J. Sc. & Tech. Univ. Peshawar, 2015, 39 (1), 23-35.

METHODOLOGICAL FRAMEWORK FOR FLOOD RISK ASSESSMENT

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Abstract: Flood risk assessment is compound, complex and multi-disciplinary process. The real time-series or dynamic flood risk assessment needs advance technology. Even with the use of advance technologies, the high number of variables and their complex inter-relationship always delimit the accuracy of flood risk assessment. This study is focuses on developing a framework for flood risk assessment. In this framework, a mechanism of understanding of flood phenomena; enlisting of variables of elements at risk, hazard, vulnerability and capacity; a procedure of inter-variables relationship; and generalization of the method of flood risk assessment are discussed in detail. Based on study analysis, the risk of a flood hazard is dependent on four major variables; causes and intensifying factors of flood; water surface run-off (magnitude of flood); elements at risk, vulnerability and capacity; preparedness, emergency response system and mitigation of flood. 42 important variables of elements at risk, hazard, vulnerability and capacity are identified with their attribute data and nature of inter-variables interaction. Seven steps procedure of inter-variables relationship for flood risk assessment is discussed in the study. Multidisciplinary approach is the prerequisite to calculate the interactive impact of each variable. A Geographic Information System (GIS) based generalized method of flood risk assessment is developed. For flood risk assessment, GIS provides the basic platform for database, number of variables analysis and model generation. This framework for flood risk assessment could be used effectively in decision support system (DSS) avoiding floods related damages.

Keywords: Flood, Risk Assessment, Modeling, GIS

Introduction

The devastating Floods–2010 affected more than 20 million people and 132,000 Sq. Km area of Pakistan. The intensity, duration and damages are unmatchable with all previous disasters, especially in the floods' history of Pakistan. It has been observed that the Floods – 2010 was the joint episode of flash and riverine floods (GOP, 2011). It exposed the lack of capacity of the institutions to respond to extreme hydro-meteorological events in the country. For effective disaster management, there is a need for comprehensive disaster coping strategy and decision support system. The modern technology like Remote Sensing (RS), Geographic Information System (GIS), Early Warning System, Emergency Response Equipment etc. play a vital role in providing this Decision Support System (DSS). The DSS provides a platform for gathering the information regarding disaster risk assessment, available disaster coping strategy, resources, level of risk and response

mechanism. The collected information in simple way is ultimately shown in disaster risk assessment model. Such accurate and scientifically sound disaster risk models that effectively support the DSS represents the whole scenario in such a way that is easily grasped by the line agencies is an important product of a disaster management research.

Disaster and its management is a continuum of inter-linked activities it has two major components: risk and emergency management (Fig. 1). Disaster management is increasingly more important to the society, and risk assessment is seen as an integral part of flood management (UNISDR, 2004; ADPC, 2008; GOP, 2010). Flood risk assessment is used for planning as well as for forecasting floods so that mitigating measures can be taken in time. Decision support systems (DSS) based on flood risk assessment are increasingly being used by disaster managers, engineers and scientists in disaster management (United Nations Educational, Scientific and Cultural Organization [UNESCO, 2010). The flood risk assessment serves this purpose accordingly. It represents the real world data in simplest form which could be verified through field observations/case studies. The flood risk assessment model visualizes the complicated data of flood risk assessment and flooding situation in simplest form for decision makers. Flood risk assessment has the capacity to show the impacts of the decisions for flood risk reduction. The flood visualization, incorporating the risk assessment process, testing of situation, using flood risk assessment model in DSS and testing the impacts of decisions for flood risk reduction are shown in Fig.2.

This study focuses on the framework for flood risk assessment. In this framework, the available options, associated problems, opportunities and local limitations in flood risk assessment are discussed. The components of available options for flood assessment are risk assessment techniques, GIS, RS data, analysis software, and hydrological models etc. The execution phase of flood risk assessment shows certain limitation of these technologies. The flood risk assessment is very complicated and dynamic phenomenon in which the interactive modes of variables are certainly changed with time as well as due to their cross dependency nature. For accurate flood risk assessment, multi-disciplinary approach is essential which is rarely practiced in less developed countries. As a result, the accuracy level of the parameters is decreased. Similarly, the GIS time-series/dynamic models have certain limitations particularly in case of flood risk assessment. The existing practiced method of GIS time-series/dynamic models are very difficult to use for developing countries like Pakistan due to nature of advance and high cost technologies involved. The better option for flood risk assessment is focusing on the multi-disciplinary approach and creating a database in GIS software environment. The flood risk assessment generated with GIS can be executed in other specialized software that generates time-series/dynamic flood risk assessment.

