WATER HAZARDS CAUSED BY NATURALLY-OCCURRING HYDROLOGIC EXTREMES

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Contents

Summary

The natural hazards that are triggered exclusively by hydrological extreme-event phenomena of nature are called "hydrological hazards" or simply "water hazards." Comparison of different disasters in terms of fatalities over the period 1950–2000 shows that first, disasters tend to be rather periodic in occurrence, with an interval of five to ten years; and second, flood, *tsunami*, and drought disasters account for 40–90 percent of total fatalities of all disasters which have taken place annually around the world. Therefore, water hazards need to be a crucial concern when we attempt to reduce the number of deaths caused by natural disasters in the world. Comparison by economic losses shows that disasters have been increasing over the last fifty years and that 10–30 percent of total economic losses tend to be derived from water disasters. Among these economic losses those caused by flood disaster are the most dominant, with a share of 50 to nearly 100 percent of the total losses caused by water disasters.

1. Definition of Hazard and Disaster

Rigorously speaking, the terms "hazard" and "disaster" need to be distinguished. Hazards refer to any direct and indirect causes and factors that may eventually lead to a disaster, while a disaster can be defined as "the state of society being damaged in the whole sense physically, vitally, physiologically, economically, and socio-culturally." In the event of the occurrence of any hazard, it could be the case that no disaster follows or that, at worst, the damage is kept to a minimum. Importantly, hazards (and thus disasters) are non-deterministic events that tend to entail uncertainties and unknowns. If mathematically well-formulated, such non-deterministic hazards may well be treated as stochastic events based on applied probability and statistical theories. Statistically, many hazards are categorized as "extreme events" since they tend to appear in the tails of the probabilistic distribution for the entire set of data on the observed phenomena. Any hazard that is triggered directly by nature is called a "natural hazard." In contrast, any that is caused directly by human activities or societal mishap is called a "social hazard."

2. Hydrological Hazards or Water Hazards

In this section we will focus on those natural hazards that are triggered exclusively by the hydrological extreme-event phenomena of nature. Let us call them "hydrological hazards" or simply "water hazards." To avoid unnecessary confusion, the terms disasters and hazards will be used here synonymously, though more rigorous distinctions will be made when necessary (as stated above.)

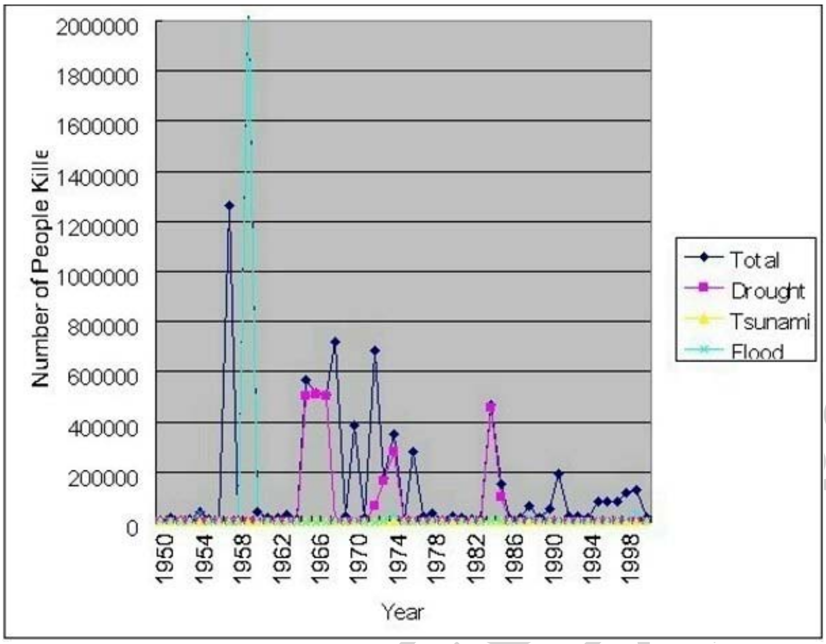

Figure 1. The number of deaths by water related disasters

Figure 1 compares different disasters in terms of fatalities that occurred in the world over the period 1950–2000. The percentage comparison is shown in Figure 2. From these figures we learn that:

- Disasters tend to be rather periodic in occurrence, with an interval of ten to five years.
- Flood, *tsunami*, and drought disasters account for 40–90 percent of total fatalities of all disasters that have taken place annually around the world. Above all, flood disasters are significantly dominant in terms of fatalities.
- All this indicates that water hazards need to be a crucial concern when we attempt to reduce the number of deaths caused by natural disasters in the world.

