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Hydrological Disasters Management and Risk Assessment

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Abstract

In India, floods and droughts are recurrent hydrological phenomenon causing huge losses to lives, livelihood, properties and infrastructure due to non-uniformly distributed rainfall both in time and space leading to the dimensionally opposite problems of flood and drought in different parts of the country. Out of 3290 lakh hectares geographical area,40 million hectares is prone to floods which show high risk, vulnerability and is one of the most common hydrologic extremes frequently experienced by our country. On the other hand drought has a varying frequency from once in two years to once in fifteen years. It has been observed that there is flood in one part of country and severe drought in the other part. Various short term and long term measures should be adopted to prevent and mitigate the consequences of floods and drought rather than causing damages and losses due to interfering of the natural processes. In this paper, drought and flood problems in India are highlighted along with some of the important management issues requiring immediate attention. Further more, it presents the recently developed non-structural techniques for flood forecasting, flood plain zoning, glacial lake outburst modeling and decision support system.

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Introduction

India has a peculiar climate diversity under which nearly 80 percent of the annual precipitation is limited to a brief monsoon period generally less than 100 days. Even though the country receives an annual rainfall of 1170 mm on an average, the complex system of monsoon winds and the peculiar orientation of mountains give rise to some excessively low rainfall regions and well-diversified pockets of water scarcity in one part of the country and simultaneously the other parts of the country receives high rainfall resulting extensive flooding. Every year one part or the other of the country is experiencing extensive devastation due to floods because of damages to crops, houses and public utilities, and loss to human lives. The extensive flooding in Mumbai and in other parts of the Maharahtra and Gujarat during the month of July and August, 2005 are resulted due to the occurrence of intense rainfall (more than 900 mm rainfall in a day

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occurred in Mumbai) for few days causing heavy damages to the lives and properties of the people and disrupting the traffic and normal life during the flood period. Other factors which causes flood include cyclone, Tsunami, land slide, coastal flooding due to high tides, ice jams, drainage congestion and failure of flood control structures. Tsunami waves were generated in the Indian Ocean due to an earth quake in Sumatra, Indonesia on December 26, 2004 flooding the coastal areas of Tamil Nadu, Pondicherry, Andaman and Nikobar Island damaging the lives and properties of the people in the affected areas. In Tibet, due to breach in the artificial Parchhu lake formed last year due to damming of the Parchhu river by a landslide,flash flood occurred in the Sutlej basin of Himachal Pradesh and the threat of flood due to the bursting or rupturing of the artificial dam persisted for one year. However, during winters the water in the lake started freezing which reduces the chance of breaching of the artificial dam. But in the peak summer season of 2005, melting of frozen water of the lake and nearby glacier due to the heavy rains in the region mounted a huge pressure on the dam, causing breaching of the dam and the water blocked by dam flowed down to the river Sutlej that flooded the entire region from Khab in Kinnaur to Tattapani in Shimla, Himachal Pradesh. Other recent damages due to flooding are reported as: Uttarakhand Flood, 2013[1], Jammu & Kashmir Floods, 2014, Chennai Flood 2015, Gujarat Flood 2017. In the past extensive damages have been reported due to the flooding resulted from the structural failure. The failures of Machhu dam II in Gujarat and Morvi dam in Andhra Pradesh are some of the examples of flooding due to structural failure. A number of non-structural measures for flood management e.g. real time flood forecasting, flood plain zoning, Dam break flood simulation, flood hazard and flood risk mapping etc. have been suggested by the researchers. Such studies provide techniques and tools for planning the flood management programme and to prepare emergency action plan and acts to minimize the human intervention in the flood plain[2,3,4].