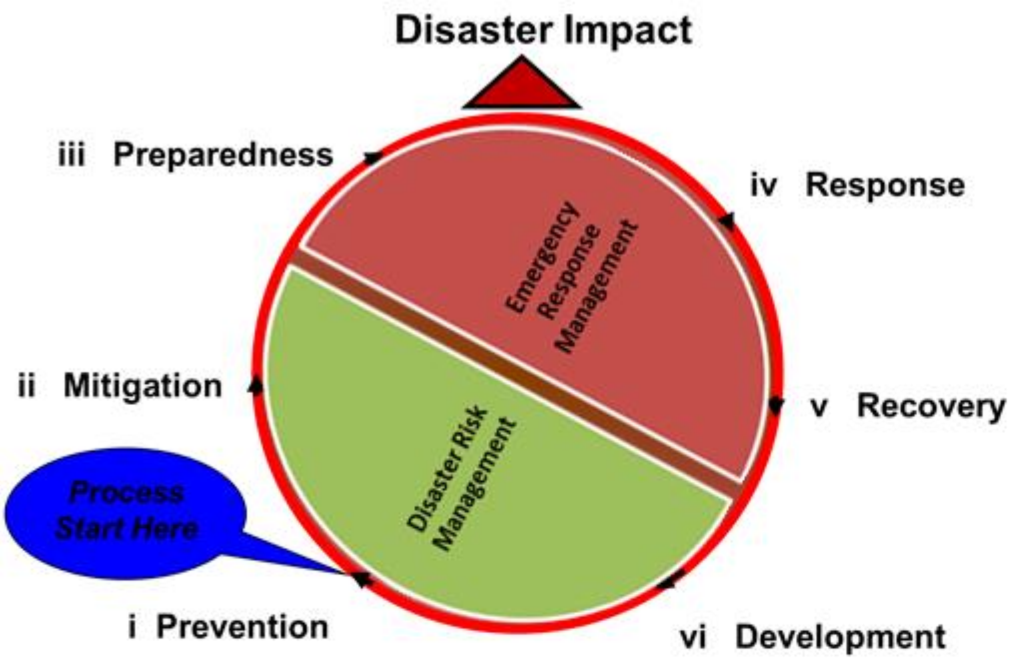

Fig.1. Disaster Management Cycle
Source: (ADPC, 2008)

