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A Review Article

Flood Risk Assessment: A Review

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ABSTRACT: The paper reviews some of the techniques of flood risk assessment using case studies from different countries in the world. These techniques are meteorological, hydrological, hydrometeorological, socio-economic and those based on Geographic Information System (GIS). The paper concludes that GIS technique appears to be most promising as it is capable of integrating all the other techniques of flood risk assessment.@ *JASEM*

Flooding is the most common of all environmental hazards and it regularly claims over 20,000 lives per year and adversely affects around 75 million people world-wide (Smith, 1996). The reason lies in the widespread geographical distribution of river floodplains and low-lying coasts, together with their long standing attractions for human settlement. Death and destruction due to flooding continue to be all too common phenomena throughout the world today, affecting millions of people annually. Arising from this, The International Decade for Natural Disaster Reduction (IDNDR) was launched by the General Assembly of the United Nations in 1987 to run from 1990 to 2000. It's aim is to reduce the loss of life, property damage and social and economic disruption caused by natural disasters (Askew, 1999). The resolution proclaiming the Decade makes specific reference to flood, tsunamis, drought and desertification among the principal disasters to be considered. **Floods** cause about one third of all deaths, one third of all injuries and one third of all damage from natural disasters (Akew, 1999).

The year 1994 marked the mid-point in the Decade and as a consequence, the United Nations conveyed a World Conference on Natural Disaster Reduction that was held in Yokohama in May of that year. One of the 10 "principles" underlying the Yokohama strategy is that "risk assessment is a required step for the adoption of adequate and successful disaster reduction policies and measures".

The need for a review of some of the techniques of flood risk in order to reduce large-scale losses to lives and property has been stressed in the literature (Askew, 1999; Smith, 1999; Ologunorisa, 2001). The objective of this paper therefore is to review and synthesize some of the techniques of flood risk assessment into a coherent piece. The paper undertakes first a theoretical clarifications of the concept of risk before reviewing flood risk assessment techniques.

Theoretical Clarifications

Risk is an integral part of life. Indeed, the Chinese word for risk "weji-ji" combines the characters meaning "opportunity/chance" and "danger" to imply that uncertainty always involved some balance between profit and loss (Smith, 1996). Since risk cannot be completely eliminated, the only option is to manage it. Risk assessment is the first step in risk management. Risk assessment according to Kates and Kasprson (1983) comprises of three distinct steps.

a) An identification of hazards likely to result in disasters, e.g. what hazards events may recur?
b) An estimation of the risks of such event, e.g. what is the possibility of such event?
c) An evaluation of the social consequences of the derived risk, e.g. what is the loss created by each event?

However, for sound risk management to occur, there should be a fourth (d) step which addresses the need to take post-audits of all risk assessment exercises. When risk analysis is undertaken, risk (P) is taken as some product of probability (P) and loss (L).

$$R = P \times L \ldots\ldots(1)$$

Flood risk involves both the statistical probability of an event occurring and the scale of the potential consequences (Smith, 1996). All development of land within the floodplain of a watercourse is at some risk of flooding, however, small. The degree of flood risk is calculated from historical data and expressed in terms of the expected frequency 10 year, 50 year or 100 year flood.

Flood risk is a function and a product of hazard and vulnerability (Ologunorisa, 2001). That is, Risk = Hazard x Vulnerability. A real flood risk level requires a certain level of hazard, and for the same location, a certain level of vulnerability. A situation of risk is due to the incompatibility between hazard and vulnerability levels on the same land plot. The United Nations Commission for Human

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Settlements (UNCHS – HABITAT) (1981) has defined the three terms in the following way:

a) Hazard: is the probability that in a given period in a given area, an extreme potentially damaging natural phenomena occurs that induce air, earth movements, which affect a given zone. The magnitude of the phenomenon, the probability of its occurrence and the extent of its impact can vary and, in some cases, be determined.

2. Vulnerability – of any physical, structural or socio-economic element to a natural hazard is its probability of being damaged, destroyed or lost. Vulnerability is not static but must be considered as a dynamic process, integrating changes and developments that alter and affect the probability of loss and damage of all exposed elements.