Drought usually occurs because of the deficient rainfall causing water scarcity in the region. Except some pockets of the North Eastern Region and Kerala every one part or the other faces the problem of the drought in India.Various short term and long term measures are taken in the drought prone areas for its management. These include managing the water by increasing the water availability through supply and demand management. Drought mitigation strategies have been adopted by the Central and State Governments in the drought prone areas[5]. Inspite of these measures taken in the drought prone areas, the losses due to the frequent occurrence of the drought are continuously on increase from year to year[6]. It indicates that there are some short comings in the implementation of drought management plans or management plans itself. Hence, various drought management strategies and plans are required to be examined and if necessary revised plans alongwith the implementation strategies may be developed keeping in mind the objective of minimizing the losses in the drought prone areas.

Causes of Drought

Rainfall deficit is caused due to the wide spread and persistent atmospheric subsidence arising from the general circulation of the atmosphere. From the results of the recent studies carried out on interactions between global circulations and drought, it has been observed that there is a substantial contribution of El Nino phase of the Southern Oscillations (ENSO) to summer droughts which adversely affects the food grain production. The increased concentrations of the atmospheric CO_2, methane and nitrous oxide have influenced the frequency of drought leading to the climatic change. The radiation balance of the atmosphere is disturbed due to indiscriminate use of gases like chlorofluoro carbon (CFC) and use of coke in thermal power plants resulting in increased temperatures due to Green House effect. As per the Inter-governmental Panel on Climate Change (IPCC) of the World Meteorological Organisation, an increase in atmospheric temperature of the order of 0.1 to 0.3 ^{o}C by 2010 and 0.4 to 2.0 ^{o}C by 2020 in South Asia is expected which may result in a decrease in the production of cereal by 5 to 15 % in the region[7]. Also, the impact of land use change, predominately because of the extensive deforestation in vogue since centuries, has significantly affected the various components of the hydrological cycle which leads to the frequent occurrence of droughts in the country.

Drought Prone Areas In India

About 100 million ha area receives inadequate rainfall,12% of the total geographical area has annual rainfall less than 400 mm, 35% or a little over a third of the country has rainfall below 750 mm. 56 million ha of the total gross cultivated area of the country is subject to inadequate and highly variable rainfall. The Ministry of Agriculture and the Irrigation Commission have identified the drought prone districts, the former have based their list on rainfall distribution, frequency of occurrence of drought and percentage of irrigation, while the latter have used the factors of rainfall and irrigation in the areas. The Drought Area Study and Investigation Organization set up in the Central Water Commission in 1975 combined the two lists of the drought prone areas identified by the Irrigation Commission, 1972 and the National Commission on Agriculture, 1976 and made further studies. The criteria adopted for this study was that drought is a situation occurring in an area when the annual rainfall is less than 75 percent of the normal in 20 percent of the years examined and where it has occurred in more than 40 percent of the years as chronic drought areas. From the historical perspectives, it is observed that except for very small pockets in the North eastern India and Kerala, there were no areas, which have not been affected by drought at one time or the other. Technical Committee on Drought Prone areas Programme and Desert Development Programme identified about 120 million ha of the country's area, covering 185 districts (1173 development blocks) in 13 states as drought prone[8]. Based on the historical records, Jaiswal and Kolte[9] reported 120 drought or famine like incidences in one or other part of the country between 1291 and 1979. During the 20th century alone, droughts of varied intensities occurred 28 times in India[10]. An abstract of frequency of occurrence of drought in different meteorological sub-divisions is given in table 1.

Table 1: Frequency of occurrence of drought in different meteorological sub-division

Sl. No.	Meteorological sub-division	Frequency of deficient rainfall (75% of Normal or less)
1	Assam	Very rare, once in 15 years
2	West Bengal, Madhya Pradesh, Konkan, Bihar and Orissa	Once in 5 years
3	South Interior Karnataka, Eastern Uttar Pradesh and Vidarbha	Once in 4years
4	Gujarat, East Rajasthan, Western Uttar Pradesh	Once in 3 years
5	Tamil Nadu, Jammu & Kashmir and Telangana	Once in 2.5 years
6	West Rajasthan	Once in 2 years