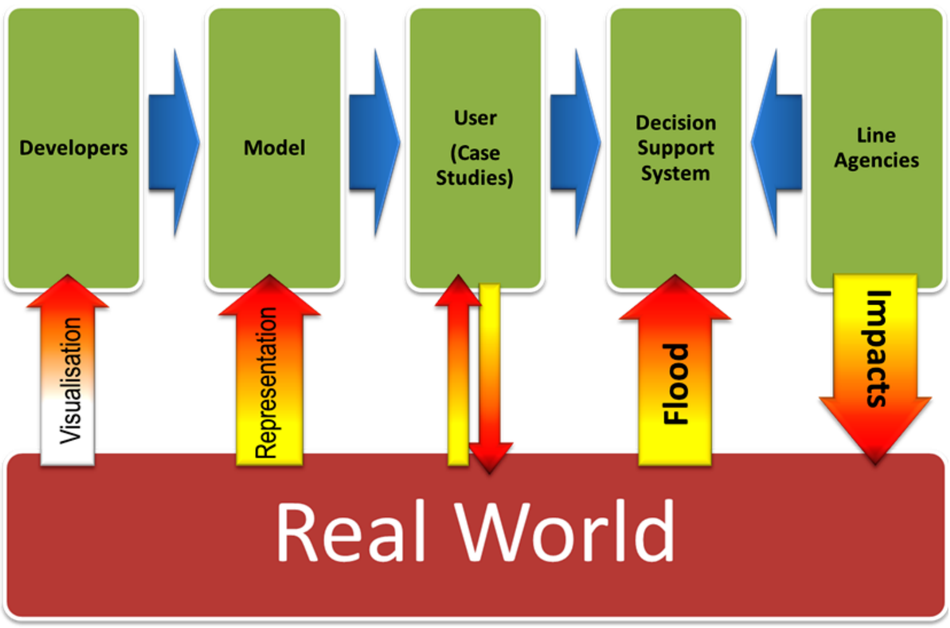

Fig.2. Flood Risk Assessment and DSS
Source: Data Analysis, 2011

Materials and Methods

The framework for flood risk assessment is developed in four major steps i.e. a mechanism of understanding of flood phenomena; enlisting of variables of elements at risk, hazard, vulnerability and capacity; a procedure of inter-variables relationship; and generalization of the method of flood risk assessment. In first step, disaster management system is studied to understand the structure and function of flood risk assessment. Flood risk assessment is required not only in risk management phases but also in emergency management particularly at preparedness and response phases. The basic essentials of flood risk assessment are studied to derive the structure of flood risk assessment. All major phases of flood management are further dived into sub-phases. From each sub-phase, the basic variables and their interrelationship in flood risk assessment are derived. In second step, variables of the flood risk assessment are identified and steps for risk assessment are devised. The flood risk assessment is based on the complex inter-relationship of flood hazard, vulnerability and capacity. All of the components of flood hazard, vulnerability and capacity are further dived into 42 major variables. The inter-relationship of each variable with flood risk assessment is formulated. The attribute data required for each variable is identified. Looking to huge number of variables and their attribute data list with complex inter-relationship, a procedure of flood risk assessment is devised. The procedure consists of six steps. These steps included data collection, level of data input, determining the type/level of hazard, inter-variable relationship, quantifying the inter-relationship, quantifying the elements at risk/area/population/level of risk and presentation of the risk. In final step, framework for flood risk assessment in GIS platform is worked out. The structure, workout and relationship with flood risk assessment of existing hydrological, surface run-off and coastal flood modeling are studied. Looking to the requirements of flood risk assessment, the ESRI Arc-GIS platform is studied and related analysis tool are identified. A single time event flood risk model is developed while using the ESRI Arc-GIS platform. A generalized flood risk assessment model has seven basic steps. Each of the steps is based on GIS platform. For quantifying the inter-variables relationship, multi-disciplinary approach is essential. For time series flood risk modeling, data availability and advance GIS platform are basic requirements. However, the structure and function of the same flood risk assessment could be used easily for real time series flood risk assessment.

Results and Discussion

Flood Management and Risk Assessment

The surface run-off, flooding, impacts and risk reduction measures are the components of flood management. These quential order and their inter relationship of flood management shows the mode of function of flood risk assessment. Each step is further dived into measures related to flood management. Incorporating all these measures into a model provide a base for understanding the mode of function of flood risk assessment (Fig. 3). The process of conducting a risk assessment is based on a review of both the technical features of hazards such as their location, intensity, frequency and probability; and also the analysis of the physical, social, economic and

environmental dimensions of vulnerability and exposure, while taking particular account of the coping capabilities pertinent to the risk scenarios (ADPC), 2008; Khan, 1993a; Khan, 1993b). The disaster risk is the probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions. Conventionally, risk is expressed by the following notation:

Risk = (Hazard x Vulnerability)/Capacity

Perception of risk of the local community is very important for risk assessment. However, it not necessary that they have the same level of understanding in which the risk may occur. Thereof the risk has three major components i.e. hazard, vulnerability and capacity which variably interact in a very dynamic and complicated way. The vulnerability is a set of prevailing or consequent conditions which adversely affect the community's ability to prevent, mitigate and prepare for or respond to hazard event. It is important to remember that a large part of vulnerability can be reduced through human capability for prevention or self-protection (coping strategies). The absence of coping strategies is part of vulnerability, and hence it has to be taken into account in the vulnerability analysis. On other hand, the capacities are strengths and resources that are present in individuals, households and the community which enable them to prevent, mitigate, prepare for, cope with or quickly recover from a disaster(Khan, 1993a; Khan, 1993b; [UNISDR], 2004; [ADPC], 2008)In fact, capacity almost works in opposite direction of the vulnerability progression.

