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APPLICABILITY OF IRIC (NAYS2DFLOOD) FOR THE PREDICTION OF FLASH FLOOD INUNDATION AREA OF BALKHAB RIVER

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Abstract - Flood hazard is a destructive environmental phenomenon. The livelihoods of many people from undeveloped countries are in areas surrounding flood plains, which suffer greatly when flood disasters occur. As a result, there is a seriously need to predict the flood inundation and morphological change of a river to mitigate the devastating effects of flooding. Numerical modeling techniques play a vital role in such studies due to their use of both hydrologic and geographic parameters to allow the assessment of risk to life and property in the floodplain, and prioritization of the maintenance of existing flood defences and construction of new protection projects. In this study Nays2DFlood has been applied for simulating flood inundation around the Balkhab River, an important river for drinking water and the agricultural sector in northern Afghanistan. The simulated results for the Balkhab River show considerable agreement with the observed flooding area. In this study, Nays2DFlood solver using globally available topographic data is determined to be a useful tool for identifying and delineating the flood vulnerable area as a fundamental step in the development of spatially accurate hazard maps.

Keywords - Nays 2D Flood, topography data, flood inundation, flood plain, river flooding, Afghanistan.

I. INTRODUCTION

Flooding is one of the most dangerous natural disasters and sometimes brings irreparable damages to the many people who are living on flood plainsin rural areas.Most of the hydraulic structures along rivers are in needof acomprehensive study for flood prediction, and formany rivers there is not sufficient observation data of flood inundation available. There is a need for a predictive model to determine areas and resources for flood inundation. These models can range in complexity from simply intersecting a plane representing the water surface with a digital elevation model (DEM) of reasonable resolution to give the flooded area. Digital Elevation Models are the most significant data source for flood inundation analysis and spatial resolution has a considerable effect on the results of the simulation [1], [2]. Recently, the application of high spatial resolution DEM data in flood inundation mapping and analysis has attracted much attention from researchers [3], [4], [5], [6], [7]. Afghanistan is a mountainous country with heavy rainfall and high amounts of snow-meltcausing periodic threats of flooding. Afghanistan is highly prone to intense and recurring natural hazards, including earthquakes, floods, flash floods, landslides, avalanches and droughts. Every year in Afghanistan,these natural disasters result in many fatalities and devastation to houses; as a result, many families are forced to immigrate elsewhere to rescue themselves and their children. For every 1 million inhabitants, 1,150 people die in Afghanistan, with 50 percent of these fatalities being from geophysical- and weather-related events [8]. This study aims to use iRIC Nays 2D Flood solver and globally available DEM data to model the potential flooding of a river located in an agricultural area of northern Afghanistan and to validate the results with qualitative data collected from local sources.

II. AREAOF STUDY

Balkh is located in the northern of Afghanistan, covering an area about 1684 square km and a population of 1.271 million people in 2014 (population density of 180/km^2) [9]. Theprovince on the north separates Afghanistan from the Tajikistan, Uzbekistan and Turkmenistan and has a border with the Kunduz province in the east, Samangan and Sari Pul provinces in the south and south-west and Jowzjan province in the west, Fig. 1.

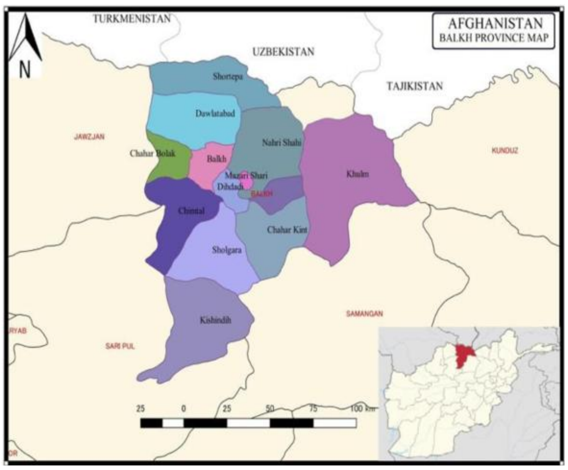

Fig. 1 Map showing Balkh Province in northern Afghanistan.

Table 1: Fatalities and Damages from the Flