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FLOOD DISASTER RISK MANAGEMENT FOR A PROJECT SITE IN INDIA UNDER THE CHANGING CLIMATE

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ABSTRACT

Flood is one of the most damage causing natural disasters in the world. Developing methodologies for minimising the sufferings as well as reducing tangible and non-tangible losses due to floods assumes a great significance. Further, due to anthropogenic changes, natural periodicity of the global energy and water cycles and impact of climate change, estimation of design floods, determination of safe-grade elevations and design of external and internal drainage systems for important project locations, such as nuclear power plants, thermal power plants and other important industrial complexes becomes a challenging task. In this paper, safe-grade elevation is estimated and internal and external drainage systems are designed for an important project site lying in north India. Design storm is estimated using the frequency analysis of daily rainfall data while synthetic unit hydrograph computed for various watershed using the catchment physical characteristics estimated by terrain analysis in ARC GIS. Flow model is developed using a coupled 1D-2D flow model considering the various sources of flooding around the plant site. The maximum flood elevation for critical case of flooding with adequate safety margin provides the safe grade level for the plant site and further used as boundary condition for design of local drainage system.

Keywords: *Flood disaster, synthetic unit hydrograph, rainfall frequency analysis, probable maximum flood, hydrodynamic flow, dam break analysis, safe-grade elevation, climate change.*

INTRODUCTION

The flood risk evaluation requires understanding of climatological and hydrological conditions (causing factor) along with the terrain characteristic (elements on risk). With continuous advancement in computational capability and public domain terrain data, the hydrological and hydraulic modeling approaches have also been attempted widely for flood hazard assessment (Anselmo et al. 1996; Machado and Ahmad 2007; Merwade et al. 2008; Chen et al. 2009; Ghoneim and Foody 2013). The site-specific effective and efficient flood damage reduction measures can be developed on the basis of local flood risk assessment considering all possibilities causing flood at a specific site. In 2D flow simulation, the floods of various exceedance probabilities are transformed into more useful and perceivable information such as flood depth and duration, flow velocity, etc. which in turn are used to quantify the hazard in spatial domain is a key factor in estimating the safe grade level for important installations as well as deciding the top level of flood protection works.

STUDY AREA

The study area is located in Northern India where an industrial plant is proposed. The area is a flat terrain marked with absence of well defined natural drainage system in most part. The nearest natural drainage exists in the northern part, while the plant site is near the ridge line of adjacent southern catchment (Fig. 1). The area is low relief terrain of high agricultural productivity where irrigation demand is fulfilled through the canal system. The branch canal B1 and feeder canal F1, both off-taking from the Main Canal M1, are running parallel and join together in their tail ends. The plant site is located on southern side of the branch canal B1 and feeder canal F1 at their tail end. The breach in the canals are reported frequently, and in addition to local intense rainfall events, are the major source of flooding in the area. The ground elevations range from mean sea level (msl) RL 209.37 m to 226.93 m. The canal is running towards the north boundary of the plant site. The various source of flooding in and around the plant site includes the spilling of the natural river, flooding due to failure/ breaching of main canal M1, branch canal B1 and feeder canal F1. Flooding due to local site rainfall and off-site precipitation routed to the site through drainage network have also been evaluated. The flooding due to natural drainage, flowing east to west, is about 26 km north of this site and is entirely in adjacent sub-basin is ignored for two reasons, firstly it is in adjacent basin and secondly alignment of main canal also prevents the spilling towards the plant site. Moreover, a major dam (with 222.5 m height and 8004 MCM storage capacity) is located on a river further north of the plant site for which dam break analysis has been carried out separately.

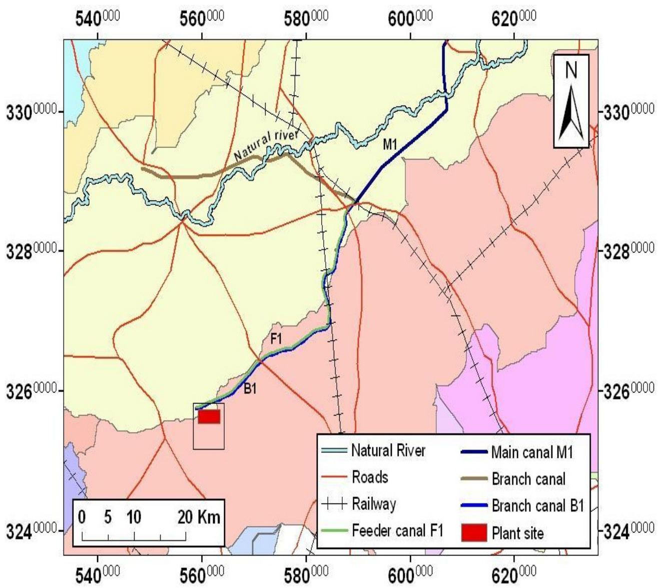

Fig. 1: Location map of the study area. Polygons of different shades are the catchments. The plant site is close to ridge line of the catchment (Mani et al. 2014).