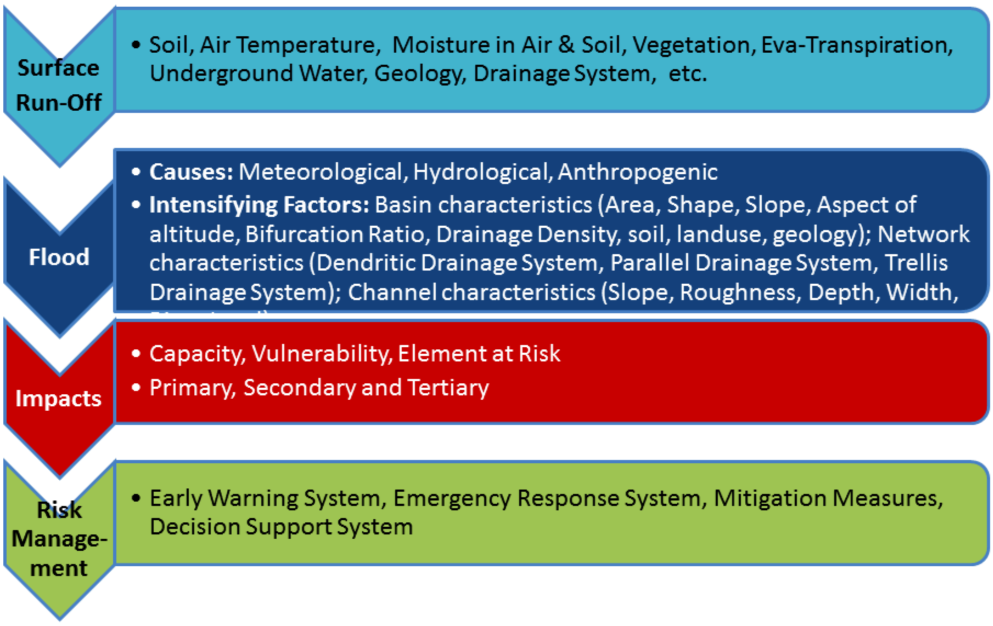

Fig.3. Mode of Function of Flood Risk Modeling
Source: Data Analysis, 2011

Flood Risk Assessment

Flood risk assessment defines the type and magnitude of flood hazards/disasters as well extent of damages that may occur. There are three essential components of the flood risk assessment process: probability of occurrence of a flood hazard at a specified severity level in a specified future time period; an inventory of those people or things which are exposed to the flood hazard and the degree of loss to each element, should a hazard of a given severity occur and the resources readily available to minimize the risk of the flood disaster (UNESCO), 2010; Khan, 2004). In first stage of flood risk assessment, 42 major variables of three major components i.e. hazard, vulnerability and capacity are listed. In second, their mode of interaction for flood risk assessment is identified. In final stage, the nature of attribute data is defined (Table 1& 2). The GIS is suitable platform for database of flood risk assessment. The major steps involved in flood risk analysis are the following:

Data Collection

Multiple techniques are available for data collection in which RS data, GIS (WMS, WFS, and WDMS etc.), Google Earth data, topographic maps, field survey and secondary data from line agencies are important one. The time series data is normally difficult for all variables due to high cost and technology involved in its processing and utilization. Similarly, the vulnerability and capacity assessment data also need intensive field work.

Level of Data Input

The collected data determine the level of data input. It is very important to understand that data availability and its utilization for risk assessment are two different stages. The utilization/input needs certain generalization of all variables for harmonic process and minimum risk of error. The generalization is a process through which data availability at different level of variables are made at almost similar stage. For example soil liquefaction is very important for surface-runoff, soil erosion and building strength etc. so that soil type and moisture data may be available at different spatial scale. After generalization, the level of data input is also defined.

Determining the type/level of hazard

Floods have three major types i.e. flash, riverine and coastal. Each type has different characteristics and implications due to different regional physical, social, economic and political structure. The intensity and duration of flood events are important parameters for each type of flood hazard. Although, flooding is time series event but for simplification, it is divided into such types which are certainly delimited by regional characteristics. Then each type is further divided into small regions (e.g. drainage basin, tributary torrent, distributary channel etc.) for which flood hazard intensity difference are measurable. On the basis of this analysis of flood hazard type, regional division and intensity level, a hierarchy of flood hazard in numerical form needs to be developed.