3. Risk – can be related directly to the concept of disaster, given that it includes the total losses and damages that can be suffered after a natural hazard: death and injured people, damage to property and interruption of activities. Risk implies a future potential condition, a function of the magnitude of the natural hazard and of the vulnerability of all the exposed elements in a determined moment.

Risk Assessment Techniques

(i) Meteorological Parameters

Various definitions have been used in defining floods (that is large rainfall surpluses) over a region depending on the purpose in view. This simple parameter, rainfall, which can reflect many aspects of flood is used in partially all definitions of flood. Meteorological flood can be defined as a situation over a region where that rainfall is mostly higher than the climatological mean value because the natural vegetation and economic activities of the region have been adjusted to the long-term average rainfall of that region (Parthasarathy, et al 1987). Therefore, the conditions which lead to flood occur when the rainfall amount over a particular region is more than a certain amount, normal for that region (Friedman, 1957, WMO, 1975).

Many countries, notably Costa Rica, Israel, Islands of Aruba, Jamaica, Botswana, Ethiopia, Malaysia, Mauritius, Korea, Pakistan, USA and Australia, use in some form or other the criterion of a given percentage departure form the normal. When the seasonal rainfall is in an excess of 26-50 percent of normal over a meteorological subdivision is regarded as a moderate flood, and an excess of more than 50 percent of the normal as a severe flood; while the rainfall between 0-26 percent of normal is regarded as a less severe flood. This is the definition that has been adopted by the Indian Meteorological Department (1971). See also Ramon (1975) Government of India (1976), and which many countries in Southeast Asia, and even U.S.A and Australia (Parthasarathy et al, 1987) have adopted.

Laughlin and Kalma (1990) developed a methodology for frost risk mapping based on regional weather data and local terrain analysis. Minimum air temperatures were measured during three winters with a network of stations in open, undulating terrain. It was observed that the change in minimum air temperature with elevation could be predicted from mean night time wind speed, total nighttime net radiation loss and a hill-top reference minimum temperature. It was also found that the deviation of temperatures at individual sites could be predicted from a local terrain parameter which reflects the extent of cold air accumulations. Finally, the study describes the model and illustrates the regional weather and terrain effect with three-dimensional block diagrams.

Single et al (1990) after considering the total seasonal rainfall of June through September as well as its time, developed an index that has been evolved for identifying a year as hydrological flood/drought in different parts of India. After giving a margin of 25% to the mean index value for normal years, frequencies of flood/drought years have been calculated. In general, frequencies of both hydrological flood and drought years are more in low rainfall areas as compared to high rainfall areas. They compared quite closely with the frequencies of meteorological excessive and deficient rainfall years respectively. But the categorization of some individual years is found to differ between meteorological and hydrological points of view. The nature of these differences is however, not uniform at all the stations.

Hayden (1988) remarked that an examination of the literature reveals neither a global classification of flooding nor a regionalization or map of flood climates types on a global basis. His major objectives was to generate such a classification and a map of the resulting flood climate types and to detail the basis for its constructed. A coherent global climatology of flooding is not easily constructed from stream discharge frequency and magnitude statistics. The difficultly arises, in part, because the frequency and magnitude of floods vary between and within drainage networks because of variability in basin characteristics. This variability is further complicated by the diversity of weather systems that may give rise to flooding, each with its own characteristics return interval spectrum. Although the variability in basin characteristics prohibits regionalization on a global scale, the meteorological causes and potential for flooding can be classified and regionalized. In the study, flood climate regions were delineated on the basis of meteorological causation.

Olaniran (1983) examined flood generating mechanisms at Ilorin. He noted that in the decade 1971-1980, the town experienced rains greater than 25.4 mm/day induce floods when they occur in a month about three or more times during the period of moisture surplus at Ilorin. The study shows further that the construction of Aso dam has not prevented the occurrence of flood at Ilorin which is situated downstream of the dam on account of the network characteristics and channel slopes of the tributary stream and the increasing rate of urban development downstream of the dam.