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METHODOLOGY

The major analysis carried out in the study includes; design flood estimation, dam break analysis, flood simulation analysis and design of local drainage system. Design flood has been estimated using six different methods viz. at site rainfall frequency analysis using L-moments, regional rainfall frequency analysis using L-moments, probable maximum flood (PMF) estimation from probable maximum precipitation (PMP), rainfall frequency analysis based on EV1 distribution, approach based on CWC and regional flood frequency analysis based on L-moments. Dam break flood wave simulation is carried out using 1-D hydrodynamic flow model, MIKE 11 for an existing dam at an upstream location. Flood inundation modelling due to catchment flooding, local site rainfall and breach in nearby canals are simulated in coupled 1D-2D flood model in MIKE FLOOD. The river cross sections are extracted from the satellite (Cartosat-1 of Indian Remote Sensing Satellite) based DEM which is also used for generating the floodplain bathymetry. For plant site the detailed topographical survey data are also available and has been used for flood inundation analysis. For design of site drainage system, again coupled 1D-2D flow model has been used. The drains are proposed based on the plant layout design and the terrain topography. Open channel drains are designed for 100-year return period rainfall and its adequacy has been evaluated for 1000 year return period rainfall in maintaining the flood level below the proposed safe grade elevation for the plant site. The methodologies for design of drainage system for the plant site may be divided into two parts; firstly computing the total discharge that system requires to drain off and secondly designing the drains of required capacity and affordable maintenance. The discharge is computed from the design rainfall. In this study, the MIKE 21 model is used for transforming the rainfall into discharge. The trapezoidal drains along the natural slopes have been proposed along the roads given in the plant layout maps. The Manning formula is used for design of the drains. The flows in the drains and canal are 1-dimensional while the overland flow in MIKE 21 model is 2-dimensional. The two flows are coupled in MIKE FLOOD and the adequacy of the designed drains has been evaluated.

RESULTS AND ANALYSIS

In the L-moments approach robust frequency distribution is identified using the L-moment ratio diagram and the z_i-statistic criteria based on the comparative study of twelve frequency distributions: viz. Extreme value (EV1), General extreme value (GEV), Logistic (LOS), Generalized logistic (GLO), Normal (NOR), Generalized normal (GNO), Uniform (UNF), Pearson Type-III (PE3), Exponential (EXP), Generalized Pareto (GPA), Kappa (KAP) and five parameter Wakeby (WAK) (Kumar and Chaterjee, 2005). As the project site is located in an unaguaged catchment, synthetic unit hydrograph has been derived for convolution of the long term rainfall data of each of the six raingauge stations of the study area (CWC, 1984). The digital elevation model is prepared for the upstream catchment of the project site using the topographic levels and contours. Terrain analysis has been carried out in HEC-GeoHMS 5.0. For this purpose, the catchment characteristics viz. Area of the catchment (A) = 2,190 km^2, Equivalent stream slope (S) = 0.229 m/ km and Length of the main stream (L) = 131.56 km are obtained from DEM using. Based on the comparison of the six methods, it is observed that highest value of peak flood is estimated to be 8032.77 m^3/s for the PMF hydrograph resulting from 2-day PMP. The peak floods for 100 year and 1000 year return periods rainfall of the 2 day duration are estimated as 4135.47 and 8016.15 m^3/s respectively. The comparison of flood hydrographs for 1000 year returns period and PMF of 2-day duration is shown in Fig. 2. Considering an increase of 15% in the annual 2-day maximum rainfall due to climate change, the 1000 year return period flood is estimated as12581.88 m^3/s.

Dam break flood wave simulation is carried out using 1-D hydrodynamic flow model, MIKE 11 for an existing dam at an upstream location. Though the dam is located in the adjacent catchment, for its huge size and capacity, it is very crucial to know the extent of inundation and its impact on the plant site location. Though 1-D flow simulation is carried out for the dam break simulation, the cross sections are extended into floodplain to compute the maximum flood extent. The overlay of the dam break inundation over the plant site location in ArcGIS to assess the effect of failure of the dam at the plant site. Fig. 3 show the synoptic view of the inundation and infers that the plant site is far away and does not have any effect due to failure of the dam.