The results of a comparison based on economic losses caused by disasters are shown in Figures 3 and 4. Noticeably, disasters have been increasing in terms of economic losses over the last fifty years, particularly so over the latest ten years. It is interesting to note that the share ratio of economic losses caused by water disasters in the totals for all disasters is found to be basically the same for the last forty years. That is, 10–30 percent of total economic losses tend to be derived from water disasters. Among these economic losses caused by flood disaster are the most dominant, with a share of 50 to nearly 100 percent of the total losses caused by water disasters.

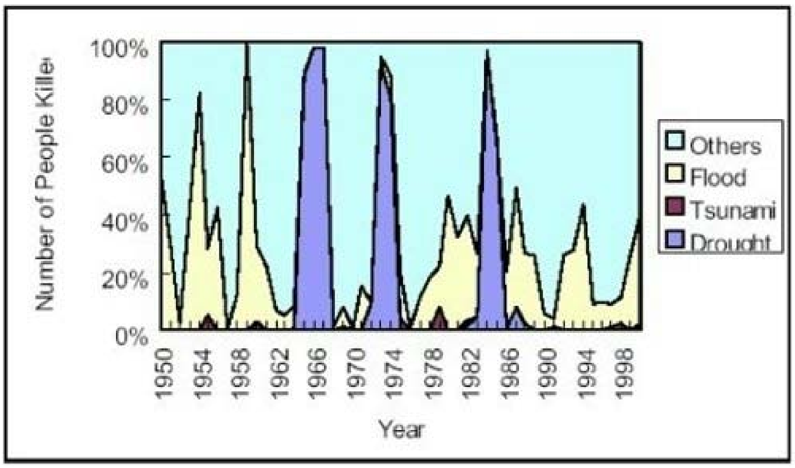

Figure 2. The percentage of the number of deaths by water related disasters

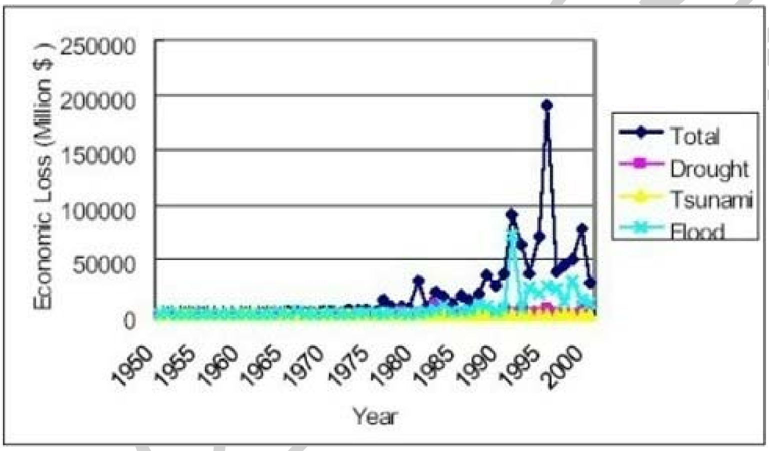

Figure 3 Economic losses by water related disasters

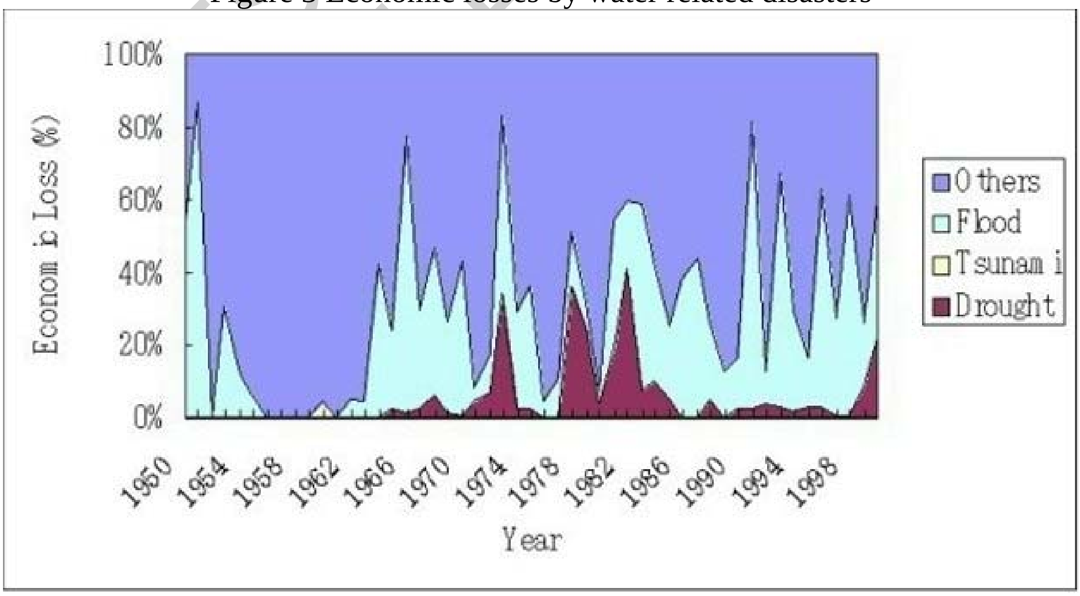

Figure 4. Percentage of economic losses by water related disasters

3. Types of Water Hazards

3.1. Weather and Climate

3.1.1. Climate Change, Global Warming, and the Greenhouse Effect

Climate change on a global scale could be the basic condition for the water-related hazards that are explained in the following sections. The Intergovernmental Panel on Climate Change (IPCC, 2001) reports that:

- The global average surface temperature has increased over the twentieth century. Since 1950, there has been a reduction in the frequency of extreme low temperatures, with a smaller increase in the frequency of extreme high temperatures.
- The overall global temperature in the lowest 8km of the atmosphere has increased since the 1950s.
- There have been decreases of about 10 percent in the extent of snow cover since the late 1960s.
- Precipitation has increased by 0.5–1.0 percent per decade in the twentieth century over most mid- and high latitudes of the northern hemisphere continents.
