto and Soldati, 1996).

The first type refers to lateral spreading affecting brittle rock masses overlying ductile terrains. It may extensively affect rock plateaus, the effects being most evident at their edges. The spreading process is generally caused by the deformation of the underlying material and favored by slope or cliff downcutting. The deformation takes place through horizontal displacements along tensile fractures or subvertical tectonic discontinuities (Conti and Tosatti, 1996). Trenches, gulls, grabens, karst-like depressions in the brittle rocks and bulges in the weaker material are typical morphological features of lateral spreading (Figure 2). The overburden of the rock slabs is generally assumed as the cause of long-term deformation affecting the underlying terrains. As a result, squeezing out of the weaker rock types and rock block spreading due to tensile stresses take place. The process may be accelerated by water percolation through the fissures and consequent softening of the weaker materials. Lateral spreading phenomena are often accompanied by collateral slope movements occurring at the edges of the plateaus, such as rock falls and topples, block slides, and earth flows. Downcutting of valleys may favor the onset of these movements. The process may continue for long periods and cause progressive spreading and dismembering of rock plateaus.

The second type of lateral spreading occurs in homogeneous, and usually brittle, rock masses and has mostly been recognized in mountain areas with high relief energy. The spreading process generally occurs without a well-defined basal shear surface or zone of visco-plastic flow. As a result of the deformation process occurring at depth, double ridges, uphill-facing scarps, ridge-top depressions, and infilled troughs can be found at surface (Figure 3). The presence of joints in the rock mass is considered as a predisposing factor, but the mechanics of the deformation has not yet been well defined.



Deep-seated Gravitational Slope Deformation, Figure 3 Lateral spreading in homogeneous rock masses (After Pasuto and Soldati, 1996; modified).

Hazard implications

Sackung and lateral spreads may evolve into faster mass movements due to various causes (e.g., earthquakes), and therefore, their presence should be adequately taken into account in landslide hazard assessment (Coltorti et al., 1985; Hewitt et al., 2008). As a matter of fact, sackung may evolve into rotational/translational slides or into rock/debris avalanches, inducing possible risk situations due to the potential high velocity of these mass movements. On the other hand, lateral spreads tend to evolve in slower movements, such as block slides occurring at the edges of the areas affected by the spreading. Nevertheless, the possible occurrence of collateral landslides favored by the lateral spreading (e.g., rock falls, rock topples, earth flows, and slides) should not be overlooked when landslide hazard has to be assessed;

these phenomena are likely to be connected with the modifications of the groundwater flow net and the stress conditions related to the active deep-seated deformations.

The awareness of the role that DGSDs can play on slope instability is fundamental when stabilization and monitoring of single landslides are to be planned. If the influence of deep-seated deformations is not considered, mitigation measures may result incomplete and noneffective in long terms. It is clear that resolving interventions aiming at the mitigation of the effects of deep-seated gravitational deformations are hard to envisage due to the large size of these phenomena. However, the application of new methods for the detection, survey, and monitoring of DGSDs is very important to understand the kinematics of the movements and foresee possible evolution scenarios. In this respect, a geomorphological survey, accompanied by high-precision topographic measurements (e.g., by means of the GPS technique), LIDAR surveys, and interferometric analyses of radar images, may provide significant outputs with respect to the areas affected and volumes involved in DGSDs, as well as on the displacement rates and trends. Structural and geomechanical analyses of the rock masses are also very important to understand the lithological and tectonic control on DGSD onset and development.

Recently, the importance of the recognition of DGSDs morphological features, especially those related to sackung, has been acknowledged in paleoseismic investigations. Actually, sackung features may represent natural archives of the recurrence of high-intensity paleoearthquakes, providing useful information for seismic hazard assessment (Gutiérrez-Santolalla et al., 2005; Gutiérrez et al., 2008). The causal and chronological relationship between sackung features and earthquakes has been shown in terms of generation and/or reactivations of sackung scarps during historic earthquakes (McCalpin and Hart, 2003; Moro et al., 2007). Therefore, timing of sackung features caused by earthquakes, as determined by trenching and radiocarbon dating of sediments, can improve existing paleoseismic catalogues. The use of this technique can be particularly important where seismogenetic faults are buried, blind, or have scarce geomorphological evidence which makes conventional paleoseismic investigations difficult. It should be added that geomorphological features generated by DGSDs, such as double ridges and scarps, are frequently interpreted as of tectonic origin. This may lead to seismic hazard overestimations with significant economic implications (Bovis and Evans, 1995) and proves the importance of detecting the role of gravity in shaping these features for a correct and reliable hazard assessment.

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Cross-references

Landslide
Lateral Spreading
Mass Movement
Sackung
Slope Movement

DESERTIFICATION

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Synonyms

Land degradation; Loss of productivity

Definition

There are many definitions of desertification, but the most widely used is that adopted by the United Nations Convention to Combat Desertification (UNCCD) http://www.unccd.int/, which defined desertification as land degradation in drylands (arid, semiarid, and dry subhumid areas) resulting mainly from adverse human impact and climate variability (Safriel and Adeel, 2005).

Introduction

Drylands, defined as areas in which the ratio between precipitation and evapotranspiration is less than 0.75, cover as much as 47% of the world’s land surface (Figure 1) and are home to over one billion people (Ezcurra, 2006). Following the UNEP definitions, drylands include areas classified climatically as hyperarid to dry subhumid. Drylands are fragile environments that experience great natural variability in climate and are easily affected by natural disturbance and anthropogenic stressors. In many areas, they are being impacted by a rapidly growing and increasingly urban population. One manifestation of natural and environmental stress in drylands is the phenomenon of desertification, a term originally used by French colonial scientists to describe environmental degradation in dry areas of West Africa. Although land degradation in drylands has been occurring locally for millennia, the problem gained prominence and recognition by the international community in the 1970s following severe drought in the Sahel region of Africa and with the United Nations Conference on Desertification held in Nairobi, Kenya, in 1977. Desertification is, however, a concept that encompasses a variety of physical and biological processes, none of which are restricted to drylands, but which take on a particular form in such areas (Thomas and Middleton, 1994).

Causes of desertification

Desertification involves the degradation of ecosystems by a combination of natural disturbance (e.g., droughts) and human stress (e.g., overgrazing, inappropriate land use). The result is a persistent reduction in the level of productivity and ecosystem services over an extended period. Desertification occurs when the natural resilience of dryland ecosystems to disturbance is impaired by anthropogenic stressors, so that it is unable to revert in the short term to its prior state when the stresses are relaxed (Whitford, 2002).

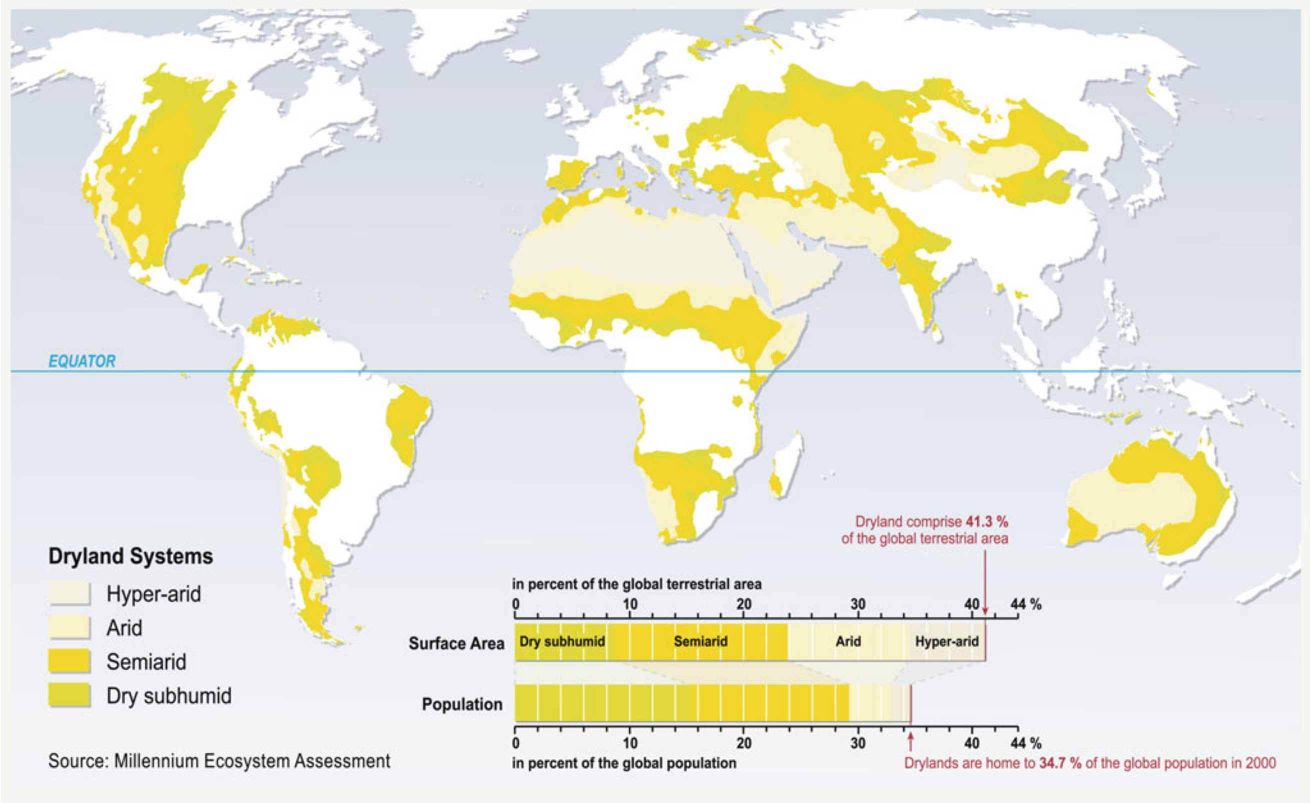
In their natural state, dryland ecosystems are resilient to natural disturbances such as drought and fire. Likewise, traditional land-use practices such as nomadic pastoralism, hunting of wildlife, and localized rain-fed agriculture have evolved to cope with a highly variable environment. Socioeconomic changes, including population growth, settling of previously mobile populations, imposition of political borders, commercial (often export-oriented) agriculture and livestock raising, provision of permanent water sources (wells and boreholes) together with poor land-use practices, such as overgrazing, fuel wood extraction, excessive irrigation, and cultivation of marginal land, impose stresses on ecosystems such that their resilience to disturbance is impaired. The result is loss of biologic and economic productivity (Adeel et al., 2005).

Occurrence of desertification

According to the UNEP, 70% of the world’s drylands (excluding hyperarid deserts), or some 3,600 million hectares, are estimated to experience varying degrees of desertification. The most vulnerable areas occur where human pressures combine with fragile ecosystems and soils, and tend to be concentrated in semiarid or desert margin areas (Figure 2). Over 250 million people are directly affected by desertification. In addition, at least one billion people in over 100 countries are at risk. These people include many of the world’s poorest, most marginalized, and politically weak citizens.

Ecological effects of desertification

Land degradation in drylands takes many forms, manifested by physical changes such as reduction in vegetation cover, changes in the types of plants, loss of soil



Desertification, Figure 1 Global extent of drylands From http://www.maweb.org/documents/document.355.aspx.pdf.

by wind or water erosion, and changes in plant nutrient distribution. Some of these changes can result in loss of primary productivity. In many areas, lower productivity is measured by reduced carrying capacity for livestock as a result of changes in the amount and composition of vegetation. For example, perennial grasses may be replaced by unpalatable or inedible shrubs, as documented in the Southwestern USA, southern Africa, and parts of Australia. Replacement of grassland by shrubs, partly as a result of overgrazing, may lead to a progressive and irreversible reorganization of soil and water resources at a landscape scale (Figure 3). Formerly widely distributed nutrients and water are concentrated into a series of "islands" of productivity nucleated by shrubs (Schlesinger et al., 1990). The intervening bare areas are subject to increasing erosion by wind and/or water, so creating a series of positive feedback loops that lead to a highly degraded and functionally different ecosystem.

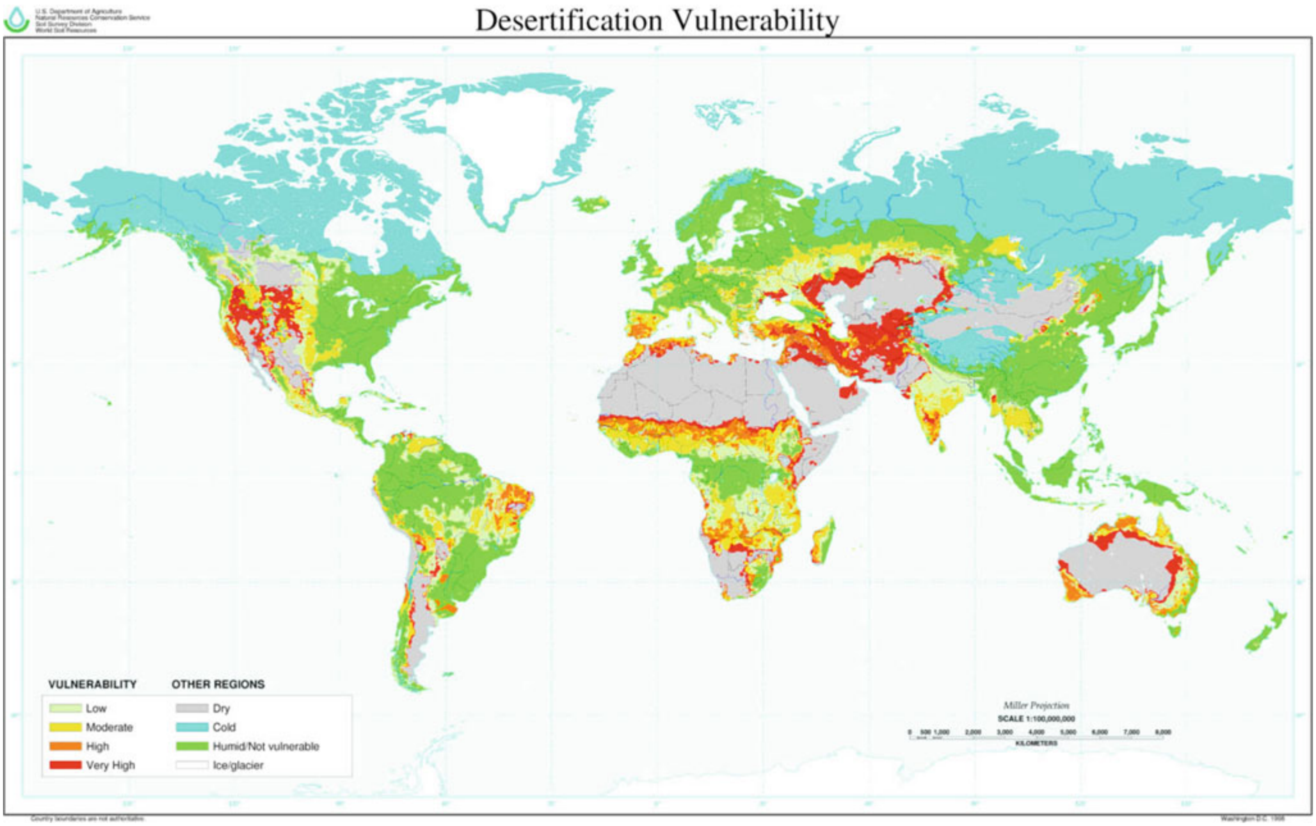
This process is well documented from the southwestern USA, where in the Chihuahuan Desert, grasses have been gradually replaced by mesquite shrubs over the past 50–100 years, with important consequences for ecosystems and geomorphic processes (Okin et al., 2001). In the Jornada area of New Mexico, the mesquite shrubs anchor coppice dunes separated by "streets" of high sand transport rates (Okin, 2008).

Grazing also damages or destroys the biological soil crusts that are important in stabilizing soils, reducing wind and water erosion, and fixing nitrogen in many desert regions. In southeastern Utah, even after 30 years without grazing, soils in areas that have been historically grazed have much lower contents of organic matter and primary nutrients, compared to areas that have never been grazed, suggesting that livestock grazing promotes increased wind erosion which reduces soil productivity in native grasslands (Neff et al., 2008).

Land degradation as a result of fire and grazing pressure may also lead to replacement of native species by invasive or exotic species. In the Great Basin of the USA, the perennial sagebrush steppe is being invaded by exotic annual grasses such as *Bromus tectorum* (cheat grass), which leads to an increase in fire frequency and inhibits recolonization by native grasses and shrubs after fires (Smith et al., 2000).

Physical effects of desertification

Desertification rarely involves the expansion of existing deserts, represented most dramatically by encroachment of active (mobile) sand dunes. Despite reports of "spreading deserts" in the Sahel region of Africa and western China, there is little scientific evidence to support such assertions (Thomas and Middleton, 1994).



Desertification, Figure 2 Global extent of desertification vulnerability – after NRCS 2003: http://soils.usda.gov/use/worldsoils/mapindex/desert.html.

Overgrazing and fire may combine with drought to reduce vegetation cover on sand dunes so that sand transport becomes more active and more widespread. Localized reactivation of vegetation-stabilized dunes has been documented from western China (Wang et al., 2008) and the Sahel region of Africa (Niang et al., 2008).

Increased sand transport, mainly as a result of a sparse vegetation cover, may also increase the occurrence of dust storms, as saltating sand grains impact fine-grained soils. An increase in the frequency of dust storms was observed during the Sahel droughts of the 1970s (Prospero and Lamb, 2003). Areas of fine-grained soils that are subject to rain-fed agriculture are particularly susceptible to wind erosion, as in the Dust Bowl of the USA in the 1930s (Goudie and Middleton, 2006) and further in the 1970s (Lee and Tchakerian, 1995).

In many areas, reduction of vegetation cover, or replacement of grasslands by shrubs on hillslopes, reduces infiltration of rainwater and leads to increased surface runoff and loss of soil (Abrahams et al., 1995). In extreme cases, extensive networks of gullies may result.

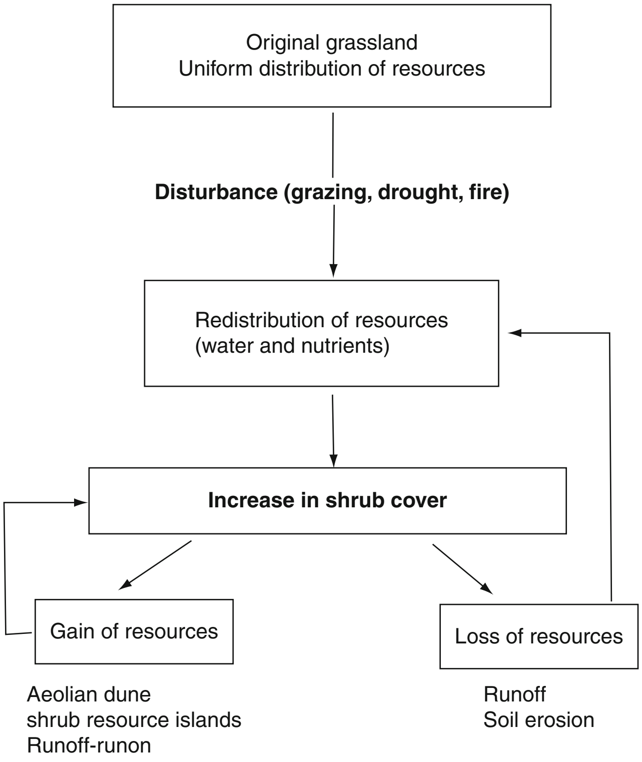
Salinization of soils is a further physical expression of desertification, resulting mainly from poor irrigation practices. Excessive application of water leads to accumulation of salts in the soil to levels that are toxic to plants. Leakage from unlined irrigation canals contributes to a rise in the water table unless countered by drainage systems.

Social dimensions of desertification

It is widely assumed that desertification is a consequence of human activities. Reduction in the productivity of drylands has many adverse effects on the populations of these areas, leading to widespread and far reaching social, economic, and political repercussions (Adeel et al., 2005; Reynolds et al., 2007). Reduced productivity of drylands leads to lower food production, competition for scarce resources, and an increase in poverty; subsistence agriculture and cattle raising are no longer viable, so people are forced to migrate to urban areas. Lack of opportunities may lead to political instability and emigration to more developed countries. A cycle of increasing poverty and loss of livelihood ensues. Even in developed nations such as the USA and Australia, land degradation and loss of agricultural productivity in drylands have serious economic consequences.

Climate change and desertification

Hydroclimatological observations show that changes in seasonal and annual temperature, precipitation, runoff,



Desertification, Figure 3 Conceptual model for progressive degradation of arid ecosystems (After Whitford, 2002).

groundwater recharge, and evapotranspiration are occurring today in most deserts and models predict that they are likely to continue in the future. Many drylands are already experiencing significant increases in temperature and a reduction in rainfall over the past two decades, manifested in extended droughts. Climate models differ in their predictions for drylands: Some may enjoy increased rainfall as monsoon circulations are enhanced, but this effect is offset by higher temperatures. Increased variability of climate will likely result in more frequent and severe drought conditions. Because human pressures in many areas are increasing, dryland ecosystems will be less resilient to natural disturbance in the future, resulting in an enhanced vulnerability to desertification and its physical, biological, and human consequences (Safriel and Adeel, 2005).

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Cross-references

Climate Change
Drought
Dust Bowl
Dust Storm
Erosion
Land Degradation

DISASTER DIPLOMACY

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Synonyms

Disaster-conflict nexus; Disaster politics; Disasters and political change

Definition

Disaster diplomacy examines how and why disaster-related activities (e.g., mitigation, prevention, response, and recovery) do and do not reduce conflict and support peace.

Overview

Disaster diplomacy research and application (see http://www.disasterdiplomacy.org) examines how and why disaster-related activities do and do not reduce conflict and support peace. Disaster-related activities include pre-disaster actions, such as prevention, mitigation, preparedness, and planning. Disaster-related activities also include post-disaster actions, such as response, recovery, and reconstruction. The range and scale of investigation and use is wide, including countries at war with each other to communities suffering internal conflict.

This field is investigated mainly through scientific research seeking policy recommendations, but practitioners have also advanced and used disaster-diplomacy knowledge (e.g., Renner and Chafe, 2007). Approaches take mainly two forms: specific case studies and overall analyses seeking patterns and predictions.

Case study examples include India-Pakistan after the 2001 Gujarat and 2005 Kashmir earthquakes, collaboration across the Middle East on seismic building codes, the internal conflicts in Sri Lanka and Aceh (Indonesia) after the 2004 tsunamis, and Cuban and American scientists collaborating on hurricane prediction and monitoring.

The case studies examined indicate that disaster-related activities do not create new approaches to conflict resolution. If, however, ongoing connections amongst antagonists exist on a solid basis, disaster-related activities in the short term can be the catalyst to turn those connections into hopes for peace. Examples of connections are peace negotiations, the desire for trade links, or a topic of common concern such as pollution or another enemy.

Over the long-term, non-disaster factors tend to overtake any disaster-related influences on peace. Examples are leadership changes, prominence of an historical conflict or grievance, or continuing distrust. As a result, disaster-related activities can exacerbate conflict, especially when a disaster has raised expectations of peace immediately following the calamity.