Impact of Droughts

Kulshrestha[11] reported the usual impact of agricultural drought in terms of loss of crops, malnutrition of human being and cattle, land degradation, loss of other economic activities, spread of diseases, and migration of people and livestock. Depending on the geographic incidence, intensity and duration of droughts, the crop losses of different magnitude have been reported. Predicted losses to agriculture in India were 50 % during the drought of 1957-58. The drought of 2002 resulted in 25 % and 16 % reduction in rice and oilseed production, respectively. Ramakrishna and Rao[12] observed that during the 1987 drought in India, the productivity of pearl millet dropped by 78, 74 and 43 % in rainfall zones of < 300, 300-400 and > 400 mm, respectively. Victor *et al.,*[13] reported similar reduction in the productivity of groundnut and millet in Andhra Pradesh during the drought. For eastern India, the loss in production of food grain due to drought averaged over 1970-96 has been estimated to be $ 400 million year^{-1}, which is equivalent to 8 % of the value of food grain production in the region[14]. The effect of drought was more pronounced on fodder availability as compared to that of food grains.

Apart from the natural causes (lack of rainfall) and the antecedent conditions (climatic characteristics, soil conditions, presence of groundwater), the interaction of the inhabitants (human and livestock) has profound impact on the growth of drought. It is not that only the farmers are adversely affected by drought but the entire society suffers due to rise in prices and additional taxation, to meet the national needs for import of food. However, the farmer is the greatest sufferer for it is this sector of society, which bears the brunt in terms of loss in production. Hence, there is a need for action to protect farmers from devastation caused by the droughts, primarily through national and also regional and international interventions[15].

Drought Management

Because droughts affect larger geographic areas than those occupied by administrative units such as districts, Tahsil or block, the ability of an individual administrative unit to respond effectively is affected by the actions of the people residing in the other districts in the drought area. The position of each community in this larger arena can be analogous to that of the individual in the community. Individual actions by each community can be counter productive to the policy best for the region as a whole. For one region, the solution may be the building of a reservoir on a stream that is the water source for other region downstream. As each community opts to resolve its water needs without regard to its neighbors, the stream can become an inadequate water source for all. The development of an administrative unit based water supply for all might be the best solution, but this may require an integrated basin development and management approach for better results.

A number of approaches based on either conservation and management of available water supply or reducing demand or to minimize impacts can be taken to mitigate drought consequences[16,17]. These are (1) Water Supply Management (2) Water Demand Management (3) Water Conservation (4) Hydrological Preparedness for Impending Drought(5) Restoration of Mined Aquifers(6) Research in Agro-meteorology (7) Remote Sensing and GIS Application (8) Decision Support System in Drought Management (9) Peoples Participation in Drought Management (10) Integrated River Basin Development and Management.

Drought Mitigation Strategy

Drought is indeed a many faceted natural disaster that leads to serious socio-economic impacts, which have long-term implications. It is in this context that development of appropriate drought management strategy is of great importance, for individual countries as well as through internationally initiatives[18]. Drought management is currently addressed by the following mechanisms and sectors[17,19]:

Governmental

- Policy issues, national, regional, and district level
- Rural development infrastructure
- Input supply, marketing and farm advisory services

Non-Governmental

- NGOs
- Rural institutions, local self governments
- Private sector
- Philanthropic organizations
- Community codes (tribes, herders)
- International aid agencies

Research and Development Institutions

- Weather forecasts
- Best practices for rainwater and soil management through linking on-station and on-farm research
- Contingency crop planning/mid season corrections
- Alternate land use systems

Flood Problems In India

In India, 75% of the annual average rainfall occurs during the monsoon season. During this monsoon the rainfall is highly non-uniform in time and space. The regions experiencing intense rainfall are affected due to flooding, whereas the regions having deficient rainfall face the problems of drought. There are incidents when one part of the country is experiencing flood while another is in the grip of severe drought. The flood problem varies from one river system to another. The rivers originating in the Himalayas carry a large amount of sediment, causing erosion of the banks in the upper reaches and over-topping in the lower segments. The Ganga-Brahmaputra-Meghana basin is one of the largest in the world. Flood is a common phenomenon in the Brahmaputra valley. All the districts of the Brahmaputra valley in Assam are inundated almost every year. An area of 30 lakh hectares out of 78 lakh hectares, i.e. about 45 per cent of Assam's total area, is flood-prone. In Ganga basin in general flood problem increases from west to east and from south to north. There is a problem of drainage congestion in the extreme western and north-western parts. The rivers such as Gandak, BurhiGandak, Bagmati and Kamla and other small rivers of the Adhwara Group, Kosi in lower reaches and Mahananda at the eastern end spill over their banks causing considerable damage. High floods also occur in the river Ganga in some of the years causing considerable inundation of the marginal areas in Bihar[20].