The flow in river and canal as well as breach in canal is simulated in MIKE 11 while the overland flow in floodplain is simulated in MIKE 21. In MIKE FLOOD, when MIKE 21 model is coupled with MIKE 11 model, the cells corresponding to River1 is blocked out to avoid double conveyance in the coupled 2-D simulation. The lateral links are created on both banks of river1 while standard links have been assigned for breach locations in F1 and M1. Grids covering the plant site are identified and a time series precipitation grid file has been generated. The rainfall values corresponding to 100 years, 1000 years return period and PMP are assigned for MIKE 21 model. Further the isohyets are lagged sufficiently so that the maximum inundation may occur when precipitation event coincides with either canal breaching or catchment flooding. This is done to ensure that the peak of PMP merges with peak of canal breach outflow. The flood model is simulated for various combinations of flood event to obtain the time series of flood depth and flood level. The critical case of flooding is due to PMF in catchment, PMP at local site and breach in F1 at bankfull condition produces the maximum flood depth of 1.1 m and RL 218.00 m as maximum flood level. The inundation map for this flooding condition is shown in Fig. 4. The figure displays the maximum water depth in a grid irrespective of its time of occurrence during the entire simulation period. The inundation patter near the plant site is shown in **Error! Reference source not found.**. In this figure, the dotted lines are the ground contours and the solid lines are the maximum flood depth contours. This figure shows that the maximum inundation of about 1.10 m occurs around the breach location on the north-west boundary of plant site where the ground elevation is of the order of 215.28 m. Hence, the maximum flood level (from mean sea level, msl) at this location is 216.38 m. It is also observed from this figure that maximum flood elevation (from msl) on the eastern border of plant site is of the order of 218.0 m, while the flood depth is only 0.1 m. Hence the value of maximum flood level in the entire plant site is not uniform and varies from grid to grid. This is due to the fact that the flooding due to local site rainfall produces inundation and is dependent of local topography, otherwise the inundation due to breaching only would generate the almost uniform flood depth within the smaller plant site. Impact of climate change may result into change into hydrological cycle. Generally the rainfall is increased by 15% to account for the climate change. The maximum flood depth in this case increases to 1.17 m which is only 7 cm higher than the flood depth for earlier case at the same location. Similarly, the maximum flood level for increased rainfall is RL 218.25 m along the east boundary of the plant. This is about 0.24 m above the maximum flood level estimated for the earlier case. Further, keeping safety margin of 1 m, the safe grade elevation is estimated as RL 219.25 m (~RL 219.3 m) for the plant site. Two alternative flood protection measures are suggested to prevent flooding at the plant site are: (i) the land formation should be of the level based on the computed maximum flood elevation for the severe most flooding scenario and considering free board of 1.0 m. This contour plan will result into development of land to safe grade elevation of all the grid points, where safety related plant structures, systems and components are to be constructed; while, the general topography of the plant site is retained in other areas. This would facilitate in designing drainage system for runoff generated from local site rainfall; (ii) a flood protection wall / embankment along the West, North and East boundary of plant site is to be constructed as shown in Fig. 6.. The area covered by safety related structures, systems and components shall have safe grade level of RL 219.30 m, which is 1.00 m above the maximum water level arrived at plant site due to critical case of flooding considering future climate change scenario

The 10 m x 10 m grid size DEM or the plant site based on topographical survey has been used for terrain analysis in ARC GIS using ARC Hydro tool. The drainage pattern and the sub-catchments have been delineated as shown in Fig. 7. The figure shows that three sub-catchment namely (1), (2) and (3) exists within the plant site with their catchment area as 168 ha, 36 ha and 388 ha respectively. The general ground slope is towards south and south west. Based on the topography and natural drainage pattern, the storm water drains have been proposed are also shown in this figure. The drains have been proposed to utilize the natural gravity to facilitate the accumulation of water at an existing reservoir from where the water would be lifted up and drained in the nearby canal. Further the plant layout has been considered while proposing the drain alignment. All the drains have been proposed along the roads in the plant site plan. Thus the main drain appear like garland drain along the peripheral road of the plant.