Inter-Variable Relationship

The most technical aspect of the risk assessment is inter-variable relationship stage. Each variable has different response for other variable at different stage of flooding and these variables are dependent on each

other. For example, the low height bridge is resource for a low flood, an obstacle for a mild flood and vulnerable element for a high flood. Similarly in flash flood region, the intensity of rainfall and soil has very complicated results. For slow and small duration flood, soil and vegetation cover provide protection to surrounding physical structure while for high intensity and long duration flood soil type and moisture increased the vulnerability of physical structures. Therefore, inter-variable relationship needs multi-disciplinary approach and research studies for standardization.

Quantifying the Inter-Relationship amongst Variables

The inter-variable analysis provides the nature of relationship for specific time, location and intensity of flood hazard. The nature of relationship has three aspects i.e. positive, negative or null. In other words, this analysis provides new variables that are to be quantified in the form of numerical values. The level and accuracy of quantification is directly dependent on the scale in which data is available. The process is rectified through similar events analysis. Similarly on a large scale, the nature and quantification of relationship is more scientifically sound and accurate. Whereas on small scale the general observation about the physical damage in itself explain the inter-relationship and its quantification.

Quantifying the Elements at Risk (Area / Population / Risk etc.)

On the basis of the analysis of inter-relationship amongst variables, the impact of flood hazard on a particular element i.e. area or population is provided in the form of numerical value. In this way individual value of all elements are merged into a single format that represents the overall risk of that particular hazard. It is very important to give proper method of representation for any extreme value comparatively of its surroundings. These extreme values represent the resource or vulnerability which is very important in emergency response management.

Interpretation of the Risk

The flood risk assessment process provides a comprehensive detail of geographic area and elements that are vulnerable to particular hazard. It also provides information regarding the available resources that are to be used in emergency response or risk management stages. The requirement details are different for an individual/community or line agencies of flood risk assessment. This best way of representation for disaster manager is a map that represents large amount of information in a simple and understandable way. Different scale maps, individual items/theme focus maps, tables and text description are some of the formats of risk interpretation.

Table 1 Flood Risk Assessment: Hazard Variables

No.	Variables	Inter-Variable Relationship	Attribute
1	Rainfall	Primary Cause	Quantity, Duration, Intensity, Area
2	Ice/snow Melt or Water Reservoir	Primary Cause	Quantity, Duration, Intensity
3	Underground Water	Causes and Intensifying Factors, Public Utilities & Services	Level, Pollution
4	Air Temperature	Surface Run-Off	Quantity
5	Humidity	Surface Run-Off	Quantity
6	Geology	Causes and Intensifying Factors	Rocks Type, River Bed & Course Material, Sedimentation, Orientation of Rocks etc.
7	Soil	Intensifying Factors, Surface Run-Off, Impacts (Erosion, Pollution, Agriculture etc.)	Type, Structure, Orientation, Area
8	Soil Moisture	Intensifying Factors, Surface Run-Off, Impacts (Erosion, Pollution, Agriculture etc.)	Quantity
9	Vegetation Cover	Surface Run-Off, Mitigation Measures, Erosion,	Types, Area
10	Contours/altitude	Causes and Intensifying Factors, Vulnerability & Capacity,	Quantity
11	Channel Length	Surface Run-Off, Intensifying Factors, Mitigation Measures	Quantity
12	Channel Width	Surface Run-Off, Intensifying Factors, Mitigation Measures	Quantity
13	Channel Depth	Surface Run-Off, Intensifying Factors, Mitigation Measures	
14	Sediment Load	Surface Run-Off, Intensifying Factors, Vulnerability	Quantity
15	Channel Bed Roughness	Surface Run-Off, Intensifying Factors,	Quantity (Formula)
16	Channel Curviness	Surface Run-Off, Intensifying Factors,	Quantity
17	Slope	Surface Run-Off, Intensifying Factors,	
18	Water Velocity	Surface Run-Off, Intensifying Factors, Vulnerability	Quantity (Formula)
19	Rise Time	Surface Run-Off, Intensifying Factors, Vulnerability	Quantity
20	Duration (Time)	Surface Run-Off, Intensifying Factors, Vulnerability	Quantity
21	Onset Speed	Vulnerability	Quantity (Formula)
22	Depth of Water	Intensifying Factors, Vulnerability	Quantity

