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Evaluation of Adaptation Techniques Through Hydro-Dynamic Flash Flood Modeling under Climate Change Conditions

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Abstract: Climate change is a global issue, yet it is felt on a local scale with diverse effects on hydrological phenomena. Flash flooding events are characterized with rapid rise and fall with little or no advance warning, usually as the result of intense rainfall over a relatively small area. Across the world they are mostly mitigated by structural measures because of their destructive and un-predictive nature. Structural measures can never completely eliminate the risk of flooding and they are rigid and static against some fix design flood intensity. While the adaptation inherits the flexibility to cope with the extremities of climate change, survey data also show that the sub-populations likely to be affected by climate change are willing to adopt adaptation measures. This has motivated the flood managers to opt for adaptation techniques. The effectiveness of adaptation techniques yet has not been evaluated through hydrodynamic modelling. This paper focuses the assessment of these adaptation techniques with the help of 2D hydrodynamic simulation. This will also help in identification of affected areas and ranking of different adaptation techniques. Scope of this paper is limited to the assessment of flood zoning in a hill torrent area of DG Khan. Hydrological, social, geographical, meteorological and land use data were collected from different government departments, NGOs and reputed private consultants. Rainfall runoff and 2D hydrodynamic modelling will be done using GIS and HEC-RAS. Damage assessment and risk based evaluation was performed for evaluation of zoning regulations. Three zoning regulations schemes Z1, Z2 and Z3 were proposed and their impacts were studied. Results have shown that proposed adaptation techniques are cost effective if based on proper hydrodynamic modelling. It was also found that the adaptation become more reliable and extremely cost effective to deal the effects of climate change. In order to ensure public safety and avoid maximum property damage it is essential to consider adaptation techniques in policy making at governmental level. However, additional adaptive techniques must be considered along with a detailed ground survey in order to refine the adaptation techniques with respect to the mindset of local population.

Key words: Flash floods · Adaptation · Zoning · Mitigation · Climate change

INTRODUCTION

Floods are natural events which can never be prevented completely and there is always a possibility of their occurrence in future, hence you cannot achieve complete safety. It can be bifurcated into different types like flash floods, river floods, urban floods, coastal flooding, etc. [1]. Flash flood is a rapid flooding of water which often contains debris that is usually transported in steep streams [2, 3], but they may also occur in areas where debris is transported easily by heavy rainfall [4]. Their sudden nature, combined with their high capacity of carrying debris, makes them one of the most dangerous meteorological-hazards in most of the world, causing substantial economic and human loss [5, 6, 7].

The global outcome of climate-change on climatic variables, for instance, temperature [8] and precipitation [9] is evident [10]. Since the future flood risk is projected to increase, due to; 1) increasing rate and intensity of

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flooding, in the context of climate changes and 2) an increased vulnerability determined by the expansion of socio-economic activities in floodplains [11, 12]. Around the world flash floods are mitigated by engineering measures like dams, dykes and levees because of their brutal and un-predictive nature. It is, progressively, acknowledged that engineering solutions cannot alone mitigate the future flooding and obviously a shift in emphasis is indispensable from hard structural measures to an integrated mixed approach which comprises of structural and as well as non-structural responses [13]. They include flood-proofing, land-use planning, risk spreading (e.g. insurance), climate change mitigation, flood mitigation at household level, land use planningetc. [14, 15].

Literature Review: It is noticed that meteorological conditions and different land uses are strongly influenced on flash floods[16]. Flood management across the world, thus, is being progressively switchedto an integrated risk management approach which include measures that mitigate damage and exposure. It includes insurance, awareness programs, flood forecasting and warning systems, ecosystem-based adaptation (EbA) strategies, flood hazard mapping and zoning, protection of environmentally-sensitive area and both emergency and recovery policies for dealing flood damages [17]. Risk-based zone mapping is a critical component of extensive flood damage mitigation and management programs and has been extensivelypracticed worldwide in past years. Food-hazard maps play vital role and utilized as effective tool for contriving the future path of city development and are generallyutilized to identify the areas which are susceptible to flood [18, 19]. Flood zoning and hazard analysis for severalregionsusuallycomprise multiple factors/criteria that must be geographically associated to each other [20]. Socio-economic (vulnerability) and physical (hazard) factors are combined in multi-parametric approaches to generate flood risk maps. However, across the world existing floodrisk plans fail to accuratelyanticipate the dynamics of climate change and socio-economic development [21]. Even now, many countries have not prepared flood hazard maps. The main reason is limited accessibilitytosatisfactory data for the flood-hazard studies for instancehistorical flood events, hydrologic observations and topographical surveys of floodplains/channels [22].