The preliminary designs of drains are performed for design basis flooding condition which includes the local site rainfall of 100 year return period and full breaching in F1 canal. Later on the adequacy of designed drains have been evaluated for passing of 1000 year rainfall with 15% increase for climate change scenario. The contours of maximum flood level are shown in Fig. 8. It is to be noted that the rainfall on covered installation of plant is routed directly in the nearby drains and therefore no inundation is shown in the figure for those locations. In MIKE FLOOD the banks of the drains are hydro-dynamically linked with the grids. When the rainwater impinges on the grids it accumulates over there and moves along the slope and then moved towards the drain through these interlinked grids. In the downstream directions more and more water accumulated from the land surface and thus the discharge increases. The discharge variations in a specified drain over time for the design basis flooding scenario are plotted in Fig. 9.

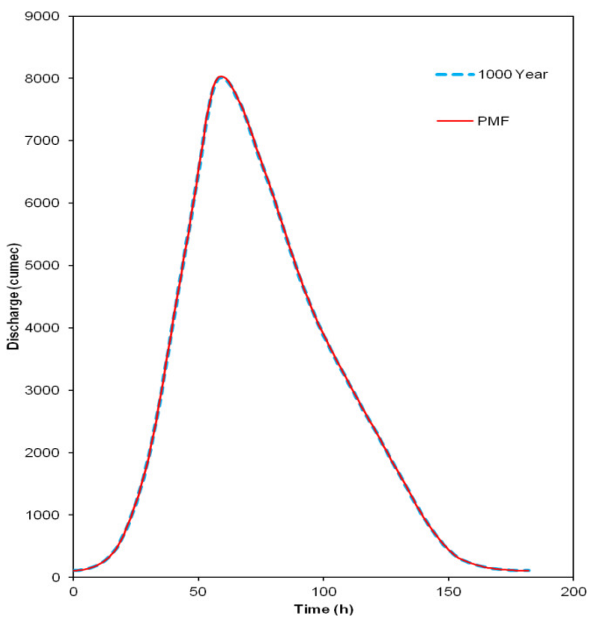

Fig. 2: Comparison of flood hydrographs for 1000 year returns period and PMF.

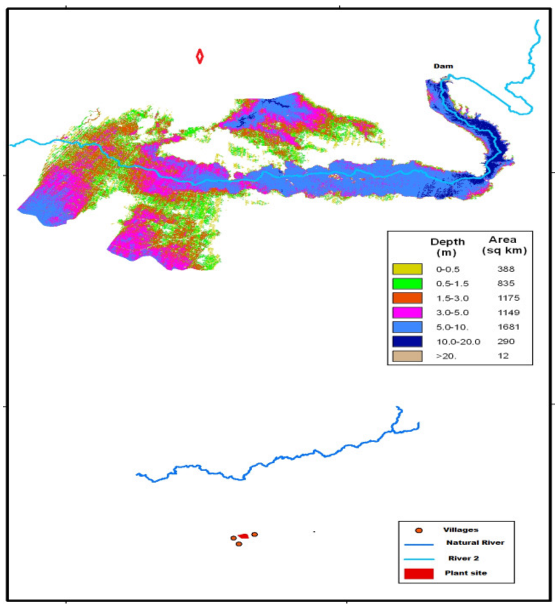

Fig. 3: Inundation map for upstram dam break and project site.

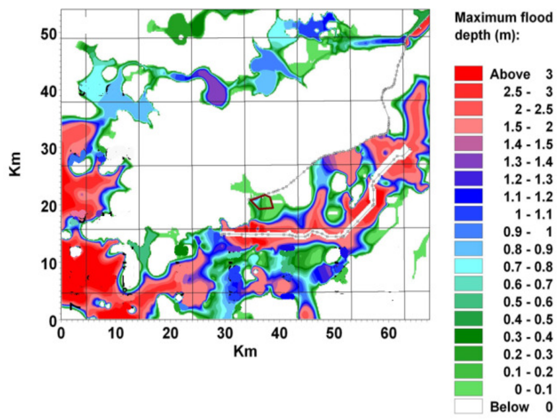

Fig. 4: Inundation due to critical case of flooding.

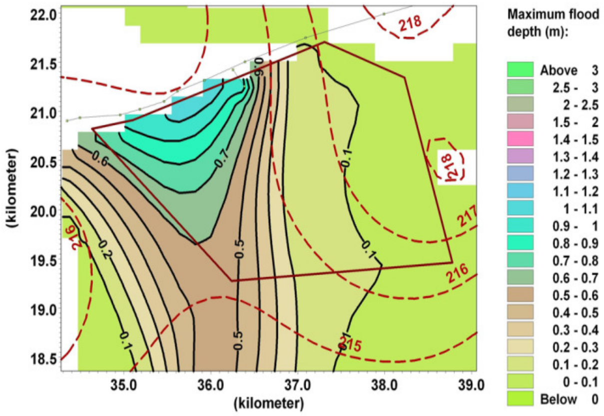

Fig. 5: Maximum inundation near the plant site.