Source: Data Analysis, 2011

Table 2 Flood Risk Assessment: Hazard Variables

No.	Variables	Inter-Variable Relationship	Attribute
1	Land use	Intensifying Factors, Surface Run-Off, Vulnerability, Capacity, Mitigation Measures	Types, Area, Location
2	Roads	Vulnerability, Capacity, Emergency Response,	Types, Length, Width, Height, Location
3	Railway	Vulnerability, Capacity, Emergency Response	Types, Length, Width, Height, Location
4	Electricity	Vulnerability, Capacity, Emergency Response	Types, Length, Height, Location
5	Telecommunication	Vulnerability, Capacity, Emergency Response	Types, Length, depth, Height, Location
6	Gas Pipe Lines	Vulnerability, Capacity, Emergency Response	Types, Length, depth, Location
7	Water supplies Lines	Vulnerability, Capacity, Emergency Response	Types, Length, depth, Location
8	Sewerage & Sanitation	Vulnerability, Capacity, Emergency Response	Types, Length, depth, Location
9	Public Buildings	Vulnerability, Capacity, Emergency Response	Types, Area, Location
10	Community Centres	Vulnerability, Capacity, Emergency Response	Types, Area, Location
11	Houses	Vulnerability, Capacity, Emergency Response	Types, Area, Location
12	Emergency Response Organizations	Capacity, Emergency Response,	Type of Capacity, Number, Equipment, Location
13	Volunteers	Capacity, Emergency Response	Type of Capacity, Number, Equipment, Location
14	Bridges	Vulnerability, Capacity, Emergency Response	Types, Length, Height, Location
15	Boats	Capacity, Emergency Response	Types, Number, Location
16	Other Resources	Capacity, Emergency Response	Type of Capacity, Number, Equipment, Location
17	Human Population	Vulnerability, Capacity, Emergency Response	Number, Area, Location
18	Livestock	Vulnerability,	Types, Location
19	Agriculture (Crops)	Vulnerability, Capacity,	Types, Area, Location
20	Culture Heritage	Vulnerability,	Types, Area, Location

Source: Data Analysis, 2011

Model of Flood Risk Assessment

The link between GIS and flood risk assessment has traditionally adopted a number of integration paradigms. It ranges from a very tight integration (or coupling) where all flood risk assessment occurs within the GIS, to less integrated approaches where GIS is used for data pre-processing, model parametric-station and post-event display and analysis via the use of common data interchange formats (Correia et al., 1997). Hydro-DSS is rapidly evolving and bridging the traditional divide between GIS and hydrologic modeling (Todini, 1999). Flood inundation predictions for risk reduction can range from aspatial, probabilistic statistical prediction of recurrence intervals and magnitudes to spatially explicit deterministic two-dimensional hydrodynamic models (Harper, 1998; Hubbert & McInnes, 1999). A lumped rainfall-runoff model, XSRAIN, was used in the first phase to describe the hydrologic behaviour of the watershed (Verdin & Morel-Seytoux, 1981). A physically based and fully distributed model, OMEGA, was used to describe the flood generation processes (Correia & Matias, 1991). *WetSpa* is a grid-based distributed hydrologic model for water and energy transfer between soil, plants and atmosphere. This model was further enhanced and adopted for flood prediction on hourly time (Liu et al., 2003). Zerger & Wealands (2004) developed a comprehensive system in which they linked database and hydrological models with GIS for Coastal Flood Risk Management (Zerger & Wealands, 2004).

GIS software encompasses a broad range of applications, all of which involve the use of some combination of digital maps and geo-referenced data amongst these, the ESRI ArcGIS is widely used in academia (ESRI, 2010). The hydrologic modeling functions in ArcGIS Spatial Analyst provide methods for describing the physical components of a surface. For real time dynamic flood risk models need sophisticated remote sensing data of rainfall, water reservoirs, air & soil temperature, and air & soil moisture etc. that are connected with model through GIS. In addition, the flow of water in each stream at different number of points is to be incorporated for the calculation of flow of water. Even the different sources of data input for calculation of flow of water in specific time period enable the system to identify the level and type of flood hazard. On large scale or higher number of calculation increase the accuracy of the model. The variables' inter-relationship analysis provides different parameters for model simulation. The geo-spatial nature of data analysis for flood risk assessment, simulate the flood risk model that has to be of different risk value for different places and objects. Once the models are produced for different hazards type/level and for different regions its risk assessment accuracy level is to be checked through previous studies. For errors and uncertainty, areas models research studies need to be carried out (Fig. 6). To simplify this whole flood risk assessment or using single model for all scenarios, simulation is beyond the capacities of present GIS system holding thus an open area for software engineering.