McEwen (1989) assessed whether there have been changes in the magnitude, frequency, duration and seasonality of extreme rainfall over the last 100 years within the middle River Tweed basin, Berwickshire, Scotland. Rainfall patterns were compared with published analysis of other long-term rainfall records to evaluate regional variations in the characteristics of extreme rainfall. Information on the magnitude and frequency of rainfall extremes was used to substantiate and augment a previously established extended flood record of the White adder Water catchment within the middle River Tweed basin. He reported a coincidence between increased frequency of heavy rainfall and increased frequency of moderate to extreme floods during the 1870-1880s and a reduced flood incidence in the 1970s which was substantiated by an absence of extreme rainfall peaks in the middle River Tweed basin, Scotland.

Durotoye (2000) elaborated on the four major sources of water that largely contribute to the inundation of the deltaic plains. These include:

(a) The annual river peak discharge of River Niger especially the "White Flood" in October and the "Black Flood" between December and March. The "Black Flood" discharge, which originates from the Niger's headwaters in Guinea generates freak episodes of high discharge during exceptionally high rain in wet years. The "White Flood" originates mostly from within the Nigerian catchment areas. It has a high suspended load of fine sand/silt and clay which are deposited to built the deltaic alluvial flood plains and levees. She observed that high peak discharges cause bank and levees failures as the stream burst their banks seasonally to create disastrous floods.

(b) The role of heavy rainfall peaks;

(c) Man induced floods through oil exploitations and explorations, and human interference with the courses of stream channels during various constructional works;

(d) Tidal floods especially in the coastal areas and mangrove swamps. The tidal flooding by ocean water created the characteristics brackish water environment. Also ocean surges also generate stormy high tides resulting in destructive flood.

Abams (1995) reported in his study of floods in Kiama (in Bayelsa State), Nigeria located in the lower deltaic flood plain on River Nun that the annual flooding experienced are a consequences of the combined effect of the "White Flood" discharges and the heavy rains from tropical storms. The rainfall is up to 3250 mm/yr, about 80% of which is received between June and October. Heavy torrential rains are known to fall continuously for several days (up to ten days a times). The rain water collects over impermeable silty clay plains. Consequently, meandering rivers not only over flow their banks but are actively eroding them and causing bank failures. It is also important to note that the ground level of water table is virtually several metres above surface (up to 9m) rains, leaving little or no room for percolation into the ground.

Durotoye (1999) highlighted the increasing tendency of human occupation of potential hazard area in Nigeria, and Niger Delta in particular. She observes that the physical conditions and natual processes prevailing in the Niger Delta environment that impinge on the safety of the people living there are numerous. She identified geo-environmental problems such as flooding, marine incursion, coastal recession and subsidence.

ii. Hydrological Parameters

Trinic (1997) **did an** hydrological analysis of high flows and floods of the Sava River near Zargred (Croatia) in the period from 1926 to 1992. Particular attention was paid to the causes of flood wave volumes from direct inflows above reference discharged and of constant duration were analyzed. The results of hydrological analysis of the flood wave hydrographic can be used to improve manipulation with waters using weirs, flood diversion canals and retentions. The article analysis flood waves of the Sava River near Zagreb for the period 1926-1992, highlighting particularly the disastrous flood of October, 1964.

Kattelmann (1997) analyzed flooding from rain-on-snow events is Sierra Nevada. He observed that the most damaging floods in rivers of the Sierra Nevada of California's have occurred during warm storms when rain fell in snow covered catchments. These large floods have inundated communities and farms in California's prime agricultural region. Forecasting of runoff from rain-on-snow events have been difficult for managers of dams and power plants within the Sierra Nevada and for downstream flood control agencies because of uncertainties about runoff production at high altitudes and snowmelt contributions at low altitudes. The results of the analysis show that the high potential for flood generation from rain-on-snow events is related to their large contributing area, intensity and duration rainfall, opportunity for snowmelt contributions, and the timing of water released fro the now pack.

Nobilis and Lorenz (1997) analyzed flood trends in Australia. The study deals with the analysis of previous floods, the assessment of damage, and the evaluation of possible changes in the flood behaviour due to natural or artificial influences. The results of the analysis show areas with predominantly linear trend and areas with predominant positive significant (P=0.05) linear trend. The authors observed that based on such investigations, realistic design values may be calculated taking into account the end of stationary due to climate change.