- El Niño–Southern Oscillation (ENSO) has become more frequent, persistent and intense since the mid-1970s, compared with the previous 100 years.

These changes occur as a result of both internal and external factors. One of the major external factors is greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and halocarbon gases ($CFCl_3$ and CF_2Cl_2), that all have an effect in warming the surface of the earth. These greenhouse gases are increasing as a result of human activities. IPCC (2001) stated that atmospheric carbon dioxide concentration has increased by 31 percent since 1750.

As a result of the global warming, precipitation is projected by the IPCC to increase in the twenty-first century. This will be the case on the global average, and particularly so in the regions located in northern mid- to high latitudes and Antarctica. The water content of soils and the discharge rate of rivers may determine the risks of flooding and droughts in many regions of the globe. The global average of river discharge rate is projected to increase by 7 percent.

However, since the evaporation rate due to the global warming will increase monotonically with decreasing latitude, flooding is likely to occur more frequently in the regions of northern high latitudes. In particular, the discharge rate of rivers flowing out into the Antarctic Sea and the north Pacific Ocean in Russia and Canada is predicted to increase by 10 to 20 percent in the end of this century. On the other hand, at low latitudes there are both regional increases and decreases over land areas. These are strongly related to the dependency of monsoon intensity and its annual variability. In the tropical areas, the Amazon and Ganges rivers are likely to increase in flow rate by 10–15 percent, while the discharge rate of the Nile, Mekong and Mississippi rivers is predicted to decrease about 10 percent. Moreover, variations in precipitation will become larger year by year in the most of those areas where the mean precipitation is projected to increase.