Work on disaster diplomacy also covers theories and patterns underlying the case study observations. Such work helps to understand why case studies do not yield disaster diplomacy. It further contributes to attempts at predicting what could occur in instances or circumstances under which disaster diplomacy might be more successful.

Explanations include why governments, organizations, or people involved in disaster diplomacy select specific pathways that try to promote or inhibit disaster-related reconciliation. Other approaches to developing typologies and explanations for disaster-diplomacy case studies cover the proximity of those involved in disaster diplomacy (e.g., if countries are involved, do they border each other?) along with their aid relationships (e.g., a donor-recipient situation or mutual aid).

The reason why disaster-related activities usually fail to support peace are complex, often involving the long histories of the parties involved and the personalities and personal interests of the current leaders. Overall, the evidence suggests that dealing with disasters appropriately and seeking peace are not always the first priorities of those involved. Consequently, disaster diplomacy has good intentions but is not likely to succeed often.

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Civil Protection and Crisis Management
Disaster Relief
Disaster Research and Policy History
Disaster Risk Reduction
Emergency Management
Federal Emergency Management Agency (FEMA)
Global Network of Civil Society Organisations for Disaster Reduction
Hyogo Framework for Action 2005–2015
Mitigation
Planning Measures and Political Aspects
Recovery and Reconstruction After Disaster
United Nations Organisations and Natural Disasters

DISASTER RELIEF

Jane Carter Ingram
Wildlife Conservation Society, Bronx, NY, USA

Synonyms

Disaster assistance; Disaster response

Definition

Disaster relief refers to interventions aimed at meeting the immediate needs of the victims of a disastrous event. Disaster relief commonly refers to aid that can be used to alleviate the suffering of national or foreign disaster victims. It often includes aid or assistance in the form of humanitarian services and transportation; the provision of food, clothing, medicine, medical services, beds, and bedding; temporary shelter and housing; and making repairs to essential services such as electricity, water supplies, and phone lines.

Discussion

Disaster relief, often commonly referred to as disaster response, is an intermediate phase of several phases in disaster management, which include (1) mitigation, (2) preparedness, (3) relief, or response, and, (4) recovery (the longest phase). Relief in this context comprises the range of actions that are necessary during the critical period immediately following a disaster when infrastructure has been damaged, communication lines have been destroyed, access to services such as electricity and water has been compromised, people have been injured and/or separated from their families, and victims' homes, assets, and/or livelihoods have been lost or damaged. Disaster relief entails ensuring that people's immediate needs such as food, shelter, and medical assistance are met, first and foremost. Relief efforts also include reconnecting severed social networks through helping people locate their family, friends, and/or loved ones if they have been separated from one another. In order to meet these basic physical and social needs, disaster relief operations may involve clearing rubble from damaged infrastructure, extinguishing fires, repairing damaged electrical lines, or reducing other potential hazards that have resulted from the disaster so that vital resources and services can be delivered efficiently to affected populations.

A major challenge during the disaster relief phase is ensuring that vulnerable people are kept safe, which often requires external support because local police or security forces may have been fragmented during a disaster. Security during the relief phase is of special concern in temporary shelters. For example, following the Indian Ocean tsunami of 2004, many people in Sri Lanka were housed in temples that were converted into temporary shelter for multiple families or were given tents in which to live until more permanent structures could be built in safe locations. Following Hurricane Katrina, thousands of people were temporarily housed in the Super Dome. While these locations may have provided relief from natural hazards, in both cases, the temporary housing options where men and women from different families were living in close quarters with each other presented security risks for vulnerable populations in society, particularly the elderly, women, and children. Furthermore, in the absence of police and security forces, looting, and other crimes may increase during the relief phase as people deal with anguish over their losses and are desperate to meet their basic needs. Thus, it is critical that relief efforts, especially those that place women, children, and the elderly in new housing situations are developed with a consideration of preexistent and new safety concerns that have arisen as a result of the disaster so that people's needs are met and their safety is not worsened by temporary conditions.

While the disaster "recovery" phase would ideally start as soon as immediate needs are met, the relief phase often lasts for quite a while due to funding delays or other constraints that hamper the recovery phase.

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Casualties Following Natural Hazards
Civil protection and Crisis Management
Cognitive Dissonance
Coping Capacity
Critical Infrastructure
Disaster
Disaster Relief
Disaster Risk Management
Disaster Risk Reduction (DRR)
Education and Training for Emergency Preparedness
Emergency Management
Emergency Shelter
Evacuation
Federal Emergency Management Agency (FEMA)
Hospitals in Disaster
Human Impact of Disasters
Integrated Emergency Management System
International Strategies for Disaster Reduction
Livelihoods and Disasters
Natural Hazard
Posttraumatic Stress Disorder (PTSD)
Red Cross and Red Crescent
Risk
Risk Assessment

DISASTER RESEARCH AND POLICY, HISTORY

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Definition

Disasters are not new phenomena. Disasters have affected humans throughout history and, consequently different forms of research (that evolved into the modern scientific method) as well as policies have been applied to deal with them. Overall, these approaches have moved from assuming a lack of control over disasters, to blaming external forces such as the "hazard" along with people affected by "hazards," to more recent approaches accepting that humans are responsible for creating the conditions that lead to disasters. To fully tackle disasters, research shows that policies should focus on reducing vulnerability which is created by humans, usually affecting others.

Introduction

Disasters have long been viewed principally as natural hazards through physical science disciplines such as seismology, volcanology, climatology, geomorphology, hydrology, and meteorology. Up until the mid-twentieth century, the responsibility for the occurrence of disasters that include physical phenomena (e.g., earthquakes or tornadoes) was therefore attributed to external natural forces or the whims of angry, vindictive, or inebriated deities.

In a 1756 letter to Voltaire regarding the 1755 Lisbon earthquake and tsunami, Rousseau was the first person known to attribute humanity's responsibility in disasters (e.g., Dynes, 1997). However, it was not until the 1940s that the human dimension of disasters began to be widely accepted. Two major research and policy paradigms developed, and were often opposed in their understanding of disasters and in the way that disaster risk should be reduced. The contemporary emphasis on climate change is a step backward in the approaches taken.

The hazard paradigm

The paradigm which has long dominated scientific studies of disasters emphasizes the importance of nature's threats, called natural hazards. This approach has been spearheaded by White's (1945) pioneering dissertation on people's adjustments to flooding in the USA. This paradigm is known as the hazard paradigm. Burton and Kates (1964, p. 413), two of White's students, define natural hazards as "*those elements in the physical environment, harmful to man and caused by forces extraneous to him*." Frampton et al. (2000) further stress their "*uncontrollable dimension*." Many more definitions of natural hazards similarly emphasize extreme (function of magnitude) and rare (function of time) natural phenomena that exceed humanity's ability to cope with them.

The "extraneous" and extreme dimension of natural hazards leads disasters identified with these natural phenomena to be considered out of the regular social fabric (e.g., Kates and Clark, 1996). Scientists, institutions, governments, and media thus often mention "extra-ordinary," "un-controllable," "in-credible," "un-predictable," and "un-certain" phenomena along with "un-expected" disasters and "un-scheduled" and "un-anticipated" damage (see Hewitt, 1983 for a critique). Regions affected are claimed to be unable to face such forces of nature and are often considered to be "under-developed," "over-populated," "un-informed," "un-prepared," and "un-planned" (again see Hewitt, 1983 for a critique). Therefore, a clear border is delineated between regions of the world which are often struck by disastrous events and those that are supposedly safe (see Bankoff, 2001 for a critique).

In this context, earth and climate scientists and engineers tend to focus on monitoring, predicting, and calculating probabilities and parameters for extreme natural events. In contrast, social scientists are interested in how people and societies perceive the potential danger and how they adjust to possible threats. Individuals and societies said to have a low perception of risk allegedly adjust poorly to possible threats. People and societies considered to have a high risk perception are assumed to adjust well to natural hazards (Kates, 1971; Burton et al., 1978; Fischhoff et al., 1978; Slovic, 1987). Factors that affect people's perception of risk are hazard related too (i.e., hazard magnitude, duration, frequency and temporal spacing, plus the recentness, frequency, and intensity of past personal experiences with hazards). Kates (1971, p. 441) underlines this held belief that those factors are independent from the socioeconomic environment.

In many countries, disaster policies and practices reflect the influence of the hazard paradigm. These policies are primarily geared toward the extreme dimension of natural phenomena and often reflect war strategies (Gilbert, 1995). In many countries, disaster policies are handled by the army or civil protection institutions, relying on military chains of command, and treating natural hazards as enemies to fight against (Alexander, 2002). Risk reduction strategies consequently tend to focus on technocratic, command-and-control measures such as engineering structures, technology-based warning systems activated only after a natural event, hazard-based land-use planning, and hazard-based risk awareness campaigns.

Internationally, disaster risk reduction policies have long relied on contrasting safe, affluent countries with dangerous, poor countries. That fits into wider development policies which foster top-down transfers of knowledge, technology, and experience from the rich to the poor, because the poor countries are allegedly unable to cope without external assistance (Bankoff, 2001; de Waal, 1997).

The vulnerability approach

In the 1970s, there was a critical evolution in the way disasters have been considered and faced (Waddell, 1977; Torry, 1979). Drawing on cases from around the world, scholars such as O'Keefe et al. (1976), Wisner et al. (1977) and Hewitt (1983) increasingly emphasized people's vulnerability in the face of natural hazards, an approach referred to as the "vulnerability paradigm."

Vulnerability in facing natural hazards reflects people's marginalization within society. Disaster-affected people disproportionately include those who are chronically marginalized in daily life (Wisner, 1993; 2004). These people are marginalized geographically because they live in hazardous places (e.g., informal settlers); socially because they are members of minority groups (e.g., ethnic or caste minorities, people with disabilities, prisoners, and refugees); economically because they are poor (e.g., homeless, underemployed and jobless); and politically because their voice is disregarded (e.g., women, non-heterosexuals, children, and elderly). People's vulnerability varies in time and space and is determined by mainly hazard-independent, structural constraints that are social, cultural, economic, and political (Watts and Bohle, 1993; Wisner et al., 2004; Gaillard, 2007).

Disasters thus most affect individuals with limited and fragile incomes (low wages, informal jobs, lack of savings), reducing their capability to deal with natural hazards (e.g., location of home, type of housing, knowledge of mitigation measures). Vulnerability and marginality also result from inadequate social protection (e.g., health insurance, health services, construction rules, prevention measures) and limited solidarity networks.

That does not necessarily indicate that means of protection are unavailable locally. In many instances, such as for famines (Hartmann and Boyce, 1983; Sen, 1983), the lack of access does not reflect the availability of food, knowledge, technologies, or financial capital, but rather an unequal distribution of available resources and the nature, strength, and diversity of people's livelihoods. Assets and resources essential in the sustainable or unsustainable livelihoods are conversely crucial in defining vulnerability.

Such an intimate relationship between livelihood and vulnerability supports the justification that many people have no other choice but to face natural hazards to sustain their daily needs. The difficulty of accessing sustainable livelihoods may further lead to environmental degradation, which often manifests in increasing natural hazards. For instance, the need for firewood may accelerate deforestation that in turn exacerbates the effects of landslides and floods.

People's incapacity to safely endure "natural hazards" therefore results from their inability to control their daily life and to choose the location of their home and their livelihoods (Blaikie, 1985). In that context, disasters highlight or amplify people's daily hardship and everyday emergencies (Baird et al., 1975; Maskrey, 1989). Thus, disastrous events cannot be considered as "accidents" beyond the usual functioning of the society (Hewitt, 1983; Wisner, 1993). Instead, disasters generally reflect development failures where the root causes of vulnerability have origins in other, usually contextual, development-related crises.

Some of the central ideas of the vulnerability paradigm have been progressively integrated into some, but not all, international policy documents such as United Nations strategies (United Nations, 1995; United Nations International Strategy for Disaster Reduction, 2005). Numerous NGOs focusing on development and disaster risk reduction have also adopted aspects from the vulnerability paradigm, translating them into sound policies (e.g., Global Network of Civil Society Organisations for Disaster Reduction, 2011). Conversely, some more powerful institutions like the International Monetary Fund (IMF) have not yet integrated the basic concepts of the vulnerability paradigm (Freeman et al., 2003), while other organizations such as the World Trade Organization (WTO) downplay the negative effects of disasters (World Trade Organization, 2006).

Community-based disaster risk reduction

Despite the advantages of the vulnerability approach, no single solution can address every situation. However, a general concept does seem to apply universally; reducing disaster risk requires increasing participation of local communities, a concept that has for a long time been encouraged in development research, policy, and practice (e.g., Chambers, 1983; Wisner, 1995). The actions of local communities are nearly always the first line of defense in reducing disaster risk. A wide consensus acknowledges the capacities of local communities in dealing with natural hazards on their own, as long as they are empowered with adequate resources (e.g., Quarantelli and Dynes, 1972; Delica-Willison and Willison, 2004). Community-Based Disaster Risk Reduction (CBDRR) fosters the participation of threatened communities in the evaluation and reduction of risk (including hazards, vulnerabilities, capacities, and resiliencies).

CBDRR empowers communities with self-developed and culturally, socially, and economically acceptable ways of coping with and avoiding crises related to natural hazards (e.g., Anderson and Woodrow, 1989; Maskrey, 1989). CBDRR enhances endogenous resources which prevent people from resorting to exogenous means that are often hard to access and which often create a cycle of dependency. CBDRR further aims at strengthening people's livelihoods to enable local communities to live with risk on an everyday basis (Benson et al., 2001; Cannon et al., 2003; Twigg, 2004), thus favoring the integration of disaster risk reduction into development policy and planning. It is often impossible to prevent people from settling in hazardous areas because these same locations provide resources to communities on a daily basis, such as fertile agricultural land that lies on floodplains and low-lying coastal zones with fisheries. Focusing on livelihoods simultaneously when considering disaster risk reduction will address people's ability to sustain their daily needs and their capacities to face natural hazards and other development threats.

CBDRR is also increasingly promoted among local governments and scientific communities in order to strengthen the links between top-down and bottom-up disaster-related measures (Kafle and Murshed, 2006) and to facilitate their integration into wider development policy frameworks. Top-down responsibility is not absolved by CBDRR, but instead should support, rather than substitute for, the capacities of communities. Local communities should indeed be externally assisted when large-scale measures are required, such as massive evacuations over long distances, regional settlement and infrastructure planning, and considerable debris cleaning. CBDRR accepts external assistance when appropriate on the *community's terms*, thereby also assisting in avoiding one community's measures creating or exacerbating problems for other communities.

CBDRR and other locally driven measures are crucial for development policy; however, these should be backed by a strong commitment from national and international institutions, especially those which have not yet incorporated the central arguments of the vulnerability paradigm (e.g., IMF, WTO). Too many disasters are rooted in governance issues, for instance, disobedience of laws such as building codes, corruption, the misuse of available resources, and the looting of natural and economic resources to benefit the most powerful (e.g., Lewis, 2008). In most cases, simple, affordable, and locally available measures as part of development policy would remediate such concerns and avoid disasters (Lewis, 1999; Hewitt, 2007).

Climate change and conceptual regressing?

The dominant hazard paradigm now seems to be regaining ground, fuelled by the media, political, and scientific discourse on climate change (Kelman and Gaillard, 2008). Uncertainties around the evolution of climate conditions constitute a powerful argument for the proponents of the hazard paradigm for considering Nature as the major threat (e.g., White, 2004). Uncertainties are frequently associated with the probability of occurrence of rare and extreme natural hazards which should be addressed through scientific models and statistical probabilities. The contemporary focus on climate change thus reinforces a paradigm where Nature is the danger source (even if exacerbated by human activity, as with climate change and many other hazards).

The recent interjection of climate change into disaster research is evident in the latest report of the Intergovernmental Panel on Climate Change (IPCC) (International Panel on Climate Change, 2007). In this IPCC document, vulnerability is defined as "*the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.*" This definition emphasizes extreme events and dependence on the climate systems, especially the magnitude of change to be experienced, which are both characteristics of the hazard paradigm.

In the face of such changing threats, people must change to deal with them. The analogy with the hazard paradigm is obvious. The vocabulary has shifted from adjustment to adaptation, but the meaning and scientific justification are the same as emphasized in the definition of adaptation provided in IPCC (2007): "*adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.*" As for the hazard paradigm, people's ability to cope with changes in climate patterns have largely been overlooked, even though their response is constrained by the same development-related factors underpinning vulnerability (Bohle et al., 1994).

Such a scientific discourse on climate change and other disasters, highly emphasized by some media, distracts national governments and international institutions from the root causes of vulnerability, making climate change a perfect scapegoat for disasters and lack of development (Kelman and Gaillard, 2008). Pinpointing a phenomenon with global scale and diffused responsibility enables governments to evade their own responsibility in addressing the root causes of vulnerability.

Therefore, there is no surprise that climate change policies and practices have reintroduced most of the actions that have failed to mitigate the occurrence of disasters over the last 60 years.

Outlook

Beyond the different, often opposing paradigms on the origins of disasters and actions to be undertaken to reduce disaster risks, there is a crucial need for increasing dialogue between the proponents of all approaches and those most affected by disasters. The top-down approach of the hazard paradigm has obviously failed to mitigate the occurrence of disasters. Consequently, it is unlikely that the similar paradigm emerging from the discourse on climate change will achieve better results.

Conversely, bottom-up actions rarely suffice to tackle the root causes of vulnerability on a large scale. Therefore, a need exists for better integration of top-down and bottom-up approaches into a single paradigm that involves working collaboratively toward the same goal, to prevent disasters (Hewitt, 2007).

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Cross-references

Climate Change
Disaster
Disaster Risk Reduction
Exposure to Natural Hazards
Global Change and Its Implications for Natural Disasters
Hazard
Hazardousness of Place
Vulnerability

DISASTER RISK MANAGEMENT

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Definition

Disaster risk management is a comprehensive approach involving the identification of threats due to hazards; processing and analyzing these threats; understanding people's vulnerability; assessing the resilience and coping capacity of the communities; developing strategies for future risk reduction; and building up capacities and operational skills to implement the proposed measures.

Introduction

Disaster risk cannot be eliminated completely, but it can be assessed and managed in order to reduce the impact of disasters (Smith and Petley, 2009). The management of disaster risks has attracted much attention since the 2005 initiative of the International Strategy for Disaster Reduction (ISDR, 2004) that defined the Ten Essentials in order to empower local governments and other agencies to implement the Hyogo Framework for Action until 2015. In the twenty-first century, our understanding of disasters that are caused by natural, technological, and/or human sources has improved significantly. Both the developing and the developed worlds have made considerable progress, within their capacity and limitations, toward the development of policies and mitigation measures to reduce future disasters. However, disasters continue to harm millions of people each year worldwide. A disaster can affect, or be affected by our natural environment, social processes, psychological elements, cultural issues, historical information, and political and economic ideologies. Certain risks are often inherent within a social system or physical location, but they can also be created due to certain natural or technological hazards (Alexander, 1999). The consequences, however, can be similar in that they wreak havoc in communities and destroy social and economic systems. In order to effectively and efficiently manage disaster risks, our focus should be on addressing vulnerability (The conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards (ISDR, 2004)) and improving the resilience and coping capacity of populations (Nirupama, 2009, 2012; Twigg, 2007; Canton, 2007; Cutter, 2001).

Risk identification is a measure of individual perception – how those perceptions are understood by society as a whole, as well as an objective assessment (Cardona, 2006). The holistic approach of disaster risk management would involve risk identification and risk reduction components, a disaster management component, which is about response and recovery; and a financial protection piece that will account for institutional support, financial resources, and risk transfer tools. The shaping of risk identification, risk reduction, and risk management strategies, policies, resource allocation, and operational plans should, ideally, engage all the stakeholders in the process. A risk management team must have adequate information and understanding of high-probability/low-consequences versus low-probability/high-consequences events. A number of risk management strategies, such as education, awareness, economic incentives for individual mitigation measures, as well as legal, and legislative requirement can be considered. The process can be challenging as transfer of knowledge from science to politics is not easy (Schneider et al., 2006).

Understanding risk

Risk is defined as a function of probability of occurrence of hazardous event, and potential loss to people, property, and/or the environment (Smith, 2004; Wisner et al., 2004; ISDR, 2004; HRVA, 2004) as shown in Eq. 1. Historical records of past disasters provide reasonable estimates of the probability of occurrence of hazards, hence risk is considered to be quantifiable using probabilities and consequences (Helm, 1996; Green, 2004; Smith and Petley, 2009). Information on vulnerable populations and elements that are particularly exposed to risk can be assessed using a variety of indicators and criteria (Birkmann, 2006; Armenakis and Nirupama, 2009, 2012). Risk perception also plays a significant role in how disaster risk management is carried out in various societies and cultures (Slovic, 2000). Therefore, perception becomes a noteworthy factor to be accounted for in risk management, and risks can vary with geographic location and local conditions. Figure 1 demonstrates various perceptions of risk.

The standard risk formula is expressed as:

$$R = H \times V \tag{1}$$

Here, R = risk; H = hazard, determined as a probability (or likelihood) of the occurrence of hazard; V = vulnerability (also loss, impact or consequences).

Several variations of standard risk formula have been proposed by experts (Table 1) and are as much practiced as the standard risk formula given in Eq. 1.

Key elements of disaster risk management

Key elements of a comprehensive disaster risk management system are shown in Figure 2. Each element is briefly explained below.

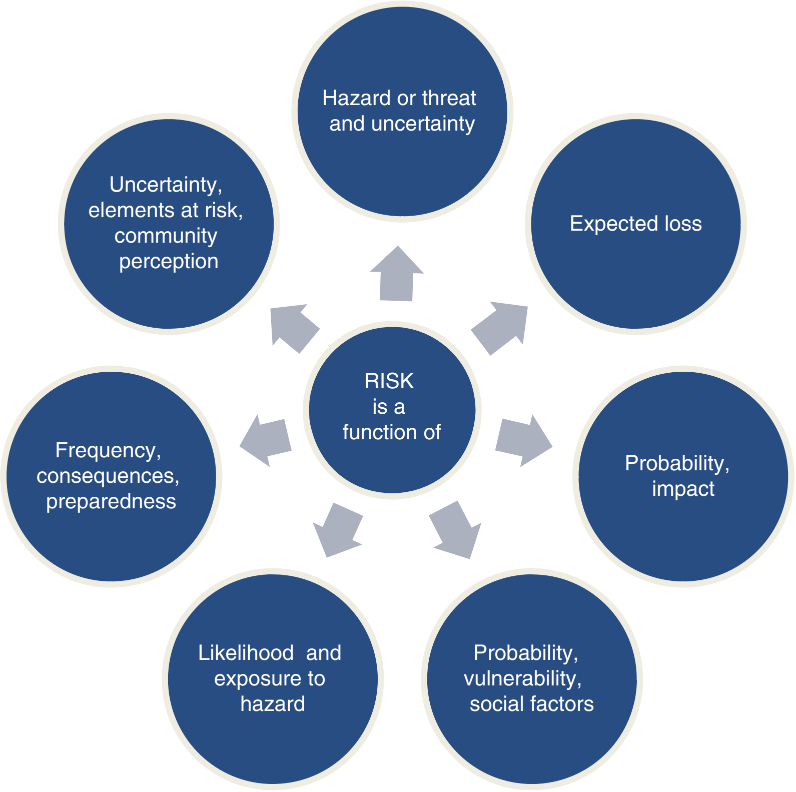
Threat recognition – risk and vulnerability identification

Identifying potential risks from natural, technological, or human-induced hazards; and recognizing vulnerable populations, such as very old, very young, single parents with young children, low income earners, unemployed, those facing language barriers, and physically and emotionally challenged people.