Bogdani and Selenica (1997) analyzed catastrophic floods and their “risk” in the rivers of Albania. The study described the main characteristics of floods in Albanian rivers including information on the highest floods observed during the last 150 years. In addition, a brief overview of flood regions in Albania, based on specific discharge is given, which forms an index of flood “risk”.

Richard et al (1997) describes a two-dimensional mathematical model and the determination of inundation risk maps for two rivers in the Rosario region of Argentina. The mapping was made over both Saladillo and Luduena rivers, for floods of return periods of 50,100 and 500 years. The studied zones embraced an areas of 7000ha, with a population of 500,000 inhabitants. Based on the results, state and local government are planning non-structural rules with the associated legislation. The paper concludes that it is important to use association simulation models for urban planning strategies and water resources management.

Kuchment (1997) estimating the risk of rainfall and snowmelt disastrous floods using physically-based model of river runoff generation. Disastrous floods can be caused by unusual combinations of hydrometeorological factors and river basin conditions that have not been observed during a long observation period. Physically-based models of runoff generation enable one to find dangerous possible combinations of hydrometeorological factors and to estimate the risk of extreme floods. Analysis of runoff generation on a number of the Russian rivers have shown that although the probable maximum precipitation rate is usually larger than the probable maximum snowmelt rate, the maximum floods of the medium and large rivers of Russia are of snowmelt origin. A comparison of the calculated maximum snow belt and rainfall discharge has been carried out. It has been revealed that in the same region, the probable maximum discharge may be of snowmelt of rainfall origin depending on the river basin area and runoff generation mechanism. The problem of the assignment of the meteorological inputs was discussed. To demonstrate the approaches used, the results of investigation of extreme floods generation based on numerical simulation of the River Sosna, the River Seim and the River Uda were shown.

(iii) Socio-Economic Factors

Oriola (1994) observed that various socio-cultural activities have promoted flooding in many of the Nigerian urban environments. These activities are characterized by stream or river channel encroachment and abuse, increased paved surface and poor solid waste disposal techniques, due to a high level of illiteracy, a low degree of community awareness, poor environmental education, ineffective town planning laws and poor environmental management. He argued that government, at various levels needs to address these issues. He concluded that flood risk in the Ondo urban environment was a function of the following factors: Land-use pattern, refuse disposal habits, the nature of the surrounding buildings, distance of building from the course of the streams, rainfall amount and duration, the relief or the terrain, slope, gradient, and other stream basin parameters.

(iv) Combination of Hydrometeorological and Socio-Economic Factors.

Hogue et al (1997) undertook an assessment of the risks involved with cyclones and storm surges in Chitagong, the second largest city in Bangladesh. The study finds the extent of storm surge flooding and the related risk in the metropolitan area. To identify the risk, the depth and extent of storm surge flooding for different probability of occurrence have been predicted and were expressed as a hazard index. The city area was divided into five categories of land-use: industrial area, commercial areas, planned housing areas, unplanned housing areas and mixed areas. For each, population density and economic importance of the areas have been considered and were expressed as an importance index. Using the hazard index and importance index, the risk for each area was calculated. On the analysis, the whole city area was classified into four categories: the low risk area, the risk area, the high risk area, and the severe risk area.

Ologunorisa **(2004)** undertook an assessment of flood risk in the Niger Delta, Nigeria using a combination of an hydrological techniques based on some measurable physical characteristics of flooding, and social-economic techniques based on vulnerability factors. Some of the physical characteristics of flooding selected include depth of flooding (metres), duration of flood (hours/weeks), perceived frequency of flood occurrence, and relief or elevation (m) while the vulnerability factors selected include proximity to hazard source, land use or dominant economic activity and adequacy of flood alleviation schemes and perceived extent of flood damage. He derived rating scale for the nine parameters selected, and 18 settlements randomly selected across the three ecological zones in the region were rated on the basis of the parameters. Three flood risk zones emerged from the analysis. These are the severe flood risk zones, moderate flood risk zones and low flood risk zones. Some strategies for mitigating the hazard of flooding in the region were identified.