The main rivers of North West region are the tributaries of river Indus, namely Sutlej, Beas, Ravi, Chenab and Jhelum, all flowing from Himalayas. These rivers carry quite substantial discharges during monsoon season and also large volumes of sediment. Compare to the Ganga and Brahmputra river regions, the flood problem is relatively small in this region.

Floods also occur in peninsular river basins which comprise of the important rivers of Central India and Deccan river region including Narmada, Tapi, Mahanadi, Godavari, Krishna and Cauvery. These rivers have adequate capacity within the natural banks to carry flood discharge except in the deltaic region. The Tapi and Narmada are flashy and are occasionally in high floods[4].

The systematic records of the flood occurrences, the damages associated and the measures taken to deal with them are available only from the year 1953 by which time the gravity of the problem passed by this natural phenomenon came to be realised by the government.

Flood Management and Control In India

In our country flood management and control are necessary because the floods impose curse on the society. Structural measures involve the construction of flood control projects such as levees, dams and channel modifications. The general approach in the past has been one of adopting structural measures such as the construction of embankments and reservoirs. A number of dams e.g. DVC dams, Hirakud dam, Bhakra dam, Ukai dam, Nagarjuna sagar etc. have all contributed enormously to reducing flood damage along the rivers. In the case of certain rivers, where reservoirs could not be constructed to store flood waters due to various reasons, other measures were introduced. For example, in the state of Bihar and Assam, extensive embankments were constructed, while for the Ghaggar River in Rajasthan, flood waters were diverted into a series of depressions caused by the natural sand dunes. As more and more developments encroach the flood plains in India, the main thrust of current flood policy focuses on the non-structural flood management measure. Non-structural measures include regulation of land use in the flood plain, acquisition and removal of flood prone structures, restoration or protection of wetland areas, flood insurance, flood warning systems, and public information and education programs. These include both short term as well as long term measures.

Evaluation of Policies on Flood Risk Assessment and Management

After the unprecedented floods of 1954, the Government of India took several initiatives and constituted a number of Committees to study the problem of floods in the country[22]. Several significant initiatives had been taken by government agencies in the past for addressing the risk and vulnerability of India to floods. The important steps are:

- Policy Statement-1954
- High Level Committee on Floods-1957
- Policy Statement of 1958
- Ministerial Committee on Flood Control-1964
- Minister's Committee on Floods and Flood Relief-1972
- Working Group on Flood Control for Five Year Plans
- RashtriyaBarhAyog –1987
- National Commission for Integrated Water Resources Development-1996
- Regional Task Forces-1996
- National Water Policy-2002
- Disaster Management Act, 2005, (DM Act, 2005)
- National Environment Policy, 2006
- National Water Policy-2012

Non Structural Measures

Various non-structural measures are proposed for flood management. These include the real time flood forecasting, flood plain zoning, Dam break flood simulation, flood hazard and flood risk mapping etc. Such measures provide the information and input for planning the flood management programme to regulate the developmental activities on the flood plain and to prepare evacuation plan during the emergency period of the flood. These measures are also used for formulating the legislation and acts to minimise the human intervention in the flood plain. Some of the popular non structural measures are discussed in brief here under.