Problem Statement: Inter-Governmental Panel on Climate Change (IPCC) has compiled research which implies changes in the events of floodoccurrence toward an increased risk of intense events. Structural measures are expensive and at times not feasible to construct because of land and economic constraints in developing countries; this research focuses on providing scientific method of their evaluation. Decision makers possibly may allot resources efficiently when planning for climaterelated disasters due to lack of additional information on the effectiveness and costs onvarious adaptation techniques. Hence, a comprehensive study is essential to evaluate the potential efficacy of several adaptation approaches in order toreduce flood risk.

MATERIALS AND METHODS

Multiple tiles of hill torrent of DG Khan were taken and collaged and clipped on Arc-GIS. The spatial digitization was done using Google Earth Pro. HEC-HMS was used for delineation of a number of catchments out of which Kaha's catchment was selected due to increased agricultural activity (it shares 19% to total agriculture of area) and high population density inside it. Hydrologic data was obtained from a number of sources as described in next section of the report. Hydrological and hydraulic behaviour of any watershed can be studied using a number of models. For predicting runoff from rainfall in the Kaha Hill Torrent HEC Geo-HMS and HEC-HMS models have been selected. The GIS model was then imported to HEC RAS in order to study the hydraulic behaviour of Kaha Hill Torrent to divide area into different zones.

Data Collection: For data collection, Digital Elevation Model of the area was downloaded from official website of United States Geological Survey. Other sources were also utilized for data collection.

National Aeronautics and Space Administration (NASA) has started a project i.e., the Shuttle Radar Topography Mission (SRTM) for topographical data. The most comprehensive highresolution digital-topographic database of earth can beobtained on a nearglobal scale using the data obtained by SRTM. It covered the data of digitaltopographic for 80% of earth's land surface having data points locatedon every 90x90 meters on a longitude/latitudegrid. The system is based on the World-Geodetic System 1984 (WGS84) datum. The development of Digital Terrain Model (DTM) of Kaha hill torrent has been done using this spatial data. The DEM of this area was used in GIS database which can be downloaded for free from official website of United States Geological Survey. It is.hgt format which is supported by a number of modelling software.

Software Modelling: Hydrodynamic modelling was done by following steps.

- For digitization, the detailed land use map of the area under study was prepared using Google Earth Pro and imported as .kml file for Arc-GIS database. Open Google Earth Pro and search for Kaha Hill Torrent's catchment on already imported GIS based map of Pakistan. Polygons were marked for each component e.g. homes, barren land and crops. Roads and rivers were marked using poly-line. This file was then imported on Arc-GIS.
- For hydrodynamic model, the data was imported from Arc-GIS and 2D mesh was prepared on the study area. Boundary conditions were given e.g. main river and end boundary. In connection withriver model a flood-plain network model was established by including the mechanism of flowtransferbetween the main channel and flood plain. The elevation-storageconnection for flood plain was establishedby land topography of flood plain, which further utilized for cross-section parameters.
- It is considered of utmost importance that model should be calibrated and verified. The calibration and performance evaluation of hydrodynamic model was performed before going for scenario analyses. Furthermore, important parameters of flood flow were compared, water level and discharge, for two sets of obtained data between the computational domain.
- Flood inundation simulations were performed for two design floods conforming to 25 and 50years of return periods. In the previous section, all the calibrated parameters were remained unchanged for scenario analyses. The maximum magnitude of flood was computed by superimposingestimatedmaximal water levels throughoutdata of land level. Flood depth at a specific location can be calculated by taking the difference between calculated maximum level of water and elevation of land at that specific point. The flood-maps produced in the ArcMap by algebraic subtraction of digital elevation model from the flood layer.