Risk analysis and assessment

Understanding the magnitude, frequency of occurrence, and severity of consequences and prioritization of risks. The standard risk formula is given in Eq. 1. A few risk evaluation methods are discussed here.

Qualitative and quantitative frameworks and methods have been developed to understand and evaluate disaster risk. Qualitatively speaking, all individual/institutional perceptions of risk carry equal weight as they choose to respond in a certain manner to a certain threat in certain circumstances (Nirupama and Etkin, 2009). Among the qualitative models, *Pressure and Release* (*PR*) *and Access to Resources* (*AR*) models (Wisner et al., 2004) are widely used. The *PR* is a static model, founded on the concept of progression of vulnerability by looking at how underlying causes create an environment that allows for some dynamic pressures (e.g., lack of education, land degradation, population growth) to translate into unsafe conditions (e.g., exposure to risk, lack of social network) in a given timeframe. Unlike the *PR*, the *AR* model is dynamic and community based. It focuses on access to



Disaster Risk Management, Figure 1 Various perceptions of hazard/disaster risk.

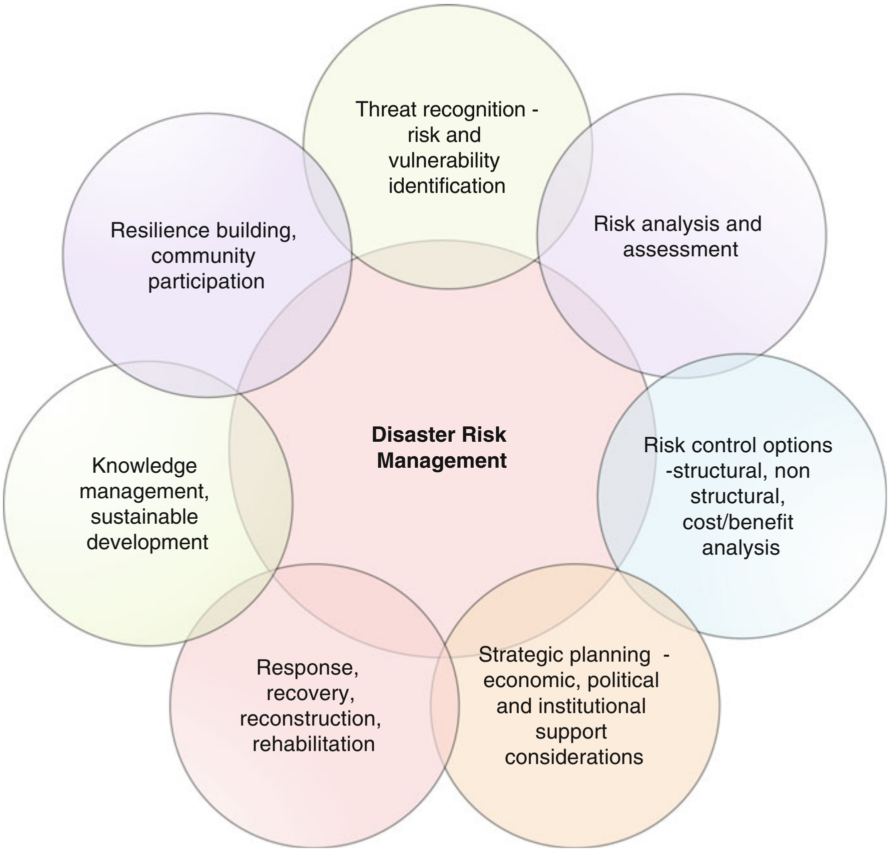
Disaster Risk Management, Table 1 List of disaster risk assessment approaches that are similar to the conventional approach as given in Eq. 1. Here, commonly known variables are: *R = risk*; *p (or H) = probability*; *L = loss*; *V = vulnerability*; *I = impact*.

Proposed risk evaluation equation	Variable other than probability and impact	Expert(s)
$R = p \cdot L^x$	x (> 1) = people's perception	Whyte and Burton (1982)
$R = P \cdot S$	S = severity	Government of Michigan (2001)
$R = p \cdot V \cdot n$	n = social consequences	Ferrier and Haque (2003)
$Risk = \frac{H \cdot L}{preparedness(mitigation)}$	Preparedness or mitigation are measurable measures	Smith (2004)
$R = p \cdot L \cdot f(x)$	$f(x)$= risk aversion factor	Schneider et al. (2006)
$R = H \cdot V \cdot M$	M = manageability or ability of humans	Noson (2009)
$R = H \cdot Elements\ at\ Risk \cdot V$	*Elements at risk = physically exposed assets*	Smith and Petley (2009)
$R = H \cdot (V \cdot cp)$	cp = community perception	Nirupama (2012)

income opportunities, and the development of coping strategies during and after a disaster.

In most quantitative risk assessment methods, two variables – probability of the occurrence of hazards and their potential impact – are commonly used. A few methods are discussed here. The HRVA (Hazard, Risk, and Vulnerability Analysis) method (HRVA, 2004) of BC, Canada evaluates disaster risk based on event likelihood; assessment of vulnerability (social, physical, economic, and environmental) and severity of consequences (fatality, injury, damage, and disruption of essential services – water, electricity, communication networks, physical, and economic impact). Although the HIRA (Hazard Identification and Risk Assessment) (HIRA, 2011) of Ontario, Canada follows similar steps: Hazard identification, risk assessment, risk analysis, and monitoring/review for future revisions, it accounts for psychosocial factors, such as panic and hoarding behavior, in assessing disaster impacts.

The FEMA (Federal Emergency Management Agency) model (FEMA) was developed in the USA to provide guidance to the nation for planning and decision making



Disaster Risk Management, Figure 2 Elements of comprehensive risk management.

during disaster management through the use of mitigation. The model accounts for threat identification and rating, assessment of assets, vulnerability, risk, and mitigation options. NOAA (National Oceanic and Atmospheric Administration)'s Geographic Information System (GIS)-based vulnerability assessment tool identifies opportunities beyond the existing built environment for reducing future hazard vulnerability and identifies the large tracts of undeveloped land in communities that can be used for future land-use planning for sustainable growth.

The SMUG (Seriousness, Manageability, Urgency, and Growth) (CDEMG, 2005) model was developed by the Civil Defence Unit of Chatham Islands Council of New Zealand. The model describes the prioritization of potential hazard risks based on four criteria: Seriousness (number of lives lost, potential for injury; physical, social, and economic consequences), Manageability (ability to mitigate, both hazard and vulnerability), Urgency (measure of capability to address the hazard), and Growth (rate at which hazard risk will increase through either an increase in the probability of occurrence, in the exposure of the community, or combination of the two); and four R's (Reduction, Readiness, Response, and Recovery).

In less developed regions such as Latin America and the Caribbean and Asian countries, national governments and NGOs usually play a pivotal role in managing disasters. The concept of risk evaluation, however, is similar to that of shown in Eq. 1 and risk assessment methodologies are similar to the ones used in developed world. In an ideal disaster risk management, a hazard and vulnerability analysis would be carried out and then appropriate action would be taken based upon the analysis (NDM, 2012).

Risk control options – structural, nonstructural, cost/benefit analysis

These considerations are based on feasibility, effectiveness, and cost/benefit analysis. Structural measures may include the building of dykes, dams, and other protective structures. Nonstructural measures may include land-use planning, hazard risk zoning, early warning systems, education and awareness campaigns, affordable disaster insurance, and legal and regulatory policy. Market-like tools, such as reinsured catastrophe funds (Mexico) and mitigation-focused insurance schemes (Barbados), have been implemented in a few countries (Freeman et al., 2002).

Strategic planning – economic, political, and institutional support considerations

Financial commitment and political will are fundamental to any successful disaster management program. The allocation of resources, the building of institutional support, the creation of social programs, and community-based initiatives toward individual and collective protection measures are most important. In North America, Europe, and other developed countries, disaster risk management programs are well established, structured, and fairly funded. These regions also have great early warning systems in place, remarkable disaster preparedness, and response and recovery capabilities. In the developing world, however, the focus has shifted to knowledge dissemination, disaster preparedness awareness, and community-based programs. For example, in India, the authorities at the state level take the main responsibility for disaster relief with financial assistance from the central government. A small Calamity Relief Fund, constituted with both state and central government contributions is managed by the Disaster Management Authority of India, under the Ministry of Home Affairs (Freeman et al., 2002). In case of a major disaster, the central government provides predetermined reimbursement sums for loss of life, limb, and partial and total loss of housing and productive assets.

Response, recovery, reconstruction, and rehabilitation

Response capability and mutual agreement with neighboring regions (depending on the size and type of the event), assistance with recovery, and reconstruction would be extremely important for the impacted communities to deal with their loss and remain optimistic about their future. The rehabilitation phase provides a rare opportunity to reassess the situation, consider various options to relocate or build a better, stronger, and more resilient community. Disaster aid – internal and/or international, bilateral (government to government or through NGOs) or multilateral (through the UN agencies) must be in place to reduce the impact of a disaster. The Government of India, in partnership with the United Nations Development Program (GOI-UNDP, 2008, 2010), has developed a Disaster Risk Management Programme through disaster preparedness and vulnerability reduction. Their goal is to strengthen institutional capacity with specific emphasis on women and other marginalized groups. They have adopted a multi-hazard approach with an objective of achieving a sustainable disaster risk reduction in some of the most hazard-prone districts in selected states in India. Another example is from Fiji, where exposure to cyclones, floods, droughts, earthquakes, and tsunamis is widespread. Fiji has been able to develop a good disaster preparedness, response, and recovery plan in which NGOs are encouraged to actively participate in all the functions of disaster risk management (Freeman et al., 2002).

Knowledge management and sustainable development

Institutional knowledge must be preserved for better learning and understanding. An approach of sustainable development would allow for the use of local resources (human, social, environmental) and thus contributes to local economy. Interestingly, in developing nations, NGOs play an active role in risk reduction activities in the region. The so-called “knowledge network” involving civil society, the scientific community, and to some extent, the market is gaining popularity among people in India.

An approach suggested by Cardona (2006) for the Americas, and which can also be applied to other regions, is to use a system of indicators to measure a country’s risk management performance. As shown in Eq. 2, the Risk Management Index (RMI) is based on a set of indicators that represent organization, development, capacity, and institutional actions taken to reduce vulnerability and losses, to prepare for crisis, and to recover efficiently from disasters.

$$RMI = \frac{(RMI_{RI} + RMI_{RR} + RMI_{DM} + RMI_{FP})}{4} \tag{2}$$

where

RMI_{RI} = risk identification, includes objective and perceived risks
RMI_{RR} = risk identification, includes objective and perceived risks
RMI_{DM} = measures of response and recovery
RMI_{FP} = governance and financial protection measures

Resilience building and community participation

The final element in the cycle of disaster risk management is to work toward building resilient communities with community participation and community owned programs. For an effective and helpful risk management program, it is critical that communities make risk-based choices to address vulnerabilities and mitigate disaster impact. Resilience building must become the foundation of future risk management programs. A well-designed communication strategy can be instrumental in the successful implementation of policy and other measures. In Asian countries, a communities based holistic approach is gaining popularity as people feel responsible for their safe future (Padmanabhan, 2008).

Summary

Disaster risk management involves overall understanding and realization of potential hazards, identification of vulnerable people and property, risk evaluation, institutional support, and the adoption of a culture invested in preserving institutional knowledge. Various qualitative and quantitative methods can be used for risk assessment for the purpose of the development of a disaster risk management framework. The use of indicators to capture a sense of the central components in a holistic risk management process is worth examining. It is, however, safe to say that in recent years, most nations have shown an increasing trend toward developing comprehensive disaster management programs. They have broadened their national disaster management programs to encompass risk assessment, risk control, mitigation, preparedness, political will, economic feasibility, response, recovery, resilience building, and strategic and sustainable development activities. The success of such a framework or program may depend on the commitment of stakeholders such as communities, professionals, academics, and policy and decision makers.

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Cross-references

Disaster
Disaster Research and Policy, History
Disaster Risk Reduction
Education and Training for Emergency Preparedness

Emergency Management
Emergency Planning
Expert (Knowledge-Based) Systems for Disaster Management
Hazard and Risk Mapping
Mitigation
Resilience
Risk
Risk Assessment
Risk Governance
Risk Perception and Communication
Vulnerability

DISASTER RISK REDUCTION

Walter J. Ammann
Global Risk Forum GRF Davos, Davos Platz, Switzerland

Synonyms

Disaster reduction and recovery; Integrative risk management; Risk reduction and disaster management

Definition

Disaster risk reduction (DRR) refers to a wide range of opportunities for risk abatement and disaster management. Risk reduction includes prevention, preparedness, and part of the recovery process, and it gives particular emphasis to the reduction of vulnerability, which is defined as "the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards" (UNISDR, 2005) Disaster management includes warning, alert, emergency response, and part of recovery. It includes a focus on methods of increasing resilience. DRR aims to limit risks – assuming that they cannot be completely avoided – and concentrates on minimizing the adverse impacts on disasters. This needs to be accomplished within the broad context of sustainable development.

Introduction

The increasing world population, coupled with globalization and urbanization, has greatly increased the risks and impacts of disasters. Climate change and land degradation aggravate the situation in terms of intensity, occurrence, and complexity. Recent disasters, such as the Asian tsunami, Hurricane Katrina, the earthquake in Haiti, and influenza pandemics confirm the global reach of disasters and the tendency for their impacts to increase over time. Trends in risk management confirm that the world we live in today is more complex, more vulnerable, and more interdependent than at any time before in history (UNISDR, 2012). When settlements or infrastructure overlap with major hazard zones, natural events can cause significant damage. Natural hazards limit the availability of living space and thus incur social costs. Studies by the World Bank (World Bank, 2005; Global Facility, 2007) show that more than 3.5 billion people are located, and about 80% of the world's gross domestic product is produced, in areas exposed to at least one natural hazard with a significant probability of occurrence.

Over the last few years numerous catastrophes have drawn attention to the fact that the extent to which life, limb, and property can be protected is limited. The protection of life is certainly the primary concern, but also economic damage has to be reduced in order to protect vital economic growth, especially in developing countries, in which large disasters can absorb more than 10% of GDP. Sustainable development and poverty reduction go hand in hand with disaster risk reduction strategies to achieve the UN Millennium Development Goals (UN MDGs). Disasters and risks should no longer be seen as a purely humanitarian affair but as an integrative part of sustainable development and adaptation to climate change (UNISDR, 2009). In fact, adaptive capacity is considered a core characteristic of a resilient socioeconomic system (CRN, 2011, p. 39).

The World Conference on Disaster Risk Reduction held in Kobe, Japan, in January 2005 (WCDR, 2005) brought consensus that to achieve risk-resilient, sustainable societies, extreme events – such as natural hazards, climate change, diseases (including pandemics), man-made hazards and terrorism – have to be managed in an integrative way. As a result, the "Hyogo Framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disasters" HFA (UNISDR, 2005) was approved by the 168 government representatives gathered in Kobe. Under the Hyogo Framework, governments committed themselves to the following five priorities:

- Make disaster risk reduction a priority: ensure that it is a national and local priority with a strong institutional basis for implementation. The creation of national platforms and national focal points is strongly encouraged.
- Know the risks and take early action: identify, assess, and monitor disaster risks, as these tasks are essential components of risk reduction that will enhance early warning.
- Build an understanding of awareness: use knowledge, innovation, and education to build a culture of safety and resilience at all levels.
- Reduce risk: identify those variables latent in society and the environment that contribute to risk and ways to mitigate them.
- Be prepared and ready to act: strengthen disaster preparedness for an effective response at all levels.

Subsequently, the UNISDR produced assessment reports on disaster risk reduction (e.g., UNISDR, 2011) and a policy discussion document on the way forward after the Hyogo initiative ends in 2015 (UNISDR, 2012). DRR is clearly going to benefit from integration with the Millennium Development Goals and the Rio + 20 resolutions. At the time of writing it is unclear what instruments will replace the five Hyogo goals and whether the succeeding initiative will be merely an extension of the current one or will involve new legal and administrative instruments to induce governments to reduce the risk of disasters.

Disaster risk reduction (DRR)

Disaster risk reduction has two components:

- *Risk reduction* refers to efforts to limit risks due to hazardous situations. This can be achieved by good prevention.
- *Disaster management* signifies the need to reduce or limit the resulting damages caused by a disaster. This can be achieved by good preparedness, an efficient disaster or crisis management system and an effective recovery process.

DRR is thus a process of both, risk reduction and disaster management and is sometimes called integrative risk management (IRM–Ammann, 2006). Besides risks due to natural hazard, which is aggravated by climate change, IRM includes numerous other risks to be considered simultaneously such as those of a technical, biological, and chemical nature; pandemics, terrorism, and financial risks.

DRR requires an approach that not only tackles multiple risks, but also involves multiple stakeholders. Although the HFA recognizes that governments have the primary responsibility to guide and implement measures for achieving DRR, to create the necessary political will at the national level, a wide group of risk management experts, practitioners, scientists, and key players from civil society and other sectors with a strong emphasis on implementation at "the last mile" has to be involved and has to interact with key players from line ministries and disaster management authorities. Practice, science, policy, and decision making have to be closely linked in the search for sustainable solutions to the complex risks society is facing today. Only an interdisciplinary approach can bridge the gap between problems and their main causes on the one hand, and governance and technology perspectives for problem solving on the other. Demand-driven, practical application has to supplant purely supply-driven scientific knowledge. The task of protecting people and private and public goods has to be the central focus of this knowledge development process, and it has to be achieved in a sustainable manner.

As climate change is aggravating the meteorological hazards in terms of frequency, intensity and interdependency, measures for *climate change adaptation (CCA)* have to be closely linked to programs for DRR (UNISDR, 2009). The *harmonization of DRR and CCA* measures is already a crucial issue. This must take place through a common process of adaptation to both the effects of climate change and the increasing impacts of disasters. Common strategies of vulnerability reduction are needed. For instance, in tropical coastal areas, settlement and livelihoods need to be made resistant not only to hurricane storm surges and tsunamis, but also to potential sea-level rise and the intensification of storms that climate change may bring. Coasts are very attractive areas for settlement and are in many cases the most economically buoyant parts of countries, rich and poor alike. However, it may be necessary to manage a retreat from the coast if the worst hazards are to be avoided or reduced. This will involve both costs and economic sacrifices.

Dealing with natural hazards is not just complex, but also contradictory when technical, social, economic, and ecological aspects have to be balanced. It is no longer adequate for risk management professionals to focus solely on risk within a particular realm. Rather, in a world with interdependent systems of rapidly growing complexity (such as critical infrastructures and interdependent processes and services), risk management must have a new vision that overcomes boundaries between subject areas, one that reaches across specialisms and departments. Safety and security have to be seen as a holistic means of enabling better planning, response, and reduction of the most pressing risks.

Integrative risk management, risk culture, and governance

The key questions are: How do we create a safer world and how can our developing knowledge support this process of change? The approach must be that of integrative risk management across subject areas, professions, and sectors, encompassing natural sciences, social sciences, and engineering. Scientific understanding must be placed at the service of business, policy responses, and citizen participation. Among the risk management communities, stronger ties have to be built with private-public partnership models, and approaches need to be devised to move toward a more truly integrative way of thinking about risk: a holistic approach to risk reduction with safety, security, and sustainability at the center. This is an approach that will help policy makers and business people, risk managers and civil society to address the complex risks around them more effectively.

To be able to take effective and efficient decisions for disaster risk reduction and climate change adaptation measures, which lead to transparent and comparable results in different risk situations, a consistent and systematic risk management approach has to be followed. Hereafter, this approach will be called "integrative risk management," a process that embodies a systematic framework for risk analysis and assessment procedures, that leads eventually to consistent decisions and to the optimized, integrative planning of risk reduction measures. A consistent risk concept provides a substantial base and allows the comparison of various risk scenarios at different locations and originating from different natural disasters. Hence, the key to the future is risk-based management, rather than an approach based solely on hazard management. A significant driving force for this paradigm shift is the demand for accountability and improved effectiveness of the risk reduction measures.

The public perception of natural hazards differs from the perception of ecological, technical, and social risks leading to conflicting security philosophies, which hinders consensus on integrative measures. Different ways in which people perceive risks have an important effect on how they may or may not accept any measures that are imposed. A strategy for protection from natural disasters has to find a way to put the various risks onto a common scale to allow for comparability and that serves as a platform from which measures can be agreed upon. Any risk to humans and the environment has to be considered within the context of social, financial, and economic consequences and increased interdependencies between the various risks. The way a society handles questions of safety and security may be summarized with the term "*risk culture*." This means that security can only be gained by risk-oriented thinking.

Risk governance looks at how risk-related decision making unfolds when a multitude of stakeholders and actors is involved, requiring coordination and possibly reconciliation between a profusion of roles, perspectives, goals, and activities. Good risk governance stands for transparency in decision making, effectiveness and efficiency of the measures, accountability, a strategic focus, sustainability, equity, fairness, respect for the law, and the need for the solution to be politically attractive and legally permissible, as well as ethically and publicly acceptable.

Integrative risk management and good risk governance are complicated by the fact that in today's society many risks are not isolated, single events with limited extent, but are trans-boundary risks that affect countries with different political systems and coping strategies.

Framework for DRR and CCA

The concept of integrative risk management (i.e., DRR) is shown in Figure 1. Integrative risk management starts with the process of identifying and analyzing risks in order to answer the question "What can happen?," followed by risk assessment, which should answer the question "Is what happens acceptable?," which leads in turn to the planning of risk reduction measures. The ultimate objective is to create protective measures. The main criterion for choosing the correct protective measures is cost-effectiveness. However, DRR (and CCA) have to overcome a number of problems and obstacles:

- The risk-oriented approach and the methodology of dealing with uncertainties may determine the solution rather than the risk itself. This applies both to the analysis and the assessment of risk.
- Measures designed to promote safety may have limitations that are greater than the expectations of safety held by civil society.
- The various points of view, attitudes, and values of all stakeholders involved and affected by the risk may differ and possibly conflict.
- Disaster risk prevention and mitigation measures have to take the whole set of pre- and post-disaster measures into consideration, as well as measures during a crisis itself, and measures to transfer risk using insurance (Figure 4).

Disaster Risk Reduction, Figure 1 Framework for integrative risk management (Source: author).

- All solutions have to fulfill the criteria of sustainability, that is, a sustainable approach to disaster risk management has to be a socially, economically, and environmentally balanced and acceptable approach.
- Integrative risk management also needs a strategic and systematic process of control, including the periodic evaluation of the risk situation and a comprehensive dialogue on risk between all stakeholders.
- When setting limits for the protection and defining the processes of decision making, there is a need for dialogue and communication in order to ensure the participation of all stakeholders. Risk communication can have a major impact on how well society is prepared to cope with risks and how people react to crises and disasters.
- A balance is needed between acceptable residual risk and the economic costs of risk reduction measures.

Risk concept

To be able to compare different types of natural hazards and their related risks and to design adequate risk reduction measures, a consistent and systematic approach has to be used (Figure 1). The risk concept represents the methodological basis of several elements: integrative risk management, the decision-making process in risk reduction and mitigation, and disaster management. It serves to aid transparency in risk dialogue between all stakeholders (Ammann, 2006). The basic principles of the risk concept are represented in Figure 2 and can be summarized by the following key questions:

- How safe is safe enough?
- What can happen?
- What is acceptable (to happen)?
- What needs to be done?

The question "What can happen?" has to be answered by risk analysis, whereas the question "What is acceptable?" needs the assessment of risks. The necessary steps

Disaster Risk Reduction, Figure 2 Basic questions and elements of the risk concept (Source: author).

Risk Anaysis	Risk Assessment	Planning of Measures
▪ Hazard Analysis – Event Analysis – Effect Analysis ▪ Exposure Analysis ▪ Impact Analysis (Vulnerability Analysis/ Robustness) ▪ Risk estimation and Risk de-scription/Visualisation	▪ Protection Goals – Life Risk - Individual Risk - Collective Risk – Assets/Material Damage ▪ Risk Categories ▪ Risk Aversion	▪ Risk- Cost- relationship ▪ Marginal Costs ▪ Integration of all possible measures ▪ Comprehensive Assessment of all measures

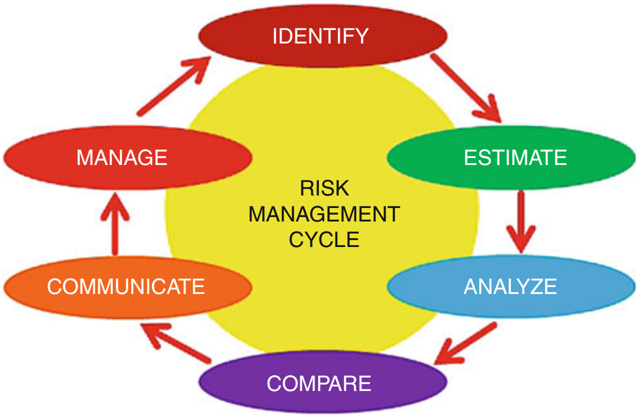
Disaster Risk Reduction, Figure 3 Necessary steps in risk analysis, risk assessment, and the integrative planning of risk reduction measures (Source: author).

are summarized in Figure 3. The goal of a risk analysis is to achieve the most objective possible identification of the risk factors for a specific, damaging event, object, or area. The question “What can happen?” has to be answered by considering a variety of factors that influence it.

Risk assessment aims to give an explicitly subjective answer to the question “What is acceptable?”. Thus, it asks how big a residual risk is acceptable. Risk assessment is by nature very complex and has to deal with the fact that risk is a mental construct but not a fully rational one. An important aspect is risk aversion, as practiced in relation to catastrophic events: people’s wish to prevent large, spectacular, or particularly frightening events may be disproportionate to the event’s real consequences. The acceptance of a risk also depends on whether it is given by active choice or not. Risk categories are defined to the extent that self-reliance and autonomy are possible.

Risk assessment is closely linked with the protection goals that people want to achieve. A protection goal is a set of criteria for the implementation of the primary goals of all efforts to improve safety. It represents the acceptable risk level and thus defines how far the measures should go. A protection goal has different meanings as it has to cover individual and collective perspectives. An individual’s protection goal is often defined in terms of the probability of dying. The marginal costs of safety measures (Ammann, 2006) have proven to be the most useful means of defining protection goals in terms of the collective perspective of society. The marginal costs represent certain expenses per fatality avoided or per human life saved. The safety measures can be increased until the desired level of risk reduction is achieved.

Determining the marginal costs of avoiding a fatality can lead to the misunderstanding that a price can be allocated to a human life. The criterion of marginal costs



Disaster Risk Reduction, Figure 4 The risk management cycle (Source: author).

should be seen as the optimization of safety measures in terms of lives saved within the limitations of available means and resources.

Planning helps identify measures that are necessary and appropriate in order to reach the protection goals. The main function of the planning of integrative measures is to achieve the intended level of safety in the most cost-effective way. Organizational, technical, and biological protective measures must be planned, checked for effectiveness, and undertaken in concert, while keeping in mind that prevention, intervention, and reconstruction are all equally valid risk management measures (Figure 4). Whereas preventive measures serve primarily to reduce vulnerability, preparedness and intervention measures primarily serve to strengthen resilience. Further criteria such as sustainability, acceptability, feasibility, and the reliability of solutions have also to be kept in mind.

Safety measures are always accompanied by side effects. The most obvious of these is financial; however, aspects of ecology, landscape protection, and land-use planning can be of equal importance. The optimal coordination of all measures has to bear in mind that all relevant aspects and activities in the field of disaster risk reduction have to be sustainable. Measures need to be environmentally sound, to consider societal preferences and to be cost-effective. Disaster risk reduction has also to integrate with the sustainable use of natural resources and with sustainable development. This is why it is considered a cross-cutting issue.

The sociopolitical aspects of sustainability are a question of development and welfare priorities and have to be seen in context of other targets such as education and health care. Especially in developing countries, a reallocation of resources is often needed after major catastrophes for recovery purposes – resources which have been allocated originally to be used for investments in, for example, education, health care, or welfare. What is needed is a political balance between long-term investments for prevention and short-term measures for disaster response and recovery.

Risk dialogue and strategic controlling

Integrative risk management not only dictates that the measures are planned, assessed, and applied in accordance with the risk concept, but also that all those who are involved and affected are included in a comprehensive risk dialogue, and in the processes of planning protection measures. Risk communication and risk dialogue with all stakeholders have to start promptly at an early stage. They will be dominated to a greater extent by questions than by answers, and by processes rather than solutions. A continuous, comprehensive risk dialogue is therefore of vital importance, as it will help ensure that risk management becomes a transparent, understandable affair of public trust.

Active information supply and communication play a dominant role in crisis situations. A well-informed public will weather a catastrophic situation much better than an ill-informed one, and the risk of panic and long-term damage can thus be reduced.

Strategic controls should be used periodically to check the risk situation and monitor the costs and benefits of measures. It is also necessary to monitor residual risks. Integrative risk management enables the overarching aims to be reached using protection measures that can be justified in technical, economic, societal, and environment terms.

Numerous factors can increase future risks and thus create additional uncertainty. Among the most important factors to be taken into consideration, monitored, and periodically checked are globalization, mass mobility, vulnerability, the spread of urban areas, the increase in fixed capital investments, sensitivity (through increasing economic interdependencies), international leisure activities, sociopolitical changes, and changing climate and weather patterns. Developments in hazard and risk management must be followed carefully and the potential for optimization exploited. In the future, the challenge will be to understand and cope with constant change; new risk scenarios, new hazards, climate change, new sociopolitical conditions, and so on. This means that strategies for dealing with risks due to natural and anthropogenic hazards will have to undergo constant adaptation.

Conclusions

Disaster risk reduction is embodied in the combination of risk reduction and disaster management. It addresses the whole risk cycle of prevention, intervention, and recovery. In coping with natural hazards, most countries still focus on reactive disaster management, whereas proactive risk reduction using preventive measures is politically more difficult to justify and implement. To cite Kofi Annan, former Secretary General of the United Nations, "The benefits of prevention are not tangible; they are the disasters that did not happen." To strengthen prevention is only possible with a risk-related approach that needs a paradigm shift from hazard-oriented reaction to risk-related preemptive action. The benefits of prevention can only be made clear with a strict risk controlling process, and political support for prevention and climate change adaptation can only be gained with continuous activities designed to raise public awareness.

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Cross-references

Climate Change
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Disaster
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Economic Valuation of Life
Emergency Planning
Frequency and Magnitude of Events
International Strategies for Disaster Reduction
Perception of Natural Hazards and Disasters
Risk
Risk Assessment
Risk Governance
Risk Perception and Communication

DISASTERS

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Introduction

In the novel Candide by Voltaire (1759), two characters debate the roots of a great earthquake that had just leveled one of Europe's greatest and most religious cities, Lisbon (Figure 1). To one, Candide, the calamity – which struck on All Saints' Day 1755 when all the pious were in church – was clearly the day of final judgment; to the other, his tutor Pangloss, it was simply Lisbon's location above a subterranean seam and an inconsequential event in what was otherwise the best of all possible worlds. The authorities of the city, a powerhouse of the inquisition, tolerated no such debate: for his sins in not recognizing divine retribution as the cause, Pangloss was rapidly hanged, whereas Candide was administered a hundred lashes for listening and watching.

Disasters, Figure 1 The cathedral in Lisbon was one of many that collapsed during the 1755 earthquake in which many of the city's inhabitants perished. The result was a cathartic reinterpretation of natural hazards as acts of God or physical nature and also the emergence of a social science paradigm that viewed disasters as the consequence of human culpability.

Voltaire's international best seller may have been parodying the new religious optimism of the Enlightenment which saw the best in everything, but the Lisbon disaster would turn out to be a turning point in the recognition that events like earthquakes were not the result of divine wrath or an unmerciful God but instead were natural phenomena. However, amid the theological fires that the quake ignited among major Enlightenment thinkers, one of them, the philosopher Rousseau, drew attention to human culpability. After all "…nature did not construct 20,000 houses of six to seven stories there, and that if the inhabitants of this great city had been more equally spread out and more lightly lodged, the damage would have been much less and perhaps of no account" (Rousseau, translation in Dynes, 2000, p. 106). What is more, Rousseau pointed out that if the population had evacuated promptly at the first tremors, they would have been safe, but instead, "How many unfortunate people have perished in this disaster because of wanting to take his clothes, another his papers, another his money?" For Rousseau, human beings were responsible for risk because their actions, not the actions of an unmerciful god, brought consequences.

Today, the 1755 Lisbon earthquake is regarded as the world's first modern natural disaster (Dynes, 2000). But two and a half centuries on, those same questions concerning the "naturalness" of disasters, and of the competing significance of their human and physical roots, remain. At the heart of contemporary hazards, research is a clash between two broad schools of thought (Alexander, 1993). The first is fixed in the pioneering US flood hazard research of Gilbert White in the 1940s, which spawned a generation of scientists – the so-called Chicago School – convinced that scientific and technological solutions could protect society against natural disasters (Burton et al., 1978). Their belief that we can adapt to destructive natural forces and reduce their adverse impacts through engineering and planning was a mainstay of the International Decade of Natural Disaster Reduction. IDNDR strategy, developed in the 1980s, sought to transfer this knowledge on disaster reduction as practiced in developed nations to hazard-prone developing countries (Press and Hamilton, 1999). Around this time, however, an opposing school of thought was emerging, gaining ground particularly among social scientists working in the field of development studies, who saw Western technocratic methods as being inadequate for tackling the root causes of most disasters, namely, underdevelopment and the marginalization of people in poor communities. The so-called radical critics increasingly argued that if an individual or a community was already economically or ecologically marginalized, a transfer of technology would not alleviate disaster (O'Keefe et al., 1976; Hewitt, 1983).

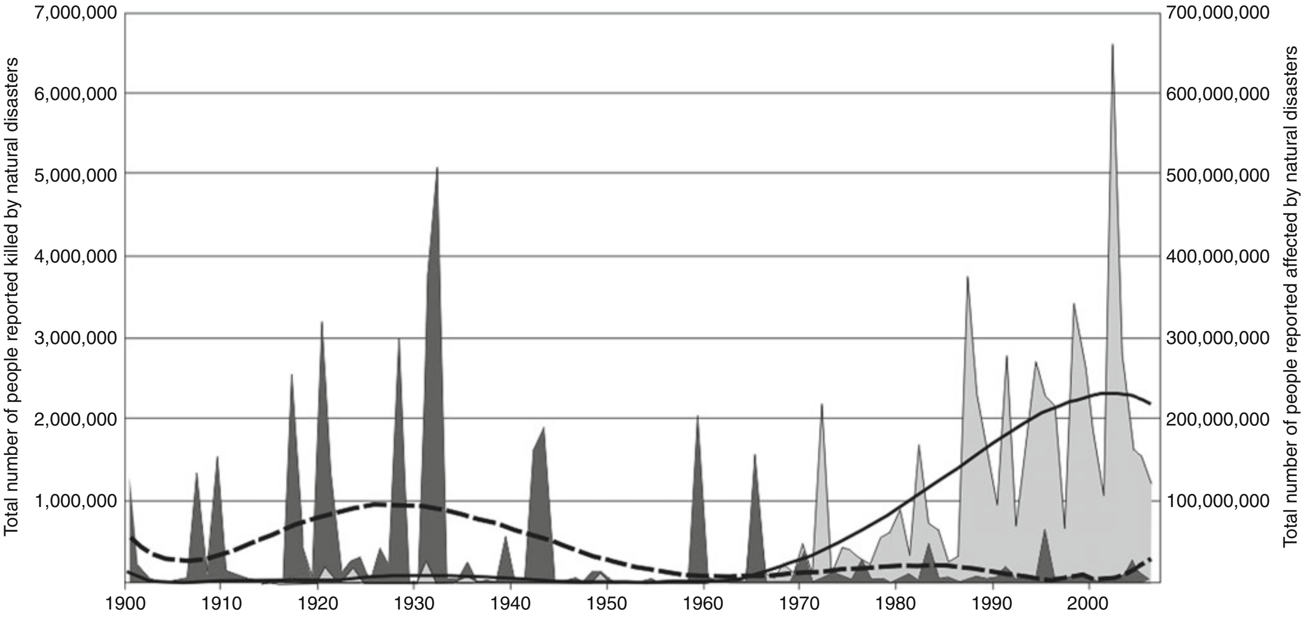
Today, the science of natural disasters is underpinned by a broad acceptance of the paradox that while the causative events (hazards) emerge from nature, the consequent disasters are made in society (Alexander, 1993; Varley, 1994; Hewitt, 1997; Pelling, 2003; Wisner et al., 2004). In other words, although an understanding of the dynamics of the physical environment is crucial for anticipating the incidence of hazardous phenomena, equally important is an understanding of the social, economic, political, and cultural dynamics within a community or society that transform a particular hazard event into a specific disaster. In the contest between the physical and human framing of natural hazards, the latter has arguably now gained the upper hand as the dominating disaster paradigm. As the prominent hazard geographer Kenneth Hewitt (1997, p. 141) notes, "…society, rather than nature, decides who is more likely to be exposed to dangerous geophysical agents."

Modern disaster science, consequently, attempts to fuse an interdisciplinary perspective in which geoscientists and engineers seek to improve their understanding of the frequency and intensity of potentially damaging physical events (the "hazard"), and social scientists reveal the characteristics of a community or society to anticipate, cope with, resist, and recover from such events (the "vulnerability") (Smith, 2001; ISDR, 2004; Wisner et al., 2004). Taken together, analysis of both the physical hazard and the social vulnerability constitutes an assessment of "risk" – the probability of loss resulting from a specified hazard event affecting a particular societal target. It is the realization of this threat that turns a "natural hazard" into a "human disaster." An event that seriously disrupts the functioning of a community or a society (causing widespread human, material, economic, or environmental losses which would exceed the ability of the affected group to cope using it own resources) is designated a "disaster" (Smith, 2001; ISDR, 2004).

The statistics of disaster

The emergence of vulnerability-oriented disaster perspectives has reflected the perceived failure of technocratic approaches to stem the swelling tide of disaster. In 1978, when Gilbert White and colleagues ushered in modern disaster science with the classic text "Environment as Hazard," they did so with opening remarks that lamented how "… the global deathtoll from extreme events of nature is increasing. Loss in property from natural hazards is rising in most regions of the earth, and loss of life is continuing or increasing among many of the poor nations of this world" (Burton et al., 1978, p. 1). Despite three decades of scientific efforts, including an international decade – the 1990s – devoted to natural disaster reduction (Press and Hamilton, 1999), the world still confronts a soaring toll of natural crises.

The raw statistics show that the past four decades have witnessed a fourfold increase in the number of reported natural disasters, from fewer than 100 per year in the mid-1970s to around 400 in the period 2000–2007 (Guha-Sapir et al., 2004; Rodriguez et al., 2009). Since the 1990s, something of the order of 1.5 million people have been killed in natural crises, with the annual death toll averaging around 55,000–65,000 fatalities. In years blighted by major catastrophes, the toll is far greater, such as in 2008 when Cyclone Nargis killed 138,366 people in Myanmar and the Sichuan earthquake in China caused the deaths of 87,476 people, producing mortality estimates more than three times the recent average. In terms of



Disasters, Figure 2 Human losses due to natural disasters, 1900–2006. *Dark shading* indicates fatalities reported due to natural disasters (scale on *left*) and *light shading* indicates total number of people affected (scale on *right*). *Dashed line* shows the smoothed trend for fatality numbers and *solid line* shows smoothed trend for number affected (Source: EM-DAT – the OFDA/CRED International Disaster database, http://www.em-dat.net, Université Catholique de Louvain, Brussels, Belgium).

those affected by disasters, the situation is even more perilous – in recent times (1994–2003), more than 255 million people have been annually affected by natural calamities (EM-DAT, 2006) (Figure 2).

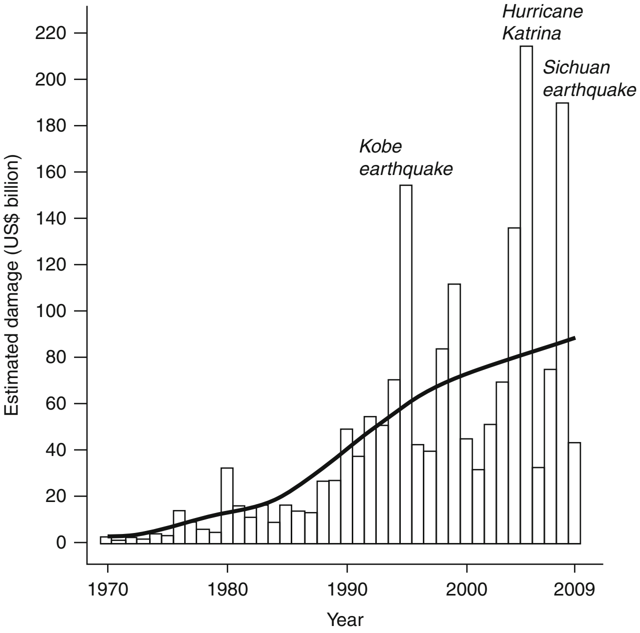
Such crude numbers obscure an underlying geography to disaster fatalities. For the period 1980–2004, the number of disasters and the at-risk populations of high-income and low-income countries are broadly similar (Stromberg, 2007). However, the numbers killed in disasters are over an order of magnitude lower in the wealthier nations – around 75,000 fatalities compared with over 900,000 for poorer nations. This reflects the fact that high-income countries have invariably have invested substantially in a wide range of preparedness and mitigation measures (Figure 3): buildings can be constructed of stronger and more durable materials or elevated above flood levels, farmland can be irrigated to reduce losses during droughts, warning systems for certain natural disasters, such as hurricanes, can save lives, and after a disaster strikes, mass evacuation and emergency medical care and food can limit the human toll of the disaster. Lacking the wealth, infrastructure, and institutional capacity to afford adequate protection, it is no surprise to find that over 90% of the hazard-related deaths are in less-developed nations.

The headline message of the economics of disaster is simple: the costliest collateral losses are incurred by wealthy industrialized nations, but the greatest fiscal burden of disasters (as a proportion of a country's gross domestic product) is inequitably borne by the least economically favored nations (Dilley et al., 2005). Moreover, the financial costs are rising (Figure 4). Current economic losses are up 14-fold compared to 1950s levels, and in the mid-1990s, natural hazards in the USA alone were estimated at US$54 billion per year – or a staggering US$1 billion per week (van der Vink et al., 1998). Currently (2000–2007), the annual global average loss is thought to be around US$82 billion. Again, a contagion of disasters make some years more expensive than others. 2008, for example, was especially costly with the Sichuan earthquake in China (US$85 billion) and hurricane Ike in the USA (US$30 billion), contributing to economic losses more than double the recent average (Rodriguez et al., 2009). As the global economy grows and the number of at-risk assets swells worldwide, the cost of natural disasters in both monetary and human terms is expected to spiral higher still.

The changing face of disasters

Despite the rising incidence of disasters over recent decades, there is little sign that the physical environment that we occupy is becoming intrinsically more dangerous. There is no appreciable increase detected in the frequency or magnitude of major geophysical phenomena such as earthquakes, volcanic eruptions, and tsunamis. It is possible that anthropogenic climate change ("global warming") is invigorating the incidence and severity of tropical storms and other hydrometeorological hazards (Mitchell et al., 2006; Knutson et al., 2010; Lubchenco and Karl, 2012), but even if a heightened level of some hazardous

Disasters, Figure 3 Two contrasting views of how urban settlements face up to the earthquake threat. (*Left*) In wealthy industrial nations considerable effort has gone into engineering buildings to withstand earthquakes, evident in this Tokyo skyscraper. However, in major cities in lesser developed nations, such as Istanbul, Turkey (*right*), it is the weakly assembled building stock that is the main threat to live and livelihood in future seismic disasters. Although engineers have the technical knowledge to design buildings to withstand moderate earthquake strikes, in many countries the implementation of good construction practices and effective planning measures is hampered by weak regulatory controls and political corruption.



Disasters, Figure 4 Estimated damages (US$ billion) caused by reported natural disasters, 1970–2009 (Source: EM-DAT – the OFDA/CRED International Disaster database, http://www.em-dat.net, Université catholique de Louvain, Brussels, Belgium).

processes is real, it is insufficient to account for the dramatic increases in natural disasters over recent times.

Instead, for many disaster scientists, the root of our more perilous predicament lies not in the physical domain but in the human one. Specifically, it lies in the increase in the world's population, its concentration in large conurbations, the high vulnerability of modern societies and technologies, and the social and economic consequences of development in highly exposed regions, such as coastlines (Smolka, 2006). Coastalization is a trend recognized worldwide whereby more and more population, property, and infrastructure squeezed along shorelines facing rising sea levels and threatened with saltwater intrusion into groundwater aquifers and inundation from storm surges and tsunamis (Figure 5). Drawing attention to the preferential migration of the most affluent sectors in US society to the popular retirement destinations of the earthquake-prone shores of California and Washington and the hurricane-prone Gulf Coast, for example, van der Vink et al. (1998, p.537) asserted "We are becoming more ulnerable to natural disasters because of the trends in our society rather than those of nature."

Along with a move to the coast, the global shift to urban living has made many cities as dangerous as the natural environments they replace. With the rise of supercities (>2 million people) and megacities (>10 million people), human settlement has been forced into marginal,

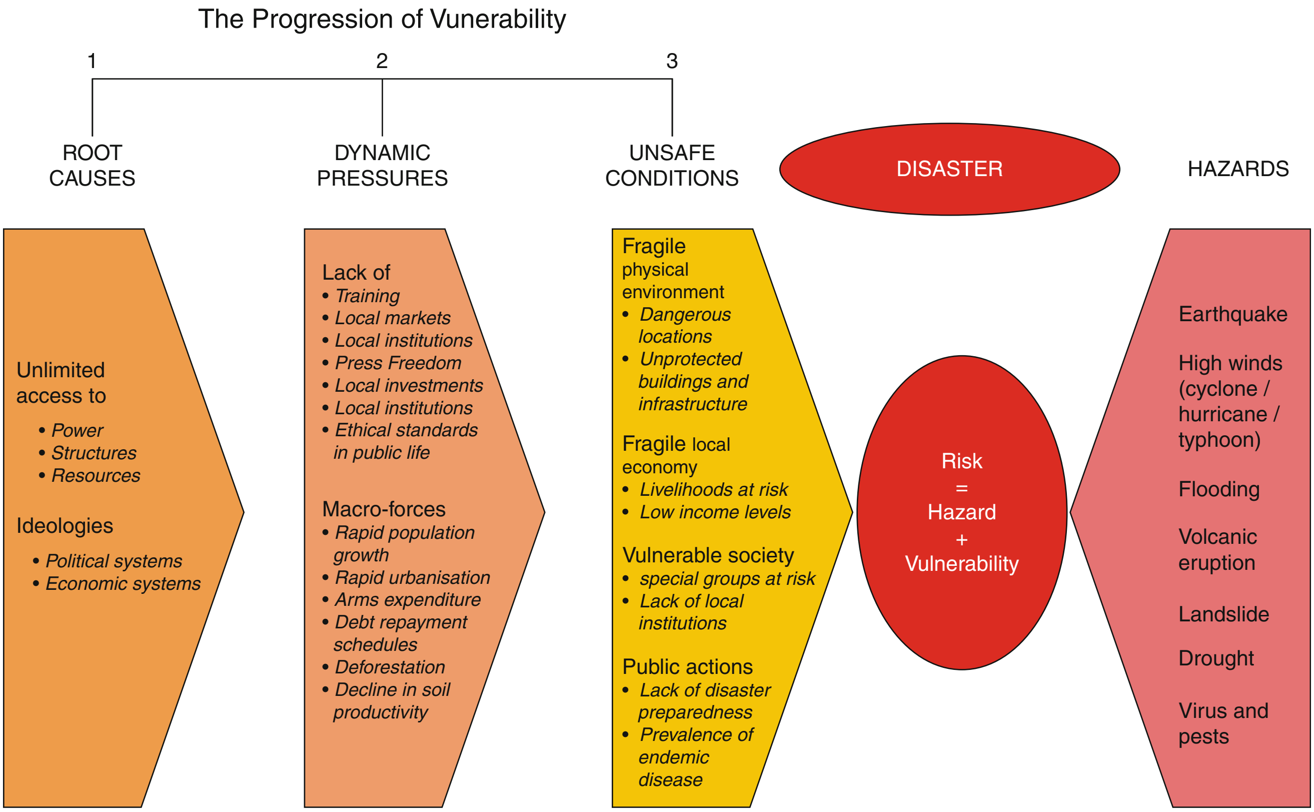
Disasters, Figure 5 The concentration of people, infrastructure and economic development along tsunami-prone shores has changed the nature and extent of vulnerability in many coastal zones. The 2004 Indian Ocean earthquake and tsunami, for example, affected 14 Asian and African countries and killed people from 48 nationalities, 34 representing foreign tourists from around the world. Expensive beachfront tourist complexes, such as one destroyed here in Khao Lak (Thailand), greatly contributed to the human and economic losses of this calamitous event.

dangerous places, sometimes within the sprawling metropolitan areas. Alongside the physical marginality of such areas is the acute social and economic marginality of the people who must inhabit them (Wisner et al., 2004). Such a situation is tragically exemplified by the slide of solid waste from the Payatas rubbish dump in central Manila (Philippines) in July 2000 which killed 300 people in the contiguous squatter settlement (Gaillard and Cadag, 2009). Such an event illustrates how, although hazard typologies have in the past made a clear separation between "natural disasters" produced by geophysical agents and "human disasters" that arise from technological failures or human conflict, such a distinction is ever more difficult to sustain in the real world. In the real world, disasters are increasingly messy amalgams between natural processes acting on human environments.

For all their unnaturalness, disasters retain a clear natural geography to their incidence. That is because the hazard processes that underpin them tend to strike repeatedly in the same places. The hazard "hot spots" are familiar: droughts have been occurring in the Sahelian region of Africa for millennia, monsoonal storm surges annually inundate the deltaic plains of Bangladesh, hurricanes seasonally batter the Atlantic and Gulf coasts of the USA, and earthquakes and volcanic eruptions routinely plague the tectonic plate boundaries like the Pacific Ring of Fire (Dilley et al., 2005). Because geophysical phenomena are, by and large, persistent offenders, knowledge of their past incidence can provide a reasonable expectation of the physical exposure to hazard in any particular geographic area. Of course, monitoring the nascent signs of impending hazards and forecasting the likely location, size, or style of their impact remain fraught with technical difficulties and scientific uncertainties. The 2011 Tohoku (Japan) earthquake provided a telling reminder of those difficulties; the giant ($M > 9$) earthquake and its accompanying tsunami were not unexpected based on geological evidence, but that data was overlooked in subsequent hazard assessments, leading to inadequate mitigation measures (insufficiently high seawalls). Nonetheless, gauging the physical exposure to floods, hurricanes, earthquake, volcanic eruptions, and the like is often more readily constrained than assessing a hazard-prone community's capacity to resist such events (e.g., Wisner et al., 2004).

The nature of vulnerability

A fundamental challenge of disaster reduction is to anticipate the intrinsic vulnerability (or lack thereof) of communities at risk? The notion of vulnerability has been confronted by disaster researchers for decades, but it is only in the past few years that it has become an issue that is explicitly addressed, and it remains a concept that is difficult to define and quantify (Bankoff, 2004; Wisner et al.,



Disasters, Figure 6 Pressure and Release (PAR) model of Blaikie et al. (1994) showing the progression of vulnerability. The diagram shows a disaster as the intersection between socio-economic pressures on the *left* and physical exposures (natural hazards) on the *right*.

2004; Cutter, 2006). As disasters lie at the intersection of socioeconomic pressures and physical exposures, different kinds of vulnerability prevail (Figure 6). Physical vulnerability (exposure to hazard threats) is the easiest to determine, identifying those that live in perilous places as being potential victims of disaster. Less easy to determine are those whose situation is made perilous because they are socially excluded, economically disadvantaged, and/or politically marginalized. Social, economic, and political vulnerability ensures that access to hazard mitigation measures and disaster reduction strategies are often unevenly distributed across and among at-risk communities. These different facets of vulnerability operate dynamically during hazard events, as is evident in this account of Bangladesh floods:

> On the eve of Bangladesh's massive floods in August 1988, this relatively powerless group (landless squatters] was living in an economically marginal situation but close to the city, on low-lying land prone to flooding. Their economic and political marginality meant they had few assets in reserve. It also meant that their children were unusually malnourished and chronically ill. This channelled the dynamic pressure arising out of landlessness and economic marginalization into a particular form of vulnerability: lack of resistance to diarrheal disease and hunger following the flooding in 1988. Factors involving power, access, location, livelihood, and biology mutually determined a situation of particular unsafe conditions and enhanced vulnerability. (Blaikie et al., 1994, p. 27)

For most practitioners, the first "line of defense" against vulnerability to disaster is livelihood – ensuring that individuals have appropriate assets to grow food themselves or make earnings (Cannon, 2008). Higher incomes and stable employment enable households to have livelihoods that are buffers against hazards. Livelihood presets a person's basic nutritional state, their baseline status, and their general health and welfare. Individuals with poor nutrition are generally less resistant to disease and less capable of making a good recovery when stressed by a hazard impact; morale and personal resilience, stress and general mental health are all factors that are likely to affect the ability to overcome the impact of a hazard. An individual's income determines their capacity to build a home that is safe from endemic hazards and their ability to site that home somewhere out of harm's way. Many people remain vulnerable precisely because they do not have the financial resources to live sufficiently above the regular flood levels or away from steep marginal slopes prone to landslides, excluded from safer areas by high land prices.

"Self protection" from hazards requires knowledge or skills that may be available from the local community or from outside agencies. Equally, for some vulnerable groups like children, the elderly, sick, or disabled, adequate protection from hazards can only be provided at a community or society level. Much of this "social protection" is conferred by local, regional, and national authorities, in the form of hazard-awareness programs, warning systems, emergency plans, and regulations to do with land-use management or engineering and building controls.

Yet ill-judged or inadequate social protection measures can also instigate human disasters, such as through inappropriate policies, weak infrastructure, poor governance and corruption, ineffective monitoring and communication, bad development decisions, injustice, and discrimination. Inaction, in the form of authorities not carrying out their expected regulatory functions, also aggravates disaster. For example, a failure to deal effectively with land squatting and irregular construction fuels vulnerability in the environs of many hazard-prone cities. In Istanbul (Turkey), for example, many people ignore mandatory requirements to live in homes approved as conforming to stringent earthquake design standards, preferring instead to illegally self-build. Yet they do so in part because of a suspicion that the formal approved building stock is "unsafe," having been built by people and using materials unknown to them and signed off as safe by potentially corrupt engineers or officials, all chronic failings of endemic construction practices exposed by the 1999 Izmit earthquake in which tens of thousands of people lost their lives through the collapse of improperly constructed buildings (Green, 2008). Given this deep distrust of the Istanbul's authorized, commercially built housing stock, Green (2008) suggests that bolstering the city's unauthorized self-built housing might actually be an effective means of providing protection against the future earthquake threat.

Regardless of levels of self- and social protection, in landscapes of chronic vulnerability like urban squatter settlements, disasters in some form are probably inevitable. As noted by Hewitt (1983), *"In most places and segments of society where calamities are occurring, the natural events are about as certain as anything within a person's lifetime*." The point here is that although Western disaster discourse typically depicts "disasters" as abnormal occurrences, in communities in many acutely marginalized parts of the world, vulnerability emerges from the "normal" order of things – hazards simply compound the struggles that are part of people's daily lives. Hazards are, in effect, the ordinary, not the extraordinary. Communities living on the margins will have a very low capacity to withstand even small damaging events. For that reason, basic capacity-building measures are a fundamental part of disaster reduction.

In less acute situations, vulnerability (and its alter ego, resilience) is difficult to track, being a dynamic that changes through time as individuals, groups, and institutions adapt to internal and external pressures (Oliver-Smith, 1999a; Turner et al., 2003; Berkes, 2007). Communities can become less vulnerable to hazards if they have a range of options for coping with external shocks and stresses. The key to reducing vulnerability, therefore, is to increase "resilience," a concept defined by the United Nations Strategy for Disaster Reduction as "the ability of a system, community, or society exposed to hazards to resist, absorb, or recover from the effects of a hazard in a timely and efficient manner." Most strategies for growing resilience involve reducing risks by spreading them out, thereby increasing opportunities in the face of hazards (Paton and Johnson, 2006). Ultimately, however, a measure of the success of a community's adaptations to anticipated threats is only apparent after the event (Cannon, 2008). Prior to acute environmental crises, the manifestations of vulnerability – social, economic, institutional, and infrastructure – may be hidden from view. Only when a hazard strikes do the societal and technical bonds of an at-risk community become truly tested and often found wanting (Oliver-Smith and Hoffman, 2002).

A potent example of the revelatory power of disasters was provided by Hurricane Katrina in 2005. The likely impact of major hurricane making landfall in the low-lying Mississippi delta was well known (e.g., Fischetti, 2001), and the landfall of the destructive Katrina storm in New Orleans was accurately forecasted and emergency evacuation plans were put in motion (McCallum and Heming, 2006). What surprised few was that the aging infrastructure of the Mississippi coast's flood protection levees – designed for a category three storm surge – failed under the onslaught of the storm, allowing widespread inundation of the city. What stunned many was the resulting institutional meltdown, which for several days left evacuees with no power, no drinking water, dwindling food supplies, understaffed law enforcement, and delayed search and rescue activities (Cutter et al., 2006).

Events like Hurricane Katrina throw into question how resilience is fostered in social systems. It has long been assumed that governments, from the federal to the municipal, comprise the backbone of emergency management, but increasing community organizations are shown to have a major role to play in the face of disaster (King, 2007). Community resilience takes the form of networks of strong and weak ties – families, churches, local volunteer and relief groups, hobby clubs, even neighborhood and crime watch organizations – that is referred collectively as "social capital" (Dynes, 2002). Through social capital, citizens assume roles as active agents rather than passive victims since they are able to draw upon collective strengths, assistance, and resources to deal with disasters, thereby being more proactive in decision making and effecting a more speedy recovery.

Cultures of catastrophe

While considerable attention has been devoted by hazard practitioners to elucidate and quantify the factors underpinning social vulnerability (Cutter, 2006), some argue

Disasters, Figure 7 The narrow streets, multi-story houses and tiled roofs of many Andean towns are a cultural import from Spanish Andalucia, transforming earlier Inca settlements into places of heightened seismic vulnerability.

that the whole concept of vulnerability is itself a Western ideological construct that fails to acknowledge how natural hazards are themselves a cultural driver, shaping community adaptations in ways that allow disasters to be incorporated into daily life. Bankoff (2003) recognizes this effect of the "normalization of threat" in Philippine culture, seeing it in "...the design and construction of buildings, in the agricultural system, in the constant relocation of settlements and in the frequency of migration. Filipino society has evolved certain 'coping mechanisms' to come to terms with the constancy of hazard and to mitigate the worst effects of disasters. Often, too, in the way in which people deal with emotional and psychological requirements of living with uncertainty may influence what are seen as 'Filipino' beliefs and character traits."

The loss or removal of such cultural coping mechanisms can expose communities to heightened hazard threats, even when that transformation happened decades or centuries before. According to Oliver-Smith (1999b), the calamitous May 31st 1970 Peru earthquake (M 7.7) in Peru had its roots five centuries before when local Andean resilience was replaced by imported Spanish practices; the dispersed design of Inca towns was replaced by the Andalucian-inspired new towns favoring narrow streets with multistory houses pressed close together. Sturdy monumental stonemasonry and anti-seismic wall ties were abandoned, and thatched roofs were replaced with heavy ceramic roof tiles, all of which made houses into earthquake death traps (Figure 7). For these reasons, Oliver-Smith (1999b) argues that the 1970 earthquake – an event which saw 70,000 people killed, 140,000 injured, and half a million homeless – was a calamity 500 years in the making.

Where indigenous cultural practices have persisted alongside recurrent hazard experiences, they are often in stark tension with Western scientific and social dialogues of hazards as interactions between extreme natural events and vulnerable human populations (Chester, 2005). Local knowledge, customs, and traditional beliefs can motivate a community's actions during a crisis, including their propensity to evacuate; in some cases, the cultural ties between community and hazard can have lethal consequences. In 1963, Bali's Mt. Agung erupted during the once-in-a generation Hindu rite killing 1,200 people, many of them waiting patiently and clothed in ritual dress within their temples and resisting attempts by officials and even priests to evacuate them. On the neighboring island of Java, spiritual ties with Mt. Merapi are part of the reason why communities on the perilous upper slopes have resisted efforts to evacuate during repeated volcanic crises, although socioeconomic factors also exert a strong control (Donovan, 2010) (Figure 8). Across many hazard-prone developing regions "...the battle against natural forces is often fought in the cultural arena – with religion as a backdrop" (Svensen, 2009).

Although indigenous cultural traits can at times undermine hazard science approaches to disaster reduction, traditional cultures can also reduce vulnerability by strengthening resilience and providing effective mitigation techniques (Cashman and Cronin, 2008). Perhaps

Disasters, Figure 8 (**a**) The fertile environs of Mount Merapi on the Indonesian island of Java is a hazardous high-population environment where lethal volcanic crises recur every few years. (**b**) Scientific studies of the volcano through monitoring of ground deformation, seismicity and summit gas activity give rise to early warning alerts and lead to mandatory evacuation orders by local authorities. However, routinely at-risk communities on the volcano's upper flanks refuse to evacuate, sometimes with lethal consequences. (**c**) During the 2006 eruption crisis, a pyroclastic flow killed 60 people attending a wedding ceremony in Turgo, a settlement located inside the high-risk exclusion zone. Reluctance to follow volcano emergency management plans reflects a complex combination of socio-economic and cultural factors.

the most dramatic example of this was the self-evacuation of coastal communities on Simeulue and Nias Islands during the 2004 Indian Ocean tsunami. Despite being close to the epicenter of the earthquake and experiencing considerable wave heights, oral traditions of calamitous tsunamis from more than a century before motivated them, at the onset of the initial tremors, to evacuate to higher ground and hardly any lives were lost (Sieh, 2006).

Along the adjacent tsunami-stricken shores of Sumatra, such cultural memories have been largely lost, eroded by economic and tourist development, and with them, have gone traditional practices that long protected communities (McAdoo et al., 2006; Gaillard et al., 2008). According to Sieh (2006, p.1947), disaster reduction in such areas "…does not necessarily involve hugely expensive or high-tech solutions such as the construction of coastal defences or sensor-based tsunami warning systems. More valuable and practical steps include extending the scientific research, educating the at-risk populations as to what to do in the event of a long-lasting earthquake (i.e., one that might be followed by a tsunami), taking simple measures to strengthen buildings against shaking, providing adequate escape routes and helping the residents of the vulnerable low-lying coastal strips to relocate their homes and businesses to land that is higher or farther from the coast."

The politics of disaster

Local disaster cultures exist because communities, and in some cases, whole societies, have coevolved with perilous nature. Strengthening or reestablishing indigenous practices may provide the means by which such communities can confront their hazard threats, but equally, the solutions may come from outside. The technical ability to construct buildings and defenses that can withstand modest hazard shocks exists, as does the scientific knowledge to identify and delineate hazard threats (e.g., Bilham, 2009). But embedding those good building practices and good land-use planning into local environments does not just require an appreciation of cultural sensitivities. Safe construction and effective planning protocols are also underpinned by robust regulatory control. Here, a very different culture can arise – a culture of ignorance, incompetence, and corruption within the authorities charged with emergency planning. With disaster reduction obligations invested in the hands of political authorities, it is the role and efficacy of the state itself that becomes the ultimate element in where and when disasters happen.

According to Berkes (2007), for example, the same hurricane striking Samoa and neighboring American Samoa in the Pacific produced markedly different results: the former was prepared and capable, whereas the latter, much less affluent and used to outside aid for disasters, had weaker institutions for response. Political environments in which there is strong linkage from local to national levels tend to withstand disasters better; Wisner (2001) has argued that so few people died when Hurricane Michelle hit Cuba severely because of the existence of strong organic links between government and people. It has also been argued that emergency crises may be less severe in countries with democratic governments (Sen, 1981), where disaster reduction measures can be more effectively monitored and made accountable through firm civil liberties and a free press (Besley and Burgess, 2002). Of course, as recent disasters in Japan and the USA testify, active democratic systems do not provide immunity from natural emergencies.

Disasters themselves are political instruments. In some cases, they can be a pretext for international political and economic "engineering," and disaster recovery is the impetus for institutional reform (Klein, 2005). In this way, governance – the manner in which power is exercised in the management of a country's economic and social resources for development – exerts a powerful influence on national and international disaster policies. After Hurricane Mitch in 1998, for example, afflicted countries in Central America agreed to a set of principles with international aid donors that included promotion of democracy and good governance, political decentralization and economic debt reduction (Wisner et al., 2004).

The realization that disasters can be significant agents of societal change leads to the paradoxical question as to whether they might, in any sense, bring positive benefits. One benign facet of natural disasters might be in aiding international diplomacy. The earthquakes that struck Istanbul and Athens, in August and September 1999, respectively, opened communication channels between feuding Greece and Turkey, whereas the Bam (southern Iran) earthquake of December 2003 prompted offers of aid from 40 countries, including the USA – the "Great Satan" – which had broken off diplomatic relations with Iran 20 years before. What patchy evidence there is on this notion of disaster diplomacy suggests that while disaster-related initiatives can be catalysts for diplomatic interchanges that have already started, they rarely cement political rapprochement, with a possible exception being the peace deal reached in Aceh after the December 26, 2004, earthquake and tsunami (Kelman, 2006).

Although natural hazards may offer up opportunities for "disaster diplomacy," they can also stir cross-border tensions. During the 2000 and 2004 floods along the India-Bangladesh border, Indian border security forces breached river embankments to allow the water to spill out, thereby ameliorating its downstream impacts in West Bengal (India) but exacerbating destruction of life, crop, and property in Bangladesh (Ali, 2007). In this instance, there was no cross-border conflict, but disasters can trigger political action. It has been argued, for example, that the cyclone and storm surge in East Pakistan in 1970 contributed to the development of the Bangladesh independence movement, while the revolutionary movement in Nicaragua from 1974 to 1979 derived some of its impetus from the effect of the Managua earthquake of 1972 (Wisner et al., 2004). Disasters striking politically peripheral regions can catalyze regional tensions, especially where existing regional deprivations are worsened by post-disaster governmental responses (Pelling and Dill, 2006). Disasters can enhance or even regain the popular legitimacy of political leaders, and many political regimes might interpret spontaneous collective actions by afflicted communities in the aftermath of a disaster as a threat and thereby respond with repression.

Overall, fractured or contested political landscapes often promote a heightened risk to disaster specifically because they sustain an inequitable distribution of resources. But economic resources too can be redefined by disasters; emergency crises can bring direct monetary gain in the form of disaster relief funds that are injected into the local economy. Following the earthquake that killed 80,000 people in China's Sichuan Province in May 2008, for example, funds allocated to rebuilding outweighed the economic loss caused by the quake, enough to raise national economic growth by 0.3% (Hewitt, 2009). Disasters may be economic catalysts at the regional level too. It has been argued that the reconstruction activities following the 1994 Northridge earthquake boosted Los Angeles economy in a similar way to Miami that benefitted after the 1992 Hurricane Andrew (Romero and Adams, 1995; Cochrane, 1997). Following the 1991 volcanic eruption of Mt. Pinatubo in the Philippines, financial resources, investment, and infrastructure poured into the area, turning Luzon into an economic hub. However, although reconstruction efforts may contribute positively to an economy (as measured by gross domestic product or GDP), the loss of productive capital may reduce it. As a result, the financial balance sheet of natural crises shows that the growth in real incomes is not significantly different in years when disasters strike than in an average year (Stromberg, 2007).

The recognition that the financial costs of natural disasters typically have comparatively little effect on most national economies is arguably less applicable to the fiscal fate of less-developed nations. Many developing nations will be hard pressed to develop economically due to recurrent hazard losses, and for many countries, probable economic losses over the next century exceeds their current financial resources (Cardona, 2005). Average losses from disasters in low-income countries (e.g., Sri Lanka, Bangladesh, Nicaragua) can be 10–20 times greater than in disasters in high-income nations (Haas et al., 1977). Whereas floods and droughts typically claim about one tenth of 1% of the GDP of industrialized countries, they cost up to 20 times more (up to 2% of GDP) in less-developed nations (Alexander, 1993).

In such a context, it is difficult to appreciate a silver lining of disasters. Indeed, most disaster scientists would contest the notion that natural calamities can be "good value" at all. A recent e-discussion on the question of whether disasters can help a country's economy drew these remarks (Hewitt, 2009): "*To say that disasters help the economy is a materialistic view. . .as well as loss of life, disasters entail a loss of investment in those who are killed, and have a long-term psychological impact on those who survive, affecting their capacities and capabilities, and resulting in a loss of productivity, opportunity costs, and more. Therefore, the indirect cost of a disaster is much larger than the direct cost. A loss is a loss and cannot be turned into an investment and produce income or benefits. In addition, losses are not limited to lives, materials, and animals, but also include traditional wisdom and knowledge, making future settlements more prone to natural disasters.*"

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Cross-references

Adaptation
Casualties Following Natural Hazards
Classification of Natural Disasters
Coping Capacity
Cost-Benefit Analysis of Natural Hazard Mitigation
Disaster Relief
Economics of Disasters
Geohazards
Hazard
International Strategies for Disaster Reduction (IDNDR and ISDR)
Models of Hazard and Disaster
Natural Hazard
Natural Hazard in Developing Countries
World Wide Trends in Natural Disasters

DISPERSIVE SOIL HAZARDS

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Synonyms

"Dispersive" soils (Volk, 1937; Fletcher and Carroll, 1948)

Definition

Some natural clay-rich soils are highly erodible by flowing water both at and below land surface. These soils contain an abundance of clay particles that disperse (slake) and deflocculate when relatively pure water is added. Such "dispersive soils" have clays with a higher exchangeable sodium percentage – the proportion of sodium cations to the total of other soluble cations (e.g., calcium and magnesium). Because of the mineralogy of their clay particles, these soils are distinct highly susceptible to erosion by gulleying, tunneling, and piping when cultivated or when disturbed to some depth below land surface.

Soil characteristics

Dispersive soils were first recognized over 120 years ago, but were not studied in depth until over 50 years later by Volk (1937) and Richards (1954), and later by Australian engineers (e.g., Aitchison and Wood, 1965). These soils contain a high proportion of clay particles that have weak electrochemical attraction to adjacent particles. These bonds are affected primarily by the type of clay minerals present, however pH, amount of organic matter, temperature, water content, thixotropy (viscosity change), and chemistry of pore water (Bell and Maud, 1994) also can affect dispersion. These soils have higher percentage of exchangeable sodium (expressed by the exchangeable sodium percentage – ESP) than most soils. Dispersive sodic soils in Australia have ESP > 6 in the top meter of the soil horizon (Northcote and Skene, 1972; Raine and Loch, 2003). Commonly, dispersive soils contain little organic matter content and have alkaline pore waters with a pH > 8.5. More recent studies have found these soils in humid tropical climates where the pore water may be acidic (Sherard et al., 1977). Often, little or no evidence of their associated instability are exposed at land surface, because the soil is covered with silty or sandy material (containing no dispersive clays) or a continuous layer of topsoil and vegetation. Since many traditional laboratory index tests, including specific gravity and Atterberg limits, fail to differentiate dispersive soils collapsible soil hazards (see entry *Collapsing Soil Hazards*) from non-dispersive soils (Sherard et al., 1972), a number of specialized experiments have been developed to measure the erodibility of dispersive soil, (Reilly, 1964; Sherard et al., 1976b, and Emerson, 2002).

Process

Erosion occurs by a process in which individual clay particles are electrochemically suspended in water ponded at the land surface or in the subsurface in soil pores. The particles are transported when the water flows. This process is significantly different than erosion taking place in other soil types, where a considerable velocity is needed for water to erode clay particles (Sherard et al., 1976a). More specifically, as water wets the soil clay particles interact with the water to weaken interparticle sodium bonds. Eventually, these bonds are broken, the sodium cations disperse, and the individual clay particles begin to deflocculate (Knodel, 1991).

Distribution

Many early studies indicated that dispersive soils form exclusively in arid and semiarid climates in alkaline soils. In alluvial floodplain deposits, slope wash, lake bed deposits, and Loess (see entry *Loess*). Some dispersed soils have been identified in residuum on marine claystone and shale, granites, and sandstone (Sherard et al., 1977; Clark, 1986). More recent field work has extended their distribution to humid climates and are now identified in United States, Venezuela, Australia, South Africa, Iran, Tasmania, Mexico, Trinidad, Vietnam, South Africa, Thailand, Israel, Ghana, and Brazil (Knodel, 1991).

Hazards

The breakdown in the internal structure of dispersive soils has led to problems such as surface crusting, reduced water infiltration, and retarded plant establishment and growth (Rengasamy et al., 1984). Dispersive soils are prone to gully erosion and piping hazards (see entry *Piping Hazard*). Damage due to subsidence has occurred in existing earth embankment dam built with dispersive soil, and in new reservoirs and buildings constructed on these soils. In the United States, the most notable failure in dispersive soils occurred at Teton Dam (Sherard, 1987). Some studies have shown that the failure of structures built on dispersive clay soils occurs after the first wetting (Knodel, 1991).

Summary

The study of dispersive soil has a long history, and a worldwide effort has been undertaken to identify and characterize them through rigorous testing, in order to develop a comprehensive classification scheme. Ancillary research has utilized this data to develop products (i.e., filters and chemical additives) used to mitigate their affect on agriculture and water-retaining structures. In many countries, major outreach programs have been developed to educate landholders, planners, and engineers to draw awareness toward the problems associated with dispersive soils.

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Cross-references

Collapsing Soil Hazards
Hydrocompaction Subsidence
Land Subsidence
Loess
Piping Hazard

DOPPLER WEATHER RADAR

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Synonyms

Doppler frequency shift

Definition

Conventional weather radar. A conventional weather radar transmits a narrow pulse of electromagnetic radiation (centimeter wavelength), and then listens to see if any energy is scattered back from distant targets before the next pulse is transmitted (e.g., Rinehart, 2010). The targets of meteorological interest are hydrometeors (raindrops, hailstones, ice crystals). The time delay between the transmitted and returned pulse determines the distance to the hydrometeors and the amount of energy received (called radar reflectivity) is proportional to the size and scattering characteristics of the hydrometeors within the pulse volume. Owing to random fluctuations of hydrometeors within the pulse volume, tens of consecutive pulses are averaged together to obtain a representative measurement.

Doppler weather radar. A Doppler weather radar is a conventional weather radar that has the additional capability of detecting a slight frequency shift (Doppler shift) in the returned pulse (e.g., Rinehart, 2010). The frequency shift is caused by *the component of hydrometeor motion toward or away from the radar.* The three basic quantities measured by a Doppler radar are radar reflectivity, Doppler velocity (the mean Doppler velocity component of hydrometeor motion within the series of returned pulses), and spectrum width (the standard deviation of the velocity components within the series of pulses).

Overview

During the mid-1950s, a few research organizations around the world started to apply Doppler radar techniques to study weather phenomena (e.g., Rogers, 1990). The first radars were pointed vertically because updrafts and downdrafts in storms could be uniquely identified. However, by the late 1960s and early 1970s, researchers began to scan radars horizontally through thunderstorms. They discovered that – even though a Doppler radar measures only the single component of flow toward or away from the radar – there are unique Doppler velocity signatures of rotating and divergent/convergent flows that have warning implications. With coordinated measurements from two or more nearby Doppler radars and a few assumptions, researchers can estimate the full three-dimensional components of airflow within storms.

During the 1980s and 1990s, based on the existence of single Doppler velocity signatures, it was becoming apparent to national weather services in various countries that they could improve the timeliness and accuracy of hazardous weather warnings by replacing their conventional radar networks with Doppler radar networks (e.g., Whiton et al., 1998). With many such networks now in existence, Doppler radar data are beginning to be assimilated into numerical weather prediction models with the goal of producing more accurate short-term (1–6 h) forecasts of evolving hazardous weather conditions.

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Cross-references

Cloud Seeding
Dust Storm
Hurricane
Hurricane Katrina
Ice Storm
Storms
Thunderstorms
Tornado
Waterspout

DOSE RATE*

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Synonyms

Radiation absorbed

Definition

Dose rate is the quantity of radiation absorbed per unit time (Gy s^{-1}).

Overview

The *absorbed dose* is the amount of energy deposited by ionizing radiation in a unit mass of medium, such as tissue.

This dose is expressed in units of joule per kilogram (J kg^{-1}), which is called the "Gray" (Gy). The unit Gray can be used for any type of radiation, but it does not describe the biological effects resulting from different radiation types. Absorbed dose rate in air (nGy h^{-1}) is commonly used to express gamma ray intensity in the air from radioactive materials in the earth and atmosphere. *Equivalent dose* relates the absorbed dose in human tissue to the effective biological damage and is expressed in the unit Sievert (Sv) (The International System of Units, 2008). To determine equivalent dose, the absorbed dose is multiplied by a quality factor that is unique to the type of incident radiation in question (e.g., alpha particles, 20; beta particles, 1; gamma and x-rays, 1). To take account of the susceptibility of organs and tissues to radiation doses, weighted equivalent doses in all the tissues and organs of the body are summed to determine the *effective dose* (Sv) (Wrixon, 2008; US Department of Health and Human Studies).

Sources and effects of human exposure to ionizing radiation

Natural radiation contributes over 80% of the average radiation dose received; approximately half the overall dose occurring due to exposure to radon gas and its decay products (Eisenbud and Gesell, 1997). Terrestrial gamma radiation – which is largely controlled by geological variation of naturally occurring radioactive materials in rocks, soils, and building materials – and cosmic radiation, which varies with altitude and latitude, contribute on average 13% and 12%, respectively of the average annual dose to the UK population (Hughes et al., 2005). The average global annual effective dose from natural radiation is approximately 2.4 mSv. This level of exposure varies around the world, usually by a factor of 3, although at some locations it can be exceeded by more than a factor of 10 (UNSCEAR, 2000).

Anthropogenic sources of exposure to ionizing radiation include medical screening and therapeutic procedures, nuclear weapons testing, electricity generation, and accidents such as the one at Chernobyl in 1986, although the contribution to dose from these sources is small in comparison to that from natural radiation (UNSCEAR, 2000).

Damage to DNA in the nucleus is the main initiating event by which radiation causes long-term damage to organs and tissues of the body (UNSCEAR, 2006). There is no convincing scientific evidence that cancer risk from radiation exposure disappears at very low doses, and this is currently the focus of major research (e.g., US Department Of Energy – Low Dose Radiation Research Programme).

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Cross-references

Natural Radioactivity
Radon Hazards

DROUGHT

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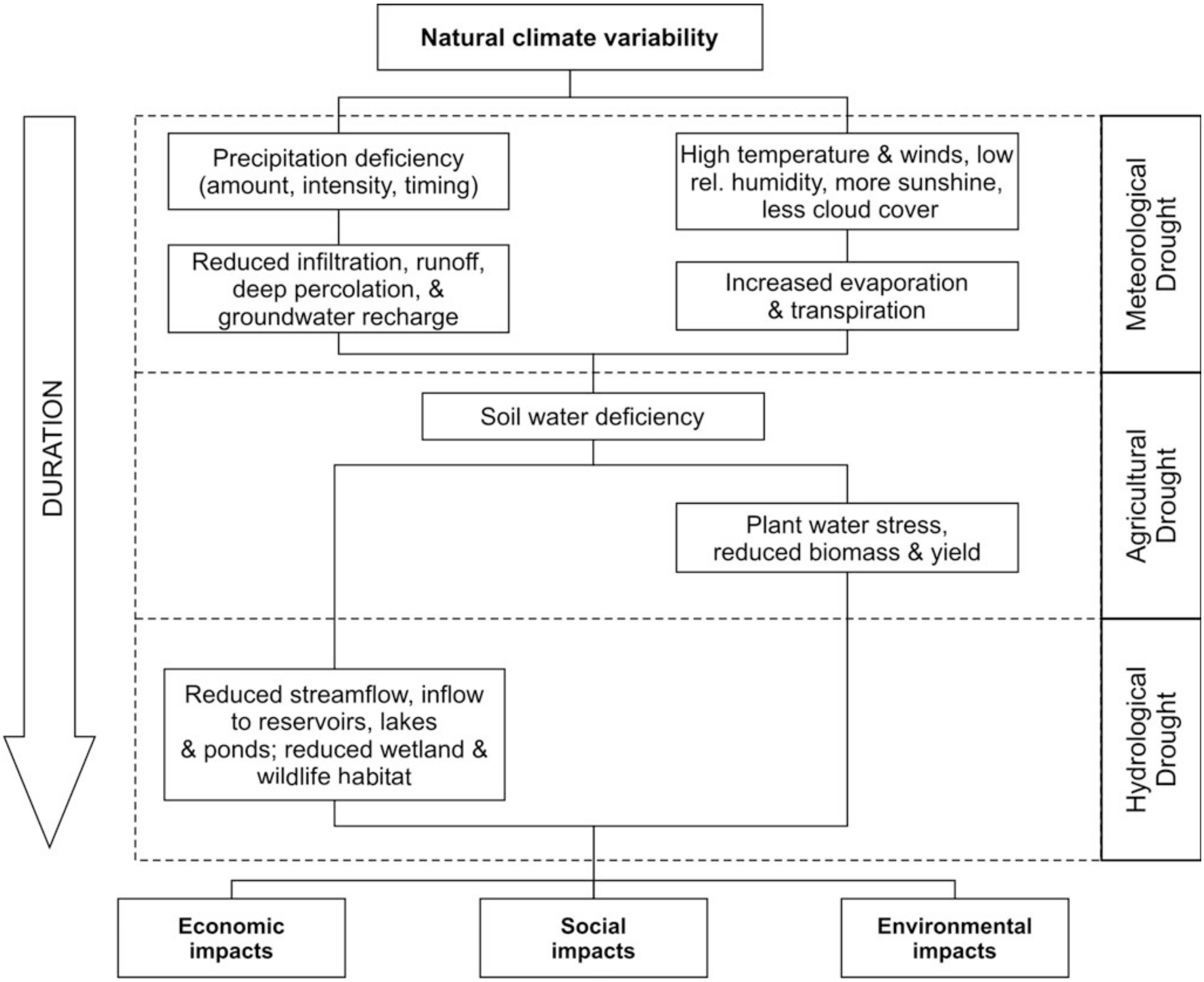
Definition

Drought is a severe natural hazard that affects more people than any other natural disaster. It is usually only recognized as a natural hazard when social, economic, or environmental impacts become apparent. Drought is different from many other natural hazards in that it lacks easily identified onsets and terminations (Maybank et al., 1995). It is also unusual in that it is a hazard of scarcity rather than one of excess. Drought is a natural, recurring pattern of climate that occurs within nearly all climatic regions. However, it is not just a physical phenomenon or natural event caused by changes in climatic conditions. Rather, drought results from a connection between the natural event of lower than expected precipitation, and the demand of human usage on water supplies (Wilhite, 2000). Anthropogenic activities can exacerbate the severity and impacts of drought, but within a natural variability range.

Drought does not have a universal definition; rather it has hundreds, as Wilhite and Glantz (1985) discussed in their classification study. Despite the number of definitions, many are not useful to policy makers or scientists. This causes some uncertainty in declaring whether a region is suffering from drought, and its degree of



Drought, Figure 1 The relationship between types of drought and duration of drought events (Figure modified from Wilhite, 2000, p. 10.).

severity. There are three major characteristics of drought – intensity, duration, and spatial extent. Drought is never small scale or short term (by definition). The effects of drought can build up over lengthy periods of time, and these effects may be felt for years after the drought has "broken," making the onset and conclusion of drought difficult to define. "Seasonal" droughts are frequent and predictable, as distinguished from "supra-seasonal" droughts, which are aberrant and unpredictable (Bond et al., 2008). It is generally accepted that drought can be divided into four categories based on disciplinary viewpoints: meteorological, hydrological, agricultural, and socioeconomic (Wilhite and Glantz, 1985). Figure 1 (modified from Wilhite, 2000) shows the relationship between the various categories of drought and their durations. Each discipline incorporates different physical, biological, and/or socioeconomic factors in its definition (Wilhite, 2000), but common to all these is inadequate precipitation.

A working definition of meteorological drought is "an extended period (season, year, or several years) of deficient rainfall relative to the statistical multiyear mean for a region" (Druyan, 1996a). A lack of rainfall does not necessarily constitute drought. It must be distinguished from aridity, which occurs in areas where there is a high probability of low rainfall for indeterminate periods of time (Druyan, 1996b). Meteorological drought must be defined on a regional basis, as deficiencies in precipitation are specific to local atmospheric conditions. Once meteorological drought establishes itself, both agricultural and hydrological drought usually follows.

Hydrological drought is associated with the effects of a persistent scarcity in rainfall on the capacity and availability of surface water (e.g., rivers, lakes, reservoirs) and groundwater supplies. The frequency and severity of hydrological drought is often defined on a catchment or basin scale. The commencement and finishing of groundwater drought both usually lag well behind that of surface water drought (Bond et al., 2008), and both are usually out of phase with meteorological and agricultural drought. As a lack of expected rainfall continues, water levels in temporary water bodies decrease, and they eventually dry up. The drought also decreases water levels in "perennial" surface water bodies, and if it continues long enough, these may also disappear. As surface waters are depleted by ongoing drought, groundwater levels may also decrease over time in those aquifers influenced by modern recharge. This can exacerbate the effects of drought in surface water systems in which groundwater forms the base flow. After a return to normal rainfall conditions, surface water drought usually breaks well before groundwater drought.

Agricultural drought is associated with a shortage of available water for plant growth. It is assessed as insufficient soil moisture to replace evapotranspiration losses, and links meteorological and hydrological drought to impacts on agriculture. Most regions can be affected by agricultural drought, but its duration and intensity varies greatly between climatic zones (Wilhite, 2000). There are many definitions of agricultural drought, but in general they account for the varying susceptibility of crops during development to deficient topsoil moisture.

Scientists tend to frame the broad social dimensions of droughts into a general category called "socioeconomic drought" (Kallis, 2008). Socioeconomic drought associates supply and demand of economic goods with at least some elements of meteorological, hydrological, and agricultural drought (Wilhite, 2000). It can result when the demand for economic goods exceeds supply because of a shortfall in water related to variations in climate. It can also occur when the demand for goods increases due to population increase and/or per capita consumption.

Drought indices

Measurements of the frequency and severity of droughts are important in the development of mitigation strategies and preparedness plans. As in drought definitions, it is generally agreed that there can be no universal drought index or operational definition (Kallis, 2008), and so numerous indices have been developed to monitor and measure drought. Droughts differ in three major ways: intensity, duration, and spatial coverage (Wilhite, 2000). Intensity is related to the precipitation deficit, and several indices measure how precipitation has deviated from historical norms. The duration of drought is a discerning characteristic, which along with intensity and timing, is closely related to the level of impact. The spatial characteristics of drought also differ as the degree of severity evolves across areas and through seasons.

Drought and its severity can be numerically defined using indices that integrate temperature, precipitation, and other variables that effect evapotranspiration and soil moisture (IPCC, 2007a). The simplest of these assess meteorological drought using a measure of the precipitation deficit over a particular time period, whereas those more complicated use models that incorporate soil moisture conditions and land-use parameters (Oladipo, 1985).

One of the main difficulties with using indices that measure precipitation deficiency is setting the threshold below which the onset of drought is defined (Wilhite, 2000). The Palmer Drought Severity Index (PDSI; Palmer, 1965) is one of the most extensively used meteorological drought indices across the world, and particularly in the USA. PDSI is a reflection of how much soil moisture is currently available compared to that for normal or average conditions (Cook et al., 2007). The PDSI was one of the first methods to successfully quantify the severity of droughts across different climates. The index is based upon a primitive water balance model which accounts for the difference between precipitation required to maintain a water balance and the actual precipitation. The PDSI also incorporates calculations that attempt to account for climatic differences between locations and seasons of the year (Wells et al., 2004). Despite its popularity, the PDSI has been widely criticized for its empiricism (Keyantash and Dracup, 2002). It does not incorporate variables such as wind speed, water vapor, or solar radiation into its calculation of potential evapotranspiration. Commonly, it is said that calculated PDSI values are not comparable between diverse climatological regions. This led to the development of a self-calibrating version of the PDSI by Wells et al. (2004) to ensure consistency with the climate at any location. A relatively new precipitation deficit index used in the USA is the Standardized Precipitation Index (SPI) developed by McKee et al. (1993, 1995) in recognition of the impacts that precipitation deficit has on groundwater, soil moisture, streamflow, and other water resources. It was designed to quantify precipitation deficit for multiple timescales, allowing for the determination of the rarity of drought as well as the probability of precipitation necessary to break a drought. In Australia, the drought definition is based on the Rainfall Deciles method (Gibbs and Maher, 1967), chosen because it is relatively simple to calculate, and requires fewer assumptions than the PDSI (Smith et al., 1993).

Similar to the PDSI is the Palmer Hydrological Drought Severity Index (PHDI), with the primary difference being stricter criterion for the ending of a drought (or wet spell). This is considered more appropriate for hydrological drought assessment, as it is much slower to build up than meteorological drought (Keyantash and Dracup, 2002). Shafer and Dezman (1982) developed the Surface Water Supply Index (SWSI) to account for snowpack and delayed runoff, and it is useful in providing a measure of hydrological drought in areas where snow makes up a significant component of the hydrological budget.

Agricultural drought is specifically related to cultivated crops rather than natural vegetation (Keyantash and Dracup, 2002), and it is characterized by short-term changes to volumetric soil moisture in the root zone. The Crop Moisture Index (CMI) was developed by Palmer (1968) and uses a meteorological approach to monitor agricultural drought. The CMI was developed from procedures within the PDSI, but it was designed to measure short-term moisture conditions across crop-producing regions, rather than monitoring long-term meteorological drought like the PDSI (Hayes, 2009).

Many parts of the world have not adopted clear indices for agricultural drought and hydrological drought, making attempts to compare the impacts of drought between places and between times difficult (Bond et al., 2008). In the context of climate change and increasing land degradation, it is becoming increasingly important to be able to calculate drought impacts if the consequences of climate change are to be understood (Vicente-Serrano, 2007).

Impacts of drought

Drought, as one of the most complicated yet least understood natural hazards, is associated with many other kinds of hazard, and these play out in impacts on economic, social, and environmental systems (Kallis, 2008). The onset of drought is difficult to identify or even recognize, although predictive capabilities are increasing. The study of past droughts can indicate what onset might look like, how drought develops and the kinds of impacts that follow. The palaeo record shows that severe droughts of the last century were greatly eclipsed by megadroughts in the past (Maybank et al., 1995; Woodhouse and Overpeck, 1998). These will occur again, and are likely to be exacerbated by greenhouse warming.

There are methodological problems in assessing the impact of droughts due to the difficulty of defining it. However, the most obvious first-order impacts are through drought impact on agricultural production, water supply, and forestry. Forests are usually less sensitive to drought as they tend to occur in wetter regions.

Reduction in crop and animal production has secondary affects on food prices and may feed through to global markets and consumer demand (Kallis, 2008). Reduction in river flows may have consequences for water supply, hydroelectricity generation, and the amount of potable water. Poor quality water can have significant negative health outcomes for affected populations.

Drought takes a heavy toll on life in Africa, causes social disruption in Asia, and has economic impacts in Western countries. Exposure and vulnerability have strongly regionalized patterns; where drought coincides with war, poverty, or recession, the impact is magnified and exposed population are made more vulnerable (Kallis, 2008).

There is a significant difference between aridity and drought. Deserts occur in areas where there is extreme heating of the surface, and/or lack of moisture. These are created when subsiding air, which becomes compressed and thus heated, forms subtropical high-pressure zones. The deserts of Australia, Peru-Chile (Atacama), southwestern USA, Namib, Sahara, and Kalahari are of this type. Additionally, deserts occur in the lee of major mountains: Patagonia, Middle East, central Asia, Ethiopia, and the Thar (India) are examples of these.

Deserts are naturally dry most of the time, and thus drought is not a hazard in them in the strictest sense. However, droughts can be a normal weather pattern in all regions.

Projected precipitation anomalies estimated from regional climate models depend heavily on the scenario applied for the simulations. The IPCC (2007b) has applied a relatively large number of simulations (21) and these show a high degree of consistency. Drought conditions will be exacerbated whenever simulations suggest a decline in precipitation, especially outside the natural regions of aridity. Figure 2 (modified from IPCC, 2007b) shows that the main areas of predicted precipitation decrease are:

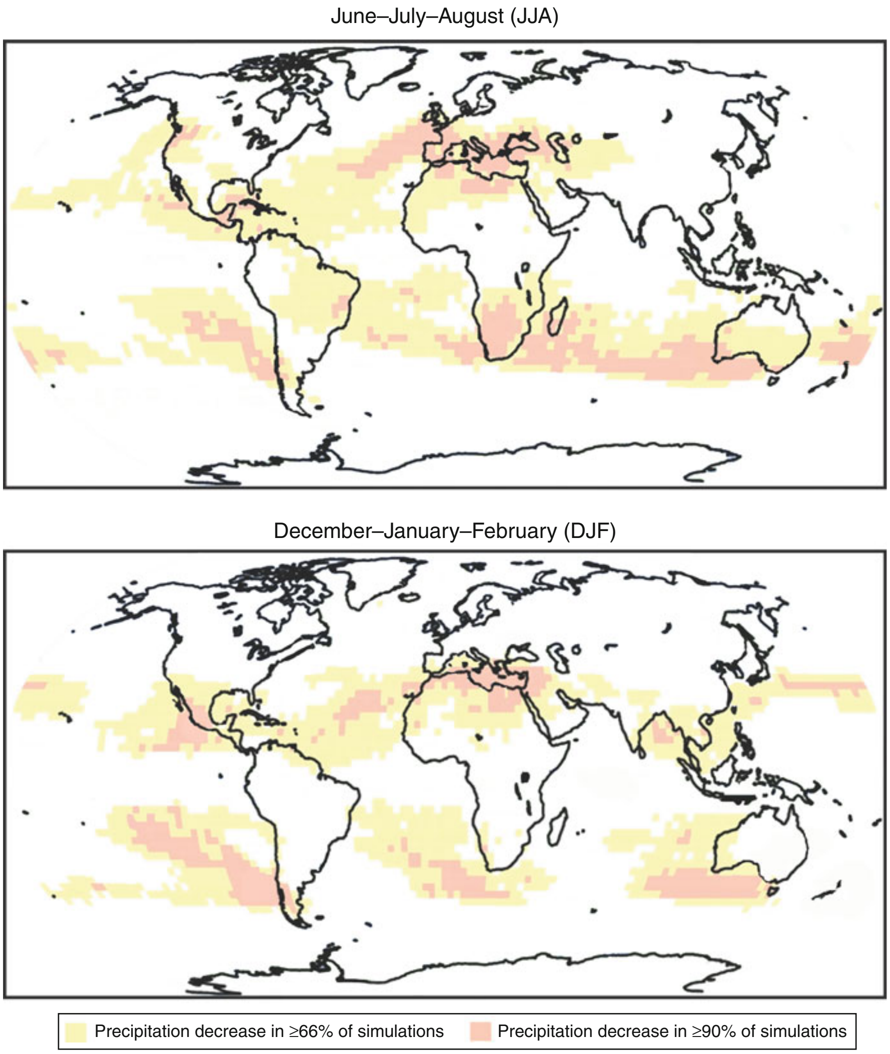
1. Annual decrease in the Mediterranean region, northern Africa, Central America, and SW USA.
2. Winter decrease in SW Australia, eastern French Polynesia, southern Africa.
3. Winter and spring decreases in southern Australia.
4. Decrease in snow season length and likely snow depth in Europe and North America.
5. Summer decrease in the southern Andes, southern SE Asia, SE South America, central Asia, central Europe, and southern Canada.

The effect of decreased precipitation will be enhanced with higher temperatures. The main regions of impact are outside the tropics and high latitude zones, and areas with winter and spring dominated rainfall patterns will be particularly disadvantaged, as will midlatitude areas dependent on snow melt for water supply. The burden of enhanced drought will fall quite unevenly across the nations of the world. These same regions will need to develop robust adaption and mitigation strategies to reduce future vulnerability to drought.

Historical impact of drought

Severe drought can have serious consequences for exposed societies. The degree of exposure depends on the kind of drought and the resilience of the society. All but the least resilient of societies can weather single seasonal droughts when they occur at some kind of recurring interval. They often do this by building reserves that can be drawn upon in times of need. Societies meet the most challenging of situations when long sequences of unexpected drought conditions occur. These may be due to rare and essentially unanticipated sequences or due to a shift in climate pattern. It is expected that climate change will, as it always has, alter the geographical patterns and severity of droughts.

In the past, many societies have encountered unexpected enduring drought conditions and they have had to adjust and adapt, migrate, or they collapse. One can wonder at



Drought, Figure 2 The fraction of 21 atmosphere–ocean global climate model simulations that predict a decrease in mean precipitation in a model grid cell (comparing the period 2080–2099 with control period 1980–1999) (Figure modified from IPCC, 2007a, p. 859.).

the thought processes that accompanied these circumstances. Initially, a poor season would have placed strains that would have been endured with the expectation that "normality" would return the next season. After all, this was what experience shows to be the case. A string of poor seasons challenges this experience, and the longer the sequence the more challenging this becomes. When do societies accept that conditions have indeed changed and adjustments must be made? This dilemma has been met before and will be visited upon many societies in the future.

An example of how this occurred in the past concerns the Classic Maya Civilization. The Maya occupied the Yucatan Peninsula region of Mesoamerica from 250 to 850 AD. The Late Classic culture (550–850 AD) was known for being a highly stratified society; there were vast trade networks, and widespread construction of urban centers and monuments. Complex language, belief systems, sports, and mathematics were embedded as elements of society. This all came to a sudden end when society seemed to be at its peak. Many potential factors have been cited for the collapse and include deforestation, overpopulation, warfare, and social upheaval for political reasons.

Recent research suggests prolonged drought was at least a contributing factor. Lake sediments reveal substantially lowered water levels and changes from freshwater to saline conditions (Hodell et al., 2001), reduction in forest cover according to pollen diagrams (Mueller et al., 2009), and increased soil erosion is recorded in marine sediments (e.g., Gischler et al., 2008). These indicate substantial environmental change, which coincides with the main phase of collapse of the Maya in terms of buildings and the desertion of urban centers. In the latter phase of the Maya, Sun God worship was evident, and this may have been an attempt to appease the Sun as the cause of ongoing drought.

Similar fates are thought to have transpired to the Harappan people of NW India as an arid phase developed over the region and made extensive irrigation systems become dysfunctional, and the base which supported a huge urban population was swept away (Staubwasser et al., 2003).

In some cases, human activities have appeared to exacerbate the impact of drought. In northern China, there is an environmental boundary between the loess and desert. Loess is windblown dust deposited by the Westerlies and is a highly productive soil where there is sufficient rain or irrigation that can be applied to it. In the northern region the loess gives way to desert sand-dominated soils, these are mobile and rarely watered by the monsoon rains which sweep in from the Pacific Ocean. The border region of the Northern Loess Plateau and Chinese deserts west of Beijing supported many Neolithic villages in the mid-Holocene. It appears that monsoon rain reached the region and provided sufficient water for millet-based agriculture and animal husbandry. By about 3,000–4,000 years ago villages were abandoned as desertification set in (Zhou et al., 2002). This may have been due to drought resulting from failure of the monsoon rains reaching the region, perhaps in concert with anthropogenic driven land degeneration. In any case, the desert sands shifted some hundreds of kilometers south, and so did the villages.

The observational record of drought

Observations of drought based on meteorological records indicate that they have become more intense, of longer duration, and occurred over wider areas of the tropics and subtropics since the 1970s (IPCC, 2007a). Reliable meteorological records for much of the world only exist for the last 100 years or so, but they provide a basis to investigate possible causes for drought.

Since the 1950s, the number of heat waves and warm nights has increased. These have contributed to the area under drought, although the drivers of changes in precipitation are also very important. While increases in continental temperatures are important for some regions, changes in snowpack and sea surface temperatures related to phenomena, such as El Niño–Southern Oscillation, are also strong drivers for climate in other regions. Extreme events such as the drought for western North America (Canada to Mexico) in 1999–2004 seem to be strongly related to a diminished snowpack and hence runoff (McCabe et al., 2004; Stewart et al., 2004). These in turn may be driven by sea surface temperatures in the tropical Pacific (Herweijer et al., 2007). Recent Australian droughts correlate well with higher continental temperatures, and the 15% decline in precipitation for southwestern Australia since the 1970s (mostly a failure of early winter precipitation) is related to sea surface temperature variation in the tropical Indian Ocean (Samuel et al., 2006).

Drought in the Sahel is due to failure of rainfall. Simulations have been good at reproducing the decadal variations in Sahel rainfall (Held et al., 2005) and these suggest sea surface temperatures of the Indian Oceans and Mediterranean are significant drivers of this, as is sulfate aerosol concentration (Rosenfeld et al., 2008).

Overall, the increased risk of drought, as measured by the Palmer Drought Severity Index suggests that the anthropogenic fingerprint is there, but simulations have this as a weaker component than the observed occurrence of drought (IPCC, 2007b).

Future vulnerability to drought

Observations show drought has already increased. Models can be used to simulate possible future drought intensity, frequency, and extent. In general, these suggest that the trends already seen can be expected to intensify, and the increase will be between 1% and 30% of land area in the next few decades – with greatest increase in midlatitude areas. The Mediterranean, western USA, Southern Africa, and northeastern Brazil are all expected to see intensification of drought. Russia, Mongolia, China, southern SE Asia will see drought intensification due to higher temperatures in the summer and drier months and due to changes in ENSO (IPCC, 2007b), and poleward migration of annual weather modes (Yin, 2005; Menéndez and Carril, 2010).

The impact of drought will be intensified due to human population increases. About one sixth of the world's population relies on meltwater, and reduced snowfall and snowpack will result in a reduction in delayed runoff. People in Bolivia, Ecuador, Peru, and the Hindu Kush – Himalaya are particularly vulnerable to this (Barnett et al., 2005). Soil moisture deficits will reduce pasture growth in the eastern South Island and Bay of Plenty regions of New Zealand (Mullan et al., 2005). There will be increased fire danger in seasonal environments of the midlatitudes (Gonzalez et al., 2010).

The high cost of drought, for example, in Australia in 1982–1983 ($2.3b), 1991–1995 ($3.8b), and 2002–2003 ($7.6b) (IPCC, 2007b), has already driven measures for adaption. A range of options have been used or are being considered for vulnerable areas. These include increased rainwater harvesting, adjustment of silvicultural techniques, channel and pipe leakage reduction and modifying crop planting dates, and choosing varieties which are more drought resistant.

Models also suggest precipitation extremes will be more prevalent, but the gaps between high magnitude events will increase, and so will the likelihood of drought. Of course the scale of these changes will depend on the willingness of nations to reduce the size of the anthropogenic fingerprint on global warming.

Mitigation

As a natural element of climate, the recurrence of hydrometeorological drought is inevitable. However, drought can also be exacerbated by anthropogenic influences such as rapid population growth, excessive water demand, and land degradation, and vulnerability to these impacts can be mitigated by appropriate drought plans (Rossi et al., 2005).

The uncertainty about drought definition leads to uncertainty about its characteristics and impacts, which contributes to poor drought management and mitigation across many parts of the world (Wilhite et al., 2007). A key element in any drought plan is a set of indicators that characterize drought conditions, and location-specific triggers (indicator values) which prompt some kind of response. Unfortunately, drought plans often contain ad hoc indicators and triggers that lack scientific validation or operational relevancy, and this can weaken the effectiveness of the mitigation plan (Steinemann and Cavalcanti, 2006). Other factors contributing to the difficulty of developing an effective drought plan include the changing spatial and temporal scales of drought impacts, the unique characteristics of each region or watershed, and changing societal structures and demands, to name just a few. Even though an existing drought may be of similar intensity and duration to one that has occurred in the past, changes in socioeconomic structures and environmental conditions can result in strikingly different impacts, and therefore changing vulnerability (Wilhite et al., 2007).

According to Wilhite (2000), drought mitigation is "short and long-term actions, programs, or policies implemented during and in advance of drought that reduce the degree of risk to human life, property, and productive capacity." These measures can be classified as either proactive or reactive. The proactive measures are prepared according to a planning strategy rather than in an emergency situation (Rossi et al., 2005). The most effective actions are long-term measures taken in advance of drought, such as building infrastructure to increase the reliability of water supply under increasing demand and drought conditions (Dziegielewski, 2003). Short-term measures are taken after the onset of drought, and these are aimed at mitigating impacts within existing infrastructure and management policies. An effective mitigation strategy will contain an appropriate mix of long- and short-term actions to reduce the vulnerability of human life, property, and production to future droughts.

Mitigating agricultural drought

Vulnerability, and therefore appropriate mitigation actions, differs significantly between the developing world, where drought can lead to livelihood loss, famine, and even death, and the developed world, where impacts are usually economic or asset losses. Numerous mitigation measures have been formulated to reduce the impacts of drought, and especially that of agricultural drought because of its huge environmental, economic, and social costs (Maybank et al., 1995).

Approximately, 80% of the world's agricultural land is rainfed (Rockström, 2003), so developing mitigation strategies to build ecological resilience in drought-prone and semiarid agricultural land is very important for food security. To a certain extent, water harvesting through small-scale systems such as farm ponds and subsurface tanks, can help mitigate the impacts of drought or dry spells in these areas. The building of ecological resilience to drought also requires strategies such as conservation farming (minimal or no tillage), improved crop varieties, and soil fertility management.

Decreases in agricultural production can have a roll-on effect leading to financial disaster for farmers and higher food prices for all consumers, unemployment, and even migration. Water is frequently wasted in agriculture practices through over-irrigation, poorly designed canals, and inefficient irrigation systems, and this waste can be reduced through adoption of improved channeling and irrigation practices (Le Houerou, 1996). A multidisciplinary approach of genetic improvement and physiological regulation to increase crop water productivity is another way to help achieve efficient and effective use of water (Cattivelli et al., 2008). Combining these biological water-saving measures with engineered solutions (e.g., water-saving irrigation methods) and agronomic and soil manipulation will contribute to an effective drought mitigation strategy for agriculture (Ali and Talukder, 2008).

Mitigating hydrological drought

Mitigation of hydrological drought primarily involves optimal water supply management under drought conditions, that is, making water more productive. This requires a contingency plan that includes a systematic evaluation of drought conditions with associated responses.

Traditionally, mitigation has focused on increasing water supplies through the construction of dams and reservoirs to capture and store increasing fractions of surface runoff. High levels of surface storage can effectively buffer against low runoff periods, especially in regions that experience high interannual variability in river flows (Bond et al., 2008). This practice was carried out with little analysis of how water was actually being used or of the impacts of this practice on the aquatic ecosystems. As new fresh surface water supplies for exploitation have dwindled, governments have turned to groundwater to augment supplies, especially during drought. However, the increased dependence on groundwater resources is leading to dwindling reserves and/or quality degradation. More and more countries are turning to nonconventional water sources to boost supplies. Desalination and waste water treatment and recycling are usually more expensive options than traditional water sources, but the associated environmental benefits can compensate for some of the costs.

Summary/Conclusions

Drought is a severe natural hazard that affects more people than any other natural disaster. It is difficult to define and recognizing its onset and termination is also difficult. It can be expressed in meteorological, hydrological, agricultural, and socioeconomic terms. The severity and extent of drought has increased in recent decades, and regional climate models suggest these will increase further in the future. The burden of dealing with drought will be unevenly distributed. Midlatitude regions and those heavily dependent on snow melt will have the greatest challenges. Multidisciplinary approaches will need to be developed to mitigate the extreme impacts of drought.

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Cross-references

Adaptation
Climate Change
Costs (Economic) of Natural Hazards and Disasters
Desertification
Disaster
Dust Bowl
Hazard
Historical Events
Land Degradation
Loess
Mitigation
Models of Hazard and Disaster
Natural Hazard
Risk
Vulnerability

CASE STUDY

DUST BOWL

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Definition

Dust Bowl. A period of drought, soil erosion, and intense dust storms that impacted the Great Plains of the United States during the 1930s.

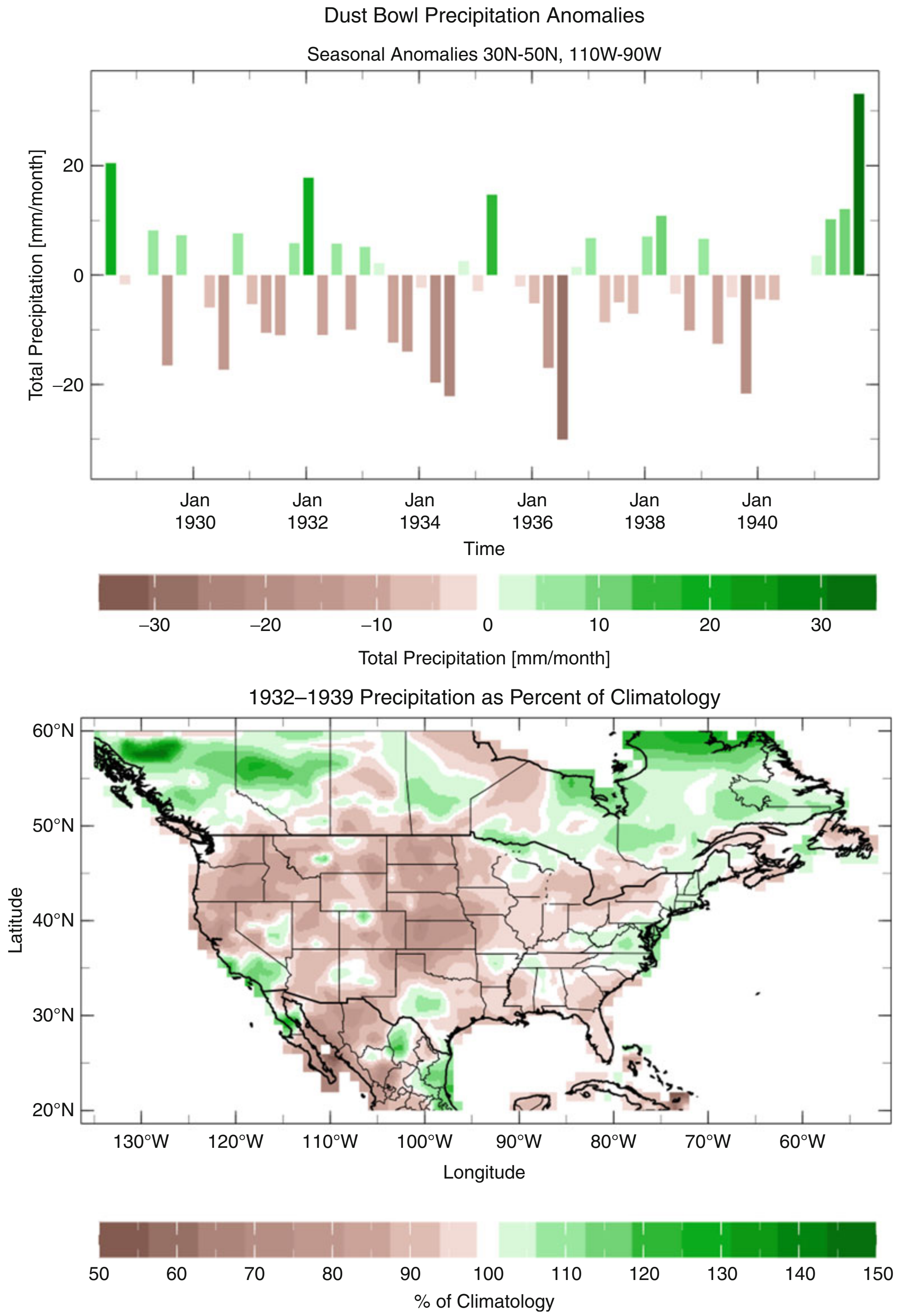
Introduction

The Dust Bowl refers to the years of drought and dust storms that affected the Great Plains of the United States during the 1930s. The term "Dust Bowl" was proposed by a reporter writing an article 1 day after "Black Sunday" – April 14, 1935 – which was one of the worst days of dust storms. The term originally referred to some of the worst affected regions in Texas, Oklahoma, Colorado, and Kansas. "Dust Bowl" is now used to refer more generally to the entire catastrophe in the 1930s comprising drought, crop failure, soil erosion, dust storms, economic collapse, and human migration.

Meteorological origins of the dust bowl

The Dust Bowl began with drought. Rain gauge data show that average precipitation over the Great Plains was less than normal for two thirds of the seasons between 1932 and 1939. Averaged over the core years of the Dust Bowl, 1932–39, the precipitation was less than 80% of normal in most of the Great Plains (Figure 1). Droughts of this length and severity are normal features of the climate in the Plains and several had occurred since European settlement with the most recent occurring in the early to mid-1890s. What made the Dust Bowl different from these earlier droughts was the widespread soil erosion and dust storms. In the period after World War I, the Plains were transformed by the expansion of agriculture (primarily wheat, much of it for export to Europe) and the removal of drought-resistant prairie grasses (Worster, 1979). During the 1920s, adequate rains allowed for bountiful crops, thereby encouraging more new planting. When the drought struck in the early 1930s, the non-drought-resistant strains of wheat that had been planted died, exposing bare soil that was easily eroded from the surface by the wind, creating the dust storms that were characteristic of the period. The scale and magnitude of wind erosion and dust storm activity during the Dust Bowl was fairly unique and did not occur during the earlier droughts.