Flood Forecasting

Central Water Commission is monitoring flood situation in the country during monsoon by observing water levels/ discharges along the major rivers in the country and issuing flood forecasts to the local administration/ project authorities/ State Governments and the Home Ministry, G/o India; covering 148 low lying area/ cities and towns besides 28 reservoirs all over the country. The network is spread on ten major river systems viz. the Ganga & its tributaries, the Indus/ Jhelum, the Brahmaputra & its tributaries, the Barak, the Eastern Rivers, the Mahanadi, the Godavari, the Krishna and the West flowing rivers covering 72 river sub-basins, over 17 states viz. Andhra Pradesh, Assam, Bihar, Chhattisgarh, Gujarat, Haryana, Jammu & Kashmir, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Orissa, Telangana, Tripura, Uttarakhand, Uttar Pradesh & West Bengal, one Union Territory of Dadra & Nagar Haveli and National Capital Territory of Delhi. The Inflow Forecasts at 28 reservoirs are used by the dam authorities in timely operation of reservoir gates for safe flood discharges downstream as well as to ensure adequate storage in the reservoirs for meeting irrigation and hydropower generation demands during non-monsoon period. The forecast are disseminated using all types of communication means such as fax, wireless, phone, mob, SMS, email, electronic media, print media, social media, website, etc. Annually, over 6000 flood forecasts and advance warnings are issued by CWC regional offices across the country to the user agencies during floods. The overall accuracy of forecasts issued by CWC over the past years is around 97%.

Flood Plain Zoning

A model draft bill for flood plain zoning legislation was circulated to all the States by the Union Government in 1975. There seems to be some hesitation in most of the States to follow up the various aspects of flood plain management including possible legislation. The State Government of Manipur had enacted flood plain zoning legislation way back in 1978 but demarcation of flood zones has yet to be taken up there. Similarly Rajasthan has also enacted the legislation for flood plain management in the State[21].

Dam Break Flood Wave Simulation

The purpose of dam break flood simulation studies is to predict the flood characteristics such as peak discharge or stage, volume, and flood wave travel time of a dam break flood considering the failure cross-section and time of failure. The dam break flood may be routed through the river in the down stream and area of submergence may be evaluated. The information obtained from the simulation of the dam break flood are useful for the decision makers and the managers for preparing the evacuation plan in order to protect the life and properties of the people likely to be submerged due to the dam break flood. In India dam safety review panels have recommended to carry out dam break flood simulation studies for most of the major and medium dams. Some of the dams for which the dam break flood simulation studies have been carried out include: Gandhi Sagar Dam, Machhu II dam, Mitti dam, Bargi dam, Barna dam, Myntdu Leska Dam, Sriramsagar dam, Lower Maniar dam etc.

Glacial Lake Outburst Modelling

Glacial hazards relate to hazards associated with glaciers and glacial lakes in high mountain areas and their impacts downstream.Outbursts from glacier lakes have repeatedly caused the loss of human lives as well as severe damage to local infrastructure. Monitoring of the glacial lakes and extent of GLOF impact along the downstream can be done quickly and precisely using remote sensing technique[3,22,23].

Soft Computing Techniques in Flood Fore casting

The soft computing techniques e.g. artificial neural networks (ANN) and fuzzy logic have been documented as a viable alternative to conceptual models for input-output simulation and forecasting and usually allow for shortening the time spent in developing the model.The soft computing techniques e.g. artificial neural networks (ANN) and fuzzy logic have been documented as a viable alternative to conceptual models for input-output simulation and forecasting and usually allow for shortening the time spent in developing the model. Applicability of soft computing techniques in flood forecasting has been demonstrated through various studies[24,25,26,27,28,29,30].

Decision Support System for Real time Flood Warning and Management

Decision support system for issuing the flood warning and managing the flood in real time is an advance software which is capable of providing the information to the decision makers for taking the necessary measures for managing the flood in real time. Such system requires the spatial and temporal data bases which include the basin characteristics, hydro-meteorological variables, social and economical data etc[31]. DSS for real time flood forecasting for Bhakra reservoir, India system has been developed[2]. Further Flash flood management and dealing with the uncertainty in flood forecasting are important issues[32,33]. Simulation of reservoir inflow time series is very important for water resources planning purpose[34].Identification of rainfall trend and study of dynamics of the South West Monsoon in Indian Sub-Continent provides important inputs for decision making[35,36,37,38,39,40, 41,42].