Methodological Framework for Flood Risk Assessment

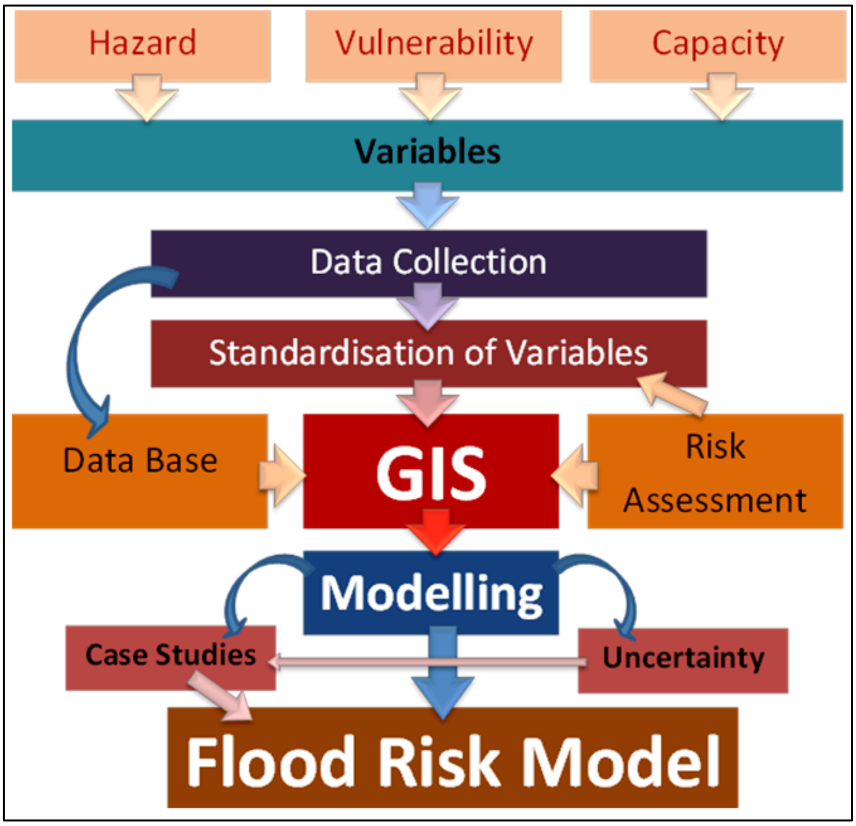

Fig.4. Model of Flood Risk assessment
Source: Data Analysis, 2011

Conclusion

Flood risk assessment models represent complicated risk assessment in a very simple form that is easily understandable for disaster mangers without knowing the basics of risk assessment or GIS. For effective disaster management, DSS is inevitable component which collect information and provides platform for selection of appropriate action to handle the situation skillfully. These flood risk assessment models are essential tool of DSS which, not only simplify the flood risk phenomena but also provides essential support for selecting different options for risk reduction measures. Advancement in technology innovated flood risk modeling. New platforms and methodologies are developed, advanced databases are linked and low cost geospatial data are currently available. The flood risk modeling has three major stages i.e. data collection, risk assessment and simulation of a model. Data for hazard, vulnerability and capacity is required for risk assessment which is further divided into 42 variables having a number of attribute data for each variable. Different sources for data collection are available. However, raster satellite imageries for DEM generation and Google Earth or Bing data for land use and geo coding of elements at risk are convenient for GIS database. The risk assessment is a multidisciplinary approach in which inter-relationship amongst all variables

is assessed and quantified. GIS provides suitable and convenient environment for this complex and compound variables analysis. ESRI ArcMap GIS provides platform for simulation of simple flood risk model of one time event process.

The real time-series or dynamic flood risk modeling needs accurate risk assessment. The high number of variables and their complex inter-relationship always delimit flood risk modeling even with the use of high technologies. For developing countries like Pakistan, the advance and high cost technologies for time-series or dynamic flood risk modeling is one of the major limitations. However, the accurate risk assessment through multi-disciplinary approach and flood modeling software are open arena for research and development. The available data sources along with GIS and risk assessment techniques provide a framework for flood risk assessment model that is to be enhanced and calibrated through further research studies.

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