Georgakos et al (1997) undertook an estimation of flash flood potential for large areas in United States of America. A methodology for determining the potential for flash floods in small basins within large geographical area was presented. Geographical Information System (GIS) technology was used to assimilate digital spatial data, remotely sensed data, with physically-based hydrological - hydraulic models catchment response. The methodology used digital terrain elevation data, digital river reach data, and the US Geological Survey land-use and land-cover data to produce estimates of the effective rainfall volume of a certain duration required to produce flooding in small streams. This flood potential index is called threshold runoff. For operational application, soil water accounting models were used to yield estimates of effective precipitation over areas of $1000km^2$. Maps of flash flood potential could then be constructed using remotely-sensed and on-site data. Examples of application in various regions of the United State of America were discussed.

(v) *Geographical Information System (GIS)*

Okoduwa (1999) applied Geographic Information System (GIS) in the prediction of urban flooding in Benin City. Nigeria. This was achieved by creating a digital database of selected variables such as land use, land cover and soil strength. The software used was Arcview 3.1 and the overlay techniques in GIS was used for analysis. The result of the analysis showed high flood prone areas, medium flood prone areas and low flood prone areas.

In carrying out the overlay operation, Okoduwa (1999) first carried out the land use and the reclassified Digital Elevation Model (DEM). The land use map and the relief map were overlayed using the union function with the geo-processing hazard contained in the Arc view. The union function was used to create new theme by overlaying two polygons of the input theme. That is, the land use them and relief theme, were split at their intersection. The dissolved function contained in the geo-processing wizard was used to enhance the merging of the feature of the two themes which generated a theme called land Relief Map (see Fig.1). The land relief map was then overlayed on the soil strength , and high intensity of land use as well as areas with low relief, are areas that are prone to high flooding, while areas with high soils strength, low intensity of land use, as well as with high relief are prone to low flooding. Also areas with medium soil strength, medium intensity of land use as well as areas with medium relief are prone to medium flooding. Having overlayed the land Relief map on the soil strength map, the overlay gave a map (of Benin City), showing areas that are prone to high flooding areas prone to medium flooding, and areas that are prone to low flooding respectively.

Okoduwa (1999) reported that in Thailand flood forecasts were prepared for the Huai nam Chun catchment of Pa Sak Watershed, phetchabun province, using a hydraulic model and a GIS. The objective was to test what extent the integration of a hydraulic model and a GIS can contribute to the quantitative assessment of effects of the upstream land use changes on downstream flood pattern. The Hec-1 hydraulic model and ILWIS (GIS) were used. The result of the simulation were able to show the effect of the land use changes on flood levels down steam. The result of the study further showed that a hydraulic model like HEC-1 makes it possible to predict the effects of upstream land use changes on down stream level. GIS appeared to be an efficient tool for the preparation of part of the input data required by such a model but it was not possible to link the GIS and the HEC-1 directly. It could not be confirmed whether the use of a GIS would be an advantage when other hydraulic model are used.

Also in Netherlands, the GIS technique was applied to Meuse in the South of Netherlands after the flooding of December 1993. It was observed that the river flooding can have a severe impact on the society and to reduce the potential damage in the future, structural measures such as increasing the storage capacity inside or outside the river bed or improving dikes are essential. To support decision making when choosing and evaluating adequate measures ‘Defit hydraulic’ developed a flood hazard model and in developing the model the GIS package known as Arc/info turned out to be a valuable tool in developing the model and this supported decision making. The model was successfully applied to calculate the impacts of potential strategies for the River Meuse in the South of the Netherlands. It is pertinent to note that while the potential of GIS as an environmental analysis technique is improving, complementing and occasionally displacing the traditional field survey technique in most developed countries and even in some developing countries, their use still remain largely un-demonstrated in many developing countries.

Conclusion:In this paper, we have reviewed some of the techniques of flood risk assessment. These techniques are meteorological especially those involving rainfall parameter; hydrological parameters involving the use of runoff data; socio-economic factors, and a combination of hydrometeorological parameters and socio-economic factors, and finally those based on the application of Geographical Information System (GIS). The study observes that the GIS techniques is the most recent and holds a lot of promises as it is capable of combining all the known techniques and parameters **of** predicting flood risk. The study concludes that the use of GIS technique should be encouraged in risk assessment of flooding as it is capable of integrating the geomorphological, hydrological, meteorological and socio-economic variables.

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