The projection of the soil water content as a result of the global warming relates to harvest of crops. The water content will also increase in the regions from the northern mid- to high latitudes. It decreases in summer and increases in winter. In contrast, in the subtropical dry areas it remains lower level throughout the whole year and thus the total area of deserts is likely to increase.

As to the extreme weather and climate events, IPCC with relatively high confidence projected much warmer days for nearly all land areas, more intense precipitation events, an increase in tropical cyclone peak wind intensities and also an increase in the tropical cyclone peak and mean precipitation intensities for certain areas. In addition, increased summer continental drying and associated risk of drought are projected for most mid-latitude continental interiors. However, for the other extreme phenomena, very small-scale phenomena, such as tornadoes, thunderstorms, and hail, climate models currently lack the ability to provide spatial details required to make reliable projections.

Human activities also affect climate at a smaller scale. In urbanized areas, the temperature is higher than surrounding areas. This phenomenon is called a "heat island." The ground surface is covered by buildings and pavement the thermal conductivity of which is higher, while the heat capacity and evaporative cooling effect are much lower than with soil and plants. Moreover, anthropogenic heat emission and air pollutants such as sulfur dioxide (SO_2) and nitrous oxide are larger. These result in higher temperature in the center of a city.

3.1.2. Change of Precipitation with Global Warming and Urbanization

Regarding the relation between global warming and precipitation, it is generally thought that global warming basically increases the mass of water vapor that can be included in the tropospheric atmosphere, resulting in an increase of cloud and precipitation generation as a global average.

In order to predict the change of climate, climate models are used. Climate models are classified into energy balance models (EBMs), one-dimensional radiative-convective models (RCMs), two-dimensional statistical-dynamical models (SDMs), and general or global circulation models (GCMs). EBMs are the simplest models and GCMs are the most complex models. These models have the following characteristics.

- Energy balance models (EBMs) are used to model the global radiation balance and the latitudinal energy balance.
- Radiative-convective models (RCMs) are used to model the radioactive transformations, convection.
- Statistical-dynamical models (SDMs) combine the horizontal energy transfer modeled by EBMs with the radioactive transformations and convection modeled by RCMs.
- General or global circulation models (GCMs) are three-dimensional models, and that are based on the laws of physics such as conservation of energy, conservation of momentum, conservation of mass, and the ideal gas. GCM generally consists of the sub-models describing atmosphere, oceans, land surface processes, etc.

Various numerical experiments with GCMs have shown that the expected global warming would increase the global averaged precipitation by 4–15 percent. Also a "decrease of the precipitation area" and "increase of convective-type precipitation outside the tropical region" are commonly predicted from various numerical experiments. Both results indicate the increase of frequency of localized heavy rainfall somewhere on the globe. The main reason for these common results is that global warming increases air temperature in the lower atmospheric layers making the atmosphere more unstable.

With the current state of the art, however, no GCM can provide reliable information on whether precipitation on a regional scale will increase or not because various numerical experiments shows contradictory results, due to the different manner of parameterization of cloud formation and the surficial hydrologic processes. This also means that GCMs cannot provide reliable information on frequency change of localized heavy rainfall in a specific region. In this sense, not only numerical experiments with GCMs, but also analyses of historical data are required.

Regarding the relation between urbanization and precipitation, we can be more confident that the former increases the latter because:

- The heat release due to the heat island phenomenon increases air temperature in the lower atmospheric layers, which results in making the atmosphere unstable.
- Increase of aerodynamical roughness induces convergence of horizontal wind.
- Industrial and other human-induced aerosols accelerate cloud formation.

These features have been gradually verified by area-wide observations and numerical experiments.