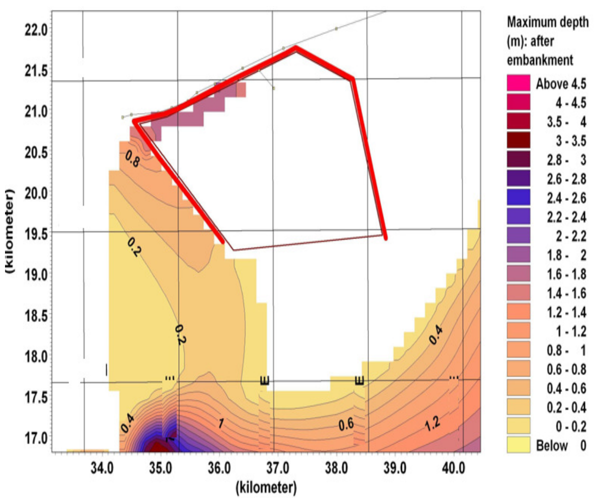

Fig. 5: Maximum flood inundation depths after construction of embankment.

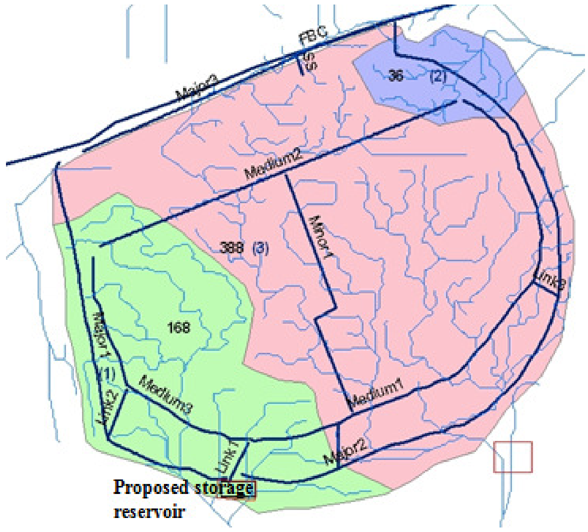

Fig. 6: Layout of proposed drainage system for the plant site.

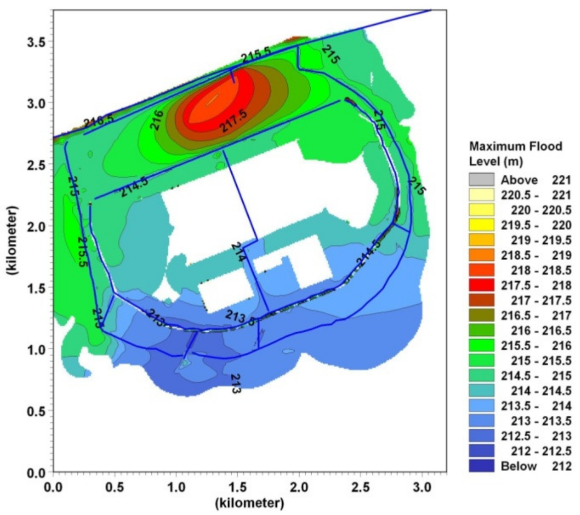

Fig. 7: Maximum flood level at plant site for design basis flooding event

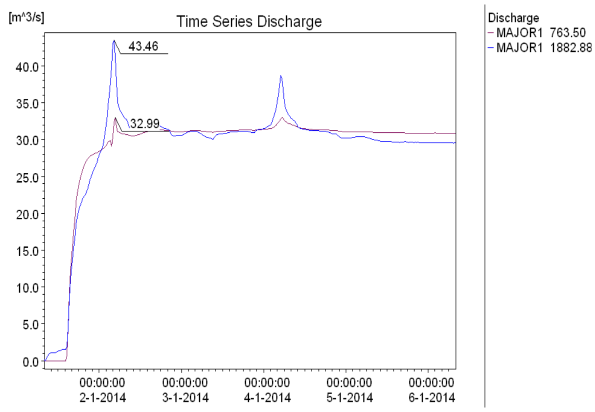

Fig. 8: Maximum discharge generated in a drain for design basis flood event

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