In the mid-2000s, computer simulations with atmosphere models forced by ship-observed historical sea



Dust Bowl, Figure 1 The precipitation anomaly (mm/day), relative to a 1900–2007 climatology, averaged over 30–50°N and 110 to 90°W, by season for the decade of the 1930s and adjacent years (*top*). The 1932–39 averaged precipitation over North America as a percent of climatology (*bottom*). Data are from the Global Precipitation Climatology Centre.

surface temperatures (SSTs) demonstrated that small variations of tropical Pacific and Atlantic SSTs forced the sequence of multiyear, persistent droughts over the Plains and Southwest North America, including the Dust Bowl drought (Schubert et al., 2004a, b; Seager et al., 2005). North American drought is particularly common when the tropical Pacific Ocean is colder than normal (referred to as a La Niña-like state) and the tropical North Atlantic is warmer than normal. This was the case during the 1930s, and again during the early to mid-1950s when a separate drought struck southwest North America (Seager et al., 2008). These SST anomalies arise naturally from ocean-atmosphere interaction and cause drought over North America through changes in the circulation and thermal structure of the atmosphere. The end result is subsidence (sinking air) over the Plains, suppressing precipitation.

The role of dust storms in modifying and intensifying the drought

Typical SST-forced droughts, however, tend to be centered in the southern Plains, southwest USA, and Mexico, whereas the Dust Bowl drought extended up into the northern Plains and the Canadian prairies. Because of this, some researchers have argued that the Dust Bowl drought was largely forced by internal atmosphere variability and not related to anomalous SSTs (Hoerling et al. 2009). An alternative theory is that the dust storms were so frequent, widespread, and intensive that they actually altered the regional climate. Climate model simulations have been performed in which an atmosphere model was forced by observed 1930s SSTs but also with bare soil placed at the surface where contemporary maps indicated wind erosion occurred. The model created dust storms that interacted with the solar radiation. By reflecting radiation to space, the dust storms induced subsiding air and suppressed conversion of water vapor into precipitation and intensified the drought (Figure 2). Since the dust transport was north and east from the Plains, the modeled drought center also shifted north with the dust, bringing the spatial pattern of the Dust Bowl drought into better agreement with observations (Cook et al., 2009).

Impacts of the Dust Bowl drought and efforts to control the soil erosion

At the peak of dust storm activity, the Plains were emitting dust at a rate equivalent to current dust emissions in the most productive areas of the Sahara (Cook et al., 2008; Laurent et al., 2008). Dust was transported eastward to coastal cities and the Atlantic Ocean, creating widespread health problems related to dust inhalation and choking of the lungs. This became known as “dust pneumonia” and led to an uncertain number of deaths (Egan, 2005). In 1935, after the wind erosion and dust storms had been ongoing for several years, the Soil Conservation Service was created specifically to address the problem of soil erosion. In 1936, the Service completed a map showing the full extent of wind and water erosion during the Dust Bowl, an area extending through the Great Plains from the Gulf of Mexico to Canada (see Hansen and Libecap, 2004).

Soil Conservation Service scientists diagnosed the cause of wind erosion to lie in a combination of drought and poor cultivation practices (i.e., lack of fallowing of land and strip cropping and the absence of shelterbelts and vegetative residue to protect soils) (e.g., Chepil, 1957). Consistently, soil erosion from cultivated land in the 1930s greatly exceeded the erosion from pasturelands (Chepil, 1957). Hansen and Libecap (2004) also noted that the small size of Dust Bowl farms encouraged farmers facing drought to plant as much area as possible to compensate for reduced yield, instead of instituting erosion control measures that would reduce erosion risk but also take land out of cultivation. In many cases, eroded soil from one farm would be transported to neighboring farms, causing a chain reaction of crop failures and wind erosion within an area. To counter such destructive practices, the Soil Conservation Service created Soil Conservation Districts that, through a mix of incentives and coercion, encouraged farmers to cooperatively practice soil conservation techniques. In addition, some marginal lands were purchased by the Federal government and allowed to return to natural grasslands. Soil conservation techniques achieved some gains against erosion, but by 1941, rains were above normal and the drought and Dust Bowl had ended.

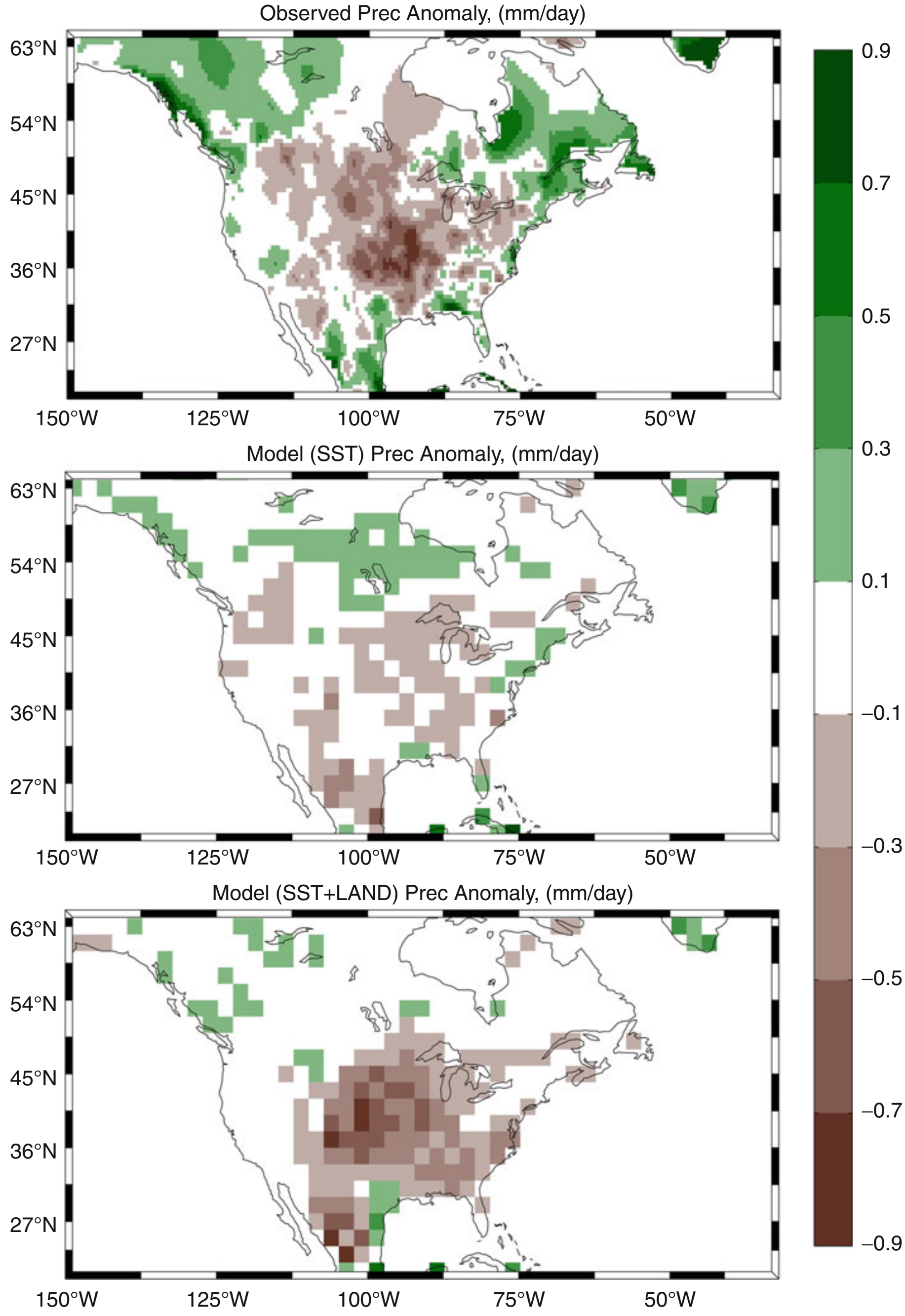
Crop failure put many farmers into debt and forced farm sales and abandonment. According to Worster (1979), by the end of the Dust Bowl, about three million people had left their farms and about 0.5 million migrated entirely out of the affected areas, with about half of those moving to California.

Legacy of the Dust Bowl

The Dust Bowl permanently altered the agricultural economy and farming of the Plains and directly led to the widespread adoption of soil conservation techniques in the United States. Out-migration led to farm consolidation. When drought returned to the Great Plains in the 1950s, the soil erosion and dust storms were more limited than in the 1930s and the social disruption was minor by comparison. Federal farm support policies and the beginning of irrigation also helped alleviate the impact of the 1950s drought on farmers (Hansen and Libecap, 2004; Worster, 1979).

Summary

The 1930s drought was, by meteorological standards, a multiyear drought of the kind the Great Plains had experienced previously and thereafter. It was forced by a combination of cold tropical Pacific and warm tropical Atlantic sea surface temperature anomalies that in turn generated changes in atmospheric circulation that suppressed precipitation in the drought region. Poor agricultural practices, such as expansive cropping of non-drought-resistant plants with little regard for soil erosion



Dust Bowl, Figure 2 Observed (*top panel*) and climate model simulated warm season (April–September) precipitation anomalies for the Dust Bowl period (1932–1939). When the model is forced with observed SSTs only (*central panel*), a weak drought is simulated that is centered too far south. If the effect of the dust storms is integrated into the model in addition to the SSTs (*bottom panel*), the drought intensifies and moves northward into the central Great Plains.

potential, turned the drought into the Dust Bowl as crops failed, bare soil was exposed, and wind erosion led to dust storms. The dust storms intensified the drought and moved its center northward. In response, the Soil Conservation Service was created and put in place conservation measures to limit the erosion. The drought ended when normal levels of rainfall returned in the early 1940s. The Dust Bowl led to a permanent transformation of Plains agriculture in terms of farm size, farming practices, and farm support policies. Subsequent droughts have not led to the same scale of soil erosion because of these changes and the introduction of irrigation.

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Cross-references

Drought
Dust Storm
El Niño/Southern Oscillation
Global Dust/Aerosol Effects
Hydrometeorological Hazards
Land Degradation

DUST DEVIL

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Synonyms

Convective vortex; Whirlwind

Definition

Warm-core vortices, normally less than 100 m high formed at the base of convective plumes often appearing as a well-defined dust funnel.

Overview

Dust devils are low-pressure, warm-core vortices with typical diameters ranging from 1 to 10 m, and heights of less than 100 m (Figure 1). However, occasionally, they can be larger or taller by more than an order of magnitude. Dust devils form at the bottom of convective plumes. Since their sources of angular momentum are local wind shears, caused either by the convective circulation itself or by larger scale phenomena, they can rotate clockwise or anticlockwise with equal probability. A distinctive feature of intense dust devils is their well-defined dust funnel. Theory indicates that dust is focused around the funnel by a dynamic pressure drop caused by increases in the speeds of the air spiraling toward the vortex.

Like waterspouts, tornadoes, and hurricanes, dust devils can be idealized as convective heat engines. They are the smallest and weakest members of this class of weather phenomena. The intensity of a dust devil depends on the depth of the convective plume and the transfer of heat from the ground into the air. When the surface is composed of loose particles, they might become airborne and make a dust devil visible. Dust particles are indirectly lifted from the surface by a process known as saltation. In this process, the larger particles are forced to move by the wind and bounce along the surface, lifting the smaller, harder to lift (because of strong cohesion forces) dust particles into the air. When loose particles are not present, intense vortices may exist and may not be visible to the observer. When a dust devil crosses a cold terrain, the dust column is cut off, and the vortex dissipates.

The abrupt increase in wind speed around dust devils is what creates a hazard; more than 10% of the accidents with light airplanes and helicopters are caused by visible or invisible dust-free dust devils. However, the abrupt reduction in visibility caused by them can also be a hazard.

Dust devils are more frequent in hot desert regions, but they also have been observed in colder regions such as the subarctic. Dust devils move with the ambient wind and slope with height in the wind shear direction. When the wind is strong, their diameters are biased toward large values.

The occurrence of dust devils increases abruptly from nearly zero at around 10 am to a maximum value at around 1 p.m. Then, dust devil activity slowly decreases toward nearly zero at the end of the afternoon. The abrupt increase at around 10 a.m. is due to increases in the solar radiation and abrupt increase in the depth of the boundary layer. The decrease to nearly zero at the end of the afternoon is due to the decrease in solar radiation and therefore convective activity.

Charge transfer occurs when sand and dust particles collide with each other and the surface. In this process, the smaller particles charge negatively and the surface and large particles positively. Then, the convective updrafts cause charge separation by carrying the smaller particles upward and electric fields of the order of 10,000 V/m can be generated. There are suggestions that

Dust Devil, Figure 1 Large dust devil photographed in the Nevada Desert in USA, July 2009 (Credit: University of Michigan).

these electric fields affect dust transport and, that on Mars they can even affect atmospheric chemistry.

Dust devils have been observed on Mars by almost all orbiters and landers that visited the planet. On Mars, they are ubiquitous, can form almost anywhere on the planet, and can have diameters of more than 1 km and heights of more than 10 km. There is evidence that dust devils play an important role on the global aerosol budget of both Earth and Mars.

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Cross-references

Dust Storm
Tornado
Waterspout

DUST STORM

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Synonyms

Haboob; Sand storm

Definition

Dust storms are weather systems that lift large quantities of dust particles into the air causing extremely low visibility.

Overview

Dust storms form when the wind speed exceeds the threshold value necessary to move sand particles over plowed fields and arid terrains. Particles of diameters between about 50 and 500 μm (sand-sized particles) are the first to move as the wind speed increases. When these sand particles move, they bounce along the surface in a process known as saltation. The impact of saltating particles on the surface consequently ejects smaller, hard to lift (because of large ratio of cohesive with wind drag forces) dust particles into the air creating a dust storm when enough dust is lifted over extensive areas. Saltation is also the process by which dust particles are lifted from the surface by smaller weather systems such as dust devils.

Dust storms can be created by large-scale low-pressure weather systems or gust fronts, areas of cool dense air propagating ahead of thunderstorms. Intense gust fronts, capable of lifting significant amounts of dust, form when rain evaporates while falling through relatively dry air. Such intense gust fronts generate impressive dust storms that can lift large amounts of dust a few kilometers above the surface, and form well-defined dust fronts. The abrupt boundary between the dust fronts and the clear air ahead of them can reduce the visibility to nearly zero in a few seconds. This abrupt reduction in visibility is one of the major causes of accidents by dust storms.

The dense cool air that may form gust fronts is known as a density current. As a first approximation, the propagation speed of a density current is proportional to its depth and the difference in density between it and the surrounding air. Thus, the denser and deeper gust fronts produced by the evaporation of precipitation falling through extremely dry air are capable of producing the strongest and fastest propagating dust storms. These are the most hazardous dust storms that frequently cause accidents in arid regions.

Large-scale frontal weather systems capable of initiating saltation usually cause moderately strong dust storms that can last a day or more. Such large-scale dust storms are more common between autumn and spring. Gust fronts usually produce stronger and more dangerous dust storms lasting no more than a few hours. The smaller, but potentially more dangerous dust storms are more common in the summer. The abrupt reduction in visibility to nearly

Dust Storm, Figure 1 A dust storm in Niger. Courtesy of the University of Michigan

zero and the strong wind make dust storms extremely dangerous. They frequently cause serious aviation and automobile accidents.

Charge transfer occurs when sand and dust particles collide with each other and the surface during saltation. During this process, the smaller particles charge negatively whereas the surface and large particles charge positively. Near-surface electric fields in excess of 100,000 V/m have been measured during dust storms. There is evidence that such large electric fields affect saltation and can even directly lift dust particles from the surface.

Dust storms are ubiquitous on arid Mars. Every few years, global dust storms form and cover the entire planet, reducing the visibility and the flux of solar energy at the surface by more than an order of magnitude. The dust storms last a few weeks and can be hazardous to landers and rovers.

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Cross-references

Aviation, Hazards to
Climate Change
Dust Devils
Erosion
Fog Hazards
Global Dust
Space Weather
Storms
Tornado
Volcanic Ash

DVORAK CLASSIFICATION OF HURRICANES

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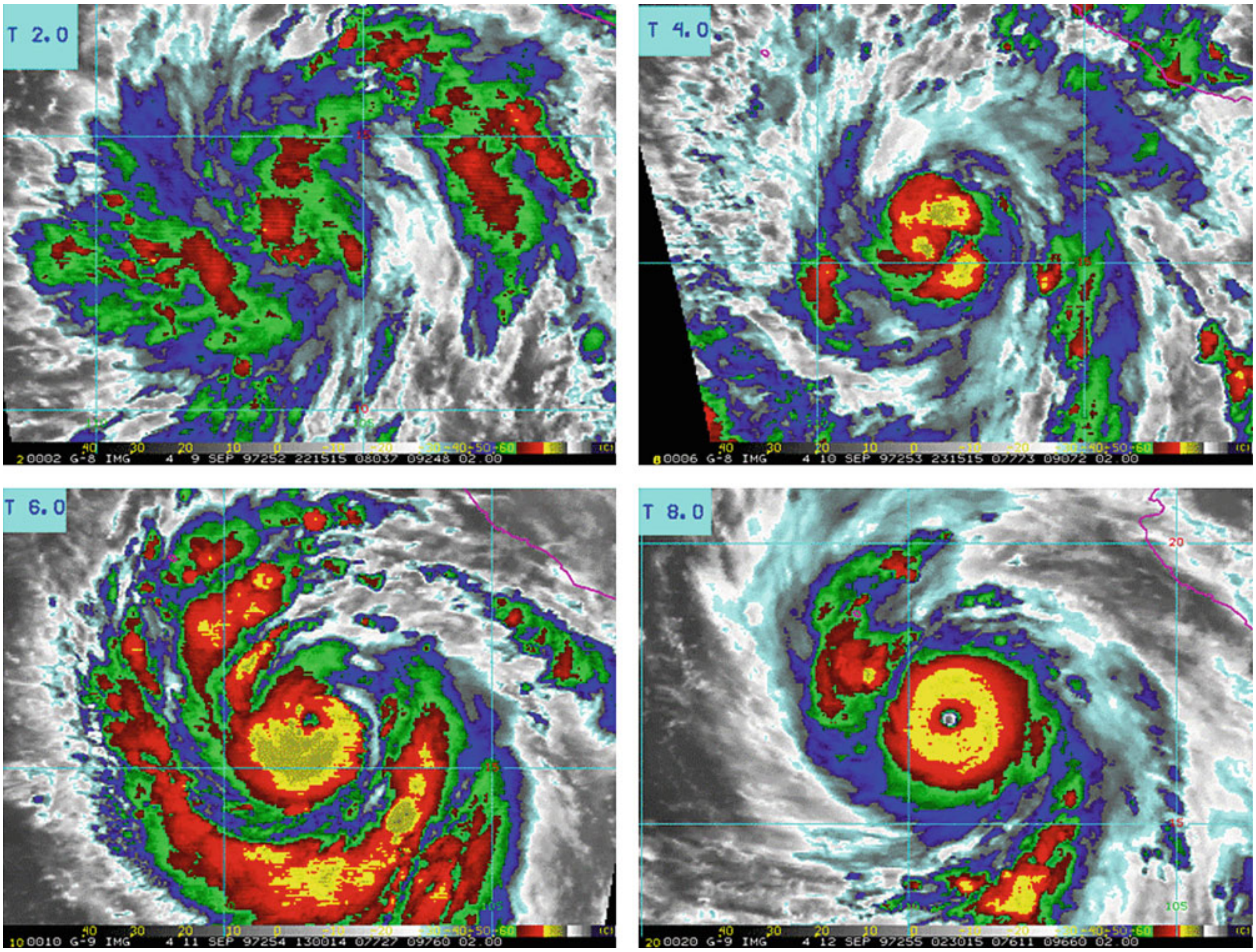
Definition

A method for estimating tropical cyclone intensity ranging in values from T1 to T8.

Overview

The Dvorak technique estimates tropical cyclone intensity using satellite images. Vernon Dvorak and his colleagues developed the Dvorak technique in the early 1970s. It was one of the first innovative applications of meteorological satellite imagery, and it is still widely used today at tropical cyclone forecast centers throughout the world (Velden et al., 2006).

The intensity of a tropical cyclone is generally quantified as the associated maximum surface wind speed. Near the United States, routine aircraft reconnaissance gives intensity estimates using dropsondes and flight level data. However, most of the world's tropical cyclone intensity analysis relies on satellite images and the Dvorak technique. Another indicator of tropical cyclone intensity is the minimum sea-level pressure near the tropical cyclone center. The Dvorak technique uses an intensity unit called



Dvorak Classification of Hurricanes, Figure 1 Enhanced IR images of Hurricane Linda at Dvorak intensities T2, T4, T6, and T8. Hurricane Linda was located in the eastern North Pacific, southwest of Mexico, during 9–17 September 1997.

a T-number in increments of ½ ranging from T1 to T8. The Dvorak T-number intensity scale is normalized according to typical observed daily changes in intensity. T2.5 is the minimal tropical storm intensity (35 knots = 18.0 m/s), whereas T4.0 is the minimal hurricane intensity (33.4 m/s). T6.0 has a wind maximum of 59.1 m/s, and T8.0 approximates record maximum intensity (87.4 m/s).

The Dvorak technique primarily uses satellite observed cloud patterns and infrared (IR) cloud top temperatures to estimate intensity, with independent methods for visible satellite images and IR images.

With weaker intensities, the Dvorak analysis is based on either the curved band pattern or the shear pattern. Using the curved band analysis, the extent to which a spiral-shaped band of deep convective clouds surrounds the tropical cyclone center determines the intensity. The shear pattern refers to the cloud pattern observed when broadscale vertical wind shear induces a distinctly asymmetric cloud pattern with respect to the tropical cyclone low-level circulation center. The degree of deep convective cloud displacement due to the vertical shear decreases with intensification.

With hurricane intensities, the cloud pattern typically evolves into what is called a central dense overcast, which describes the deep convective clouds that surround the center. As intensification proceeds, an eye is observed within this central dense overcast. The eye is the familiar cloud-free or cloud minimum area associated with the lowest pressure at the tropical cyclone center. The eye is surrounded by a circular area which has the strongest winds within very deep clouds and heavy rain, known as the eyewall. The Dvorak technique analyzes visible features and IR temperatures of the eye and the surrounding deep clouds to assign the intensity. In general, the Dvorak tropical cyclone intensity increases as they eye gets warmer and better defined, and the surrounding clouds get colder and more symmetric. A continuous, very cold circular ring of cloud tops generated by the eyewall along with a warm eye temperature indicate an intense tropical cyclone. Enhanced IR images of Dvorak intensities T2, T4, T6, and T8 are shown in Figure 1 with Hurricane Linda that was located in the eastern North Pacific in September 1997.

Dvorak (1984) gives a detailed description of the methodology and procedures of the Dvorak technique. Following Dvorak's original work, research and development efforts have been focused on replicating and refining the Dvorak approach with objective and automated routines using the IR temperatures (Velden et al., 2006). Automated Dvorak techniques give reliable results that are quickly updated as the latest IR satellite image becomes available, and the tropical cyclone intensity data supplement the general use of satellite data for analysis and forecasting.

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Cross-references

Airphoto and Satellite Imagery
Beaufort Wind Scale
Hurricanes
Hurricane Katrina
Storms