3.1.3. Mechanism of Heavy Rainfall

In cloud physics, clouds are distinguished as either "warm clouds" or "cold clouds." The temperature of a warm cloud is higher than 0 °C and ice particles do not exist in it. On the other hand, cold clouds include ice particles and they grow faster than water droplets. The cloud causing heavy rainfall is the cumulonimbus. Its life is from thirty minutes to one hour. The life-cycle of a cumulonimbus is divided into three stages: the development period, the peak period, and the weakening period. In the development period, the cloud extends upward. Since upward wind is strong, drops of water do not reach to the ground. In the peak period, the top of the cloud reaches the upper part of the troposphere and big particles, such as snow and hail, are formed. Then, ice particles begin to fall and downward wind is generated. Heat is removed by the melting of the ice particles, and downward wind is strengthened by that. In the weakening period, the remaining water droplets and ice particles fall as raindrops or evaporate, and the cloud disappears. In the case of an isolated cumulonimbus, rainfall lasts from ten minutes to one hour.

The system consisting of neighboring cumulonimbus is called a mesoscale convection system. Mesoscale convection systems have the mechanism to maintain clouds and cause heavy rainfall, lasting for hours. The air cooled-down by rainfall reaches the ground and spreads. Then the flow pushes up humid air and new clouds are generated in succession. This positive feedback system is the mechanism that maintains clouds. Among the shapes of mesoscale convection systems are those known as the multi-cell type, the super-cell type, the squall-line type, the rain-band type, and the mesoscale convective complex (MCC).

3.1.4. Mechanism of Localized Heavy Rainfall

Localized heavy rainfall is heavy rainfall whose area is relatively small. Localized heavy rainfall is often accompanied by a thunderstorm, and it appears suddenly. When dry air enters a cloud it promotes evaporation of raindrops and the descending cooled-air creates a cooled air pond on the ground. Then, the cooled-air outflow pushes up humid air and the mesoscale convection system of the multi-cell or super-cell type is maintained. Observation using radar shows that small clouds move to a stationary rain-band, and the clouds are absorbed into the rain-band. The process promotes the development of bigger clouds and heavy rainfall lasts for a long time in a small area. Therefore, a stationary rain-band and the absorbing of small clouds are necessary for localized heavy rainfall. Movement of rain-bands is stopped by geographical obstacles, such as mountains. Geographical features are also important factors affecting the occurrence of localized heavy rainfall.

Heavy rainfall for a very long time occurs only in tropical zones. Regions where a humid air current is maintained and a mountain range exists behind, suffer especially heavy rainfall. Cherrapunji in India is one example of such a region (see Table 1).

Term	**Term (minutes)**	**Rainfall (mm)**	**Date**	**Place**
1 minute	1	38.1	11/26/1970	Barot Guadeloupe
5 minutes	5	61.72	11/29/1911	Port Bells, Panama
20 minutes	20	205.74	7/7/1947	Curtea-de-Arges, Rumania
130 minutes	130	482.6	7/18/1889	Rockport, West Virginia, USA
4 hours	240	584.2	1/12/1880	Basselere, St. Kitts, West Indies
12 hours	720	1 340.10	2/28/1964-2/29/1964	Belouve, La Reunion
24 hours	1 440	1 869.95	3/15/1952-3/16/1952	Cilaos, La Reunion
48 hours	2 880	2 499.87	3/15/1952-3/17/1952	Cilaos, La Reunion
72 hours	4 320	3 240.02	3/15/1952-3/18/1952	Cilaos, La Reunion
7 days	10 080	4 109.97	3/12/1952-3/19/1952	Cilaos, La Reunion
15 days	21 600	4 797.55	6/24/1931-7/8/1931	Cherrapunji, India
31 days	44 640	9 299.96	7/1861	Cherrapunji, India
61 days	87 840	12 766.80	6/1861-7/1861	Cherrapunji, India
365 days	525 600	26 461.21	8/1860-7/1861	Cherrapunji, India

Table 1. The records of heavy rainfall (DPRI, 2001)

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Biographical Sketches

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