Flood Hazard Mapping and Zoning: Taking adequate measures to avertunsafezones or enforcingsuitableactions to protect society in such areas, initiatesto identify such areas. It is usuallyrelated to flood hazard mapping. Land use planning is executed to optimize the land usedepends on topographical, geographical, soil and climate characteristics. In the framework of urban city development, it refersbusiness, industrial and natural uses anddelineating land for residential. Developed countries such as the US have introduced the concept of flood zoning where land is categorized based on risk of inundation. This is followed by appropriate regulations to ensure that highly flood prone areas are spared from intensive capital investments and dwellers of that area are covered through flood insurance. The role of local public administration is to restrict approvals of new construction in flooding areas and resettlement.

Mainly, flood hazard mapping includes the trace of floods for synthetical events having specified return period (i.e. the 50-year flood zone). To determine the severity of a flood other than flood extent there are many indicators for instance rate of rising of the water, flow velocity and flood depth, which may be mapped as well. Many researchers suggested thatdepth and flood magnitude are considered as the most common ones used: flood magnitudedue to its characteristic, in single map, it allows depicting events with several intensities and flooding depth is another mostessential parameter affecting flood damage [15, 23, 24]. Policies related to zoning are mainly depended on quality and detail of hazard-maps specifying different zones. This may also cause a lot of serious complications, such as, delays in implementingprocess of a policy due tothe formation of detailed hazard maps. Furthermore, the final production of hazard-maps may become a politicized effort, where usually the local communities misjudging the consequences of hazard [23]. For this, maps on a scale of1:15000 or larger may be preferablehaving contours with interval of1 to 2 meters for hilly areas and at 0.5 meter for plain areas are needed. The reluctance of the states to endorseregulation on zoning of flood plain is primarily due to pressure of population and desire of other possible livelihood schemes.

One of the most practiced approaches in the modelling of natural hazard are frequency-ratio, analytical hierarchy process, fuzzy logic, logistic regression, artificial neural networks and weightsofevidence. Severalmethods have been utilized by many researchers for hydrodynamic modelling approaches to rendermapping for flood susceptibility. However, hydrological approachesinvolvehuge budget and fieldwork for thecollection of data. Tith (1999) studiedfloodplain identification by combiningGIS and HEC-RAS and concluded that comprehensive results have been achieved by combining these two geometric methods. By using GIS and HEC-RAS hydraulic behaviour of Babolrood river has been simulated and result showed that these hydraulic tools have great capability to simulate flood hazard zoning [25]. Geographic Information System is latest information technology which has been widely exercised to collect, accumulate, examine and represent a bulk amount of spatiallydistributed data in the form of layers. Modelling of flood by incorporatingGIS and hydrodynamic model can developmuch better results in the form of flooding and its outcomes.

Hazard, Vulnerability and Risk Assessment: The hazards can be estimated by usingdepth of flood and vulnerability was estimated based on assets at risk. Mainly, extreme events ranging from 25 to 50 years return periods are analysedto plan and design the water resource systems, mainly depended on purpose and structure type. Nevertheless, flooddisaster projects are usuallyplanned for a 100-year return period.

Risk area zoning and assessment:

- The first step in the classification is to recognize three zones mainly depended on their inundation probability:
- Zone I – low probability: annual probability of flooding on land is less than 1 in 1000 (<0.1%) annually.
- Zone II – medium probability: annual probability of flooding on land is between 1 in 1000 (0.1%) and 1 in 100 (1%) annually.
- Zone III-a – high probability: annual probability of flooding on land is greater than 1 in 100 (>1%) annually.
- Zone III-b – the functional floodplain: At times of flood the water will flow or be stored on this land.

The development is characterized in following categories:

Essential Infrastructure: Routes for evacuation and strategic quality infrastructure