Structural Measures

Over the centuries, a variety of structures have been evolved to mitigate the flood hazard. Their aim is to reduce flooded area, or depth of flood water, or flood discharge. Some of the structural measures which have been adopted in the flood prone areas of India include construction of reservoirs, embankments (dikes or levees) and flood walls, bypass and diversion channels to carry some of the excess flood water, and Improvement of river channels (enlarging discharge carrying capacity) etc.

Many medium and large storage dams in existence have helped in flood moderation in India. In many parts of the country construction of embankments is the most commonly undertaken in order to provide quick protection from floods. The major embankment projects taken up after Independence are on the rivers Kosi and Gandak (Bihar), Brahmaputra (Assam), Godavari and Krishna (Andhra Pradesh), Mahanadi[32], Brahmani, Baitarni and Subarnarekha (Orissa) and Tapi (Gujarat). Between 1954 to 2000, 33,630 km of new embankments and 37,904 km of drainage channels have been constructed.

Flood proofing measures taken up in the past consisted of raising of few flood prone villages, above pre-determined flood level and connecting them to nearby roads or high lands. Under this program, several villages were raised in Uttar Pradesh, West Bengal and Assam. In all 4750 villages have been raised above flood levels.

Inter-basin water transfer has been considered as a viable strategy for rectifying the regional imbalance in the availability of water. Large variation in the availability of water has created what normally referred to as a flood-drought-flood syndrome in the country. The proposed inter-basin water transfer scheme envisages construction of storage reservoirs on some of the main rivers and their principal tributaries so as to conserve monsoon flows for irrigation, hydropower and flood control. Inter linking canal system will be provided to transfer the surplus flows to the water deficit basins. Apart from various other benefits the interlinking scheme will also provide the flood moderation in the flood prone river systems.

Remarks

In different parts of India, extensive damages to the lives and properties are being reported due to frequent occurrence of floods and droughts every year. The factors causing flood in different regions of the country include intense rainfall, landslides, coastal flooding, cyclone, and drainage congestion, formation of artificial lakes in the hilly regions, ice jams, structural failure and Tsumani etc. Systematic studies are required to be taken up for understanding the flood and their characteristics alongwith the various factors (natural as well as man made) which are responsible for generating the floods. For the flood prone areas in the alluvial region, the study of the sediment transport phenomenon is also important in addition to the floods. Normally, structural and non-structural measures are taken up in the flood prone areas for managing the floods. Studies are required to be taken up to examine the efficacy of the structural measures before adopting these in the field. For this purpose, the mathematical as well as physical modeling studies are required to be taken up. Now a days, non-structural measures are being considered as more effective flood management measures. It would be appropriate to adopt a combined short term and long term strategies considering the structural and non-structural measures together. In this regard, a decision support system may be very useful for evolving the management strategies under different scenarios of flooding.

Drought is another hydrological extreme which require immediate attention by the planners and managers for reducing its impact on the society. At present most of the drought planning and management scheme are generally launched after the occurrence of the drought. There is no long-term plan and management strategies being practiced in the drought prone areas. Government and public lose interest in drought planning schemes as soon as the drought period is over. In this regard, the development of the decision support systems may be taken up for the monitoring, management and mitigation of the drought utilizing the advanced knowledge of remote sensing, geographical information system and artificial intelligence based systems. Such systems would support the decision-makers for adopting the short term and long term management strategies in the drought prone areas. For successful implementation of the drought management plans, people participation forms one of the important parts of the drought management strategies. In order to encourage the people participation, necessary steps may be taken up at political, administrative and technical levels. Publication campaign may be launched for supply and demand management, as a part of the drought management strategies, with the help of electronic and print media. Thus, there is a need to formulate the integrated approach for flood and drought management considering the various factors such as social, economical and political etc. and some unavoidable constraints.

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