Water Compatible: Water-transmission and flood mitigate structures

Highly vulnerable: Caravans, emergency services and hazardous materials

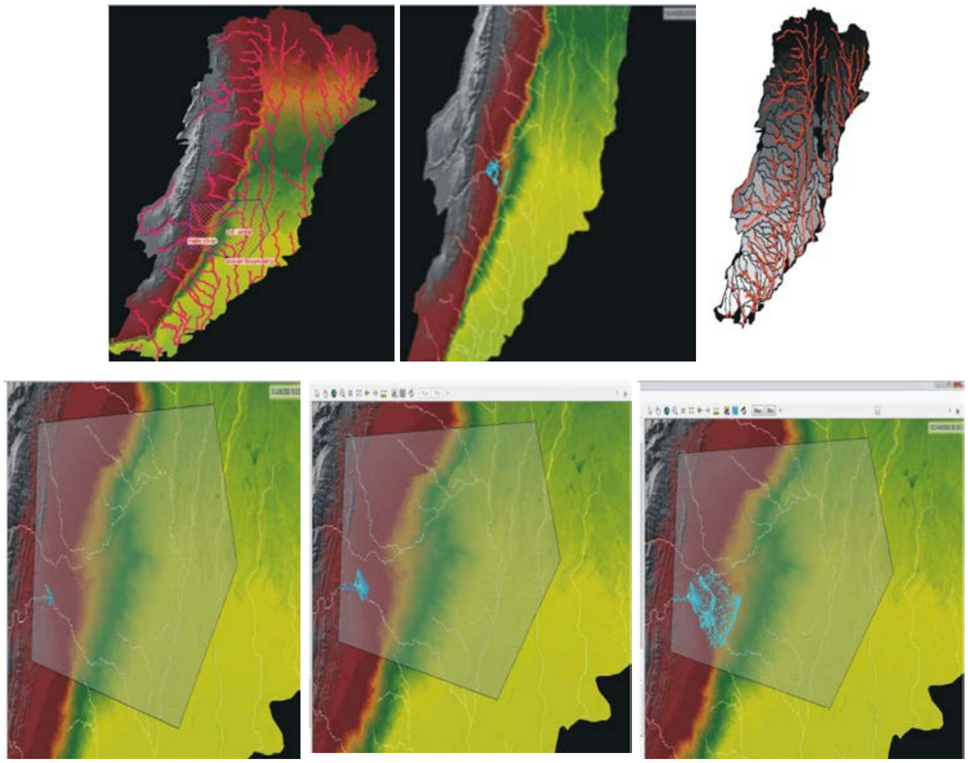
Moderately Vulnerable: Dispensaries, hospitalsand hotels

Least Vulnerable: Offices, shops and crops

RESULT AND DISCUSSION

Results have shown that proposed adaptation techniques are cost effective if based on proper hydrodynamic modelling. It was also found that the adaptation become more reliable and extremely cost effective to deal the effects of climate change. In order to ensure public safety and avoid maximum property damage it is essential to consider adaptation techniques in policy making at governmental level. However, additional adaptive techniques must be considered along with a detailed ground survey in order to refine the adaptation techniques with respect to the mindset of local population.

The proposed development is categorized as ‘acceptable’, ‘subject to an exception test’ or ‘unacceptable’ according to the vulnerability of development and the inundation probability (Table given below). The development is reclassified as acceptable or unacceptable with the help of outcome of the exception test. To be classified again as acceptable, the exception test should haveexplained that improvement (a) provides broader sustainable advantages that balance flood risk, (b) is on formerly developed land and no reasonableoptions on formerly developed land are existing and (c) a comprehensive flood-risk assessment must have shown that development will not enhance flood-risk to another place and where possible will mitigateoverall flood risk.



Catchment Area of DG Khan and Flood Simulation

Zone	Essential infrastructure	Water Compatible	Highly Vulnerable	Moderately Vulnerable	Least Vulnerable
I	✓	✓	✓	✓	✓
II	✓	✓	Exception	✓	✓
III-a	Exception	✓	x	Exception	✓
III-b	Exception	✓	x	x	x

CONCLUSIONS

Hydrological and Hydraulic Analysis of DG Khan watershed has been carried out by using combination ofdifferent models and software's including Arc GIS.Peak discharges of 25, 50 years return periods was estimated 69, 821 cusecs and 76, 657 cusecs respectively using HEC-HMS model. Model calibration shows that results are within the safe limit of 8%.The primary contribution of this research is the assessmentofflood hazard and risk in DG Khan city. This assessment has never been done before inthis area.An intensemitigation system and floodcontrol is necessary for this city.The significance for flood managementof each area must be based on the relevantsequence of risk level.The results shown herein specifyuseful information relatedto degrees of hazard, vulnerabilityand risks for various parts of the DG Khancity flood-plain. The severeand high-riskzones were nominatedalong the DG Khan city, especially in urbanareas, while the medium and low-risk zones werefoundfar from the river banks. Several risk zoneswere securedwithroad embankments and highways.Risk-free zones were in higher-elevationareas. The current paper also identified high-risk areas forpriority-based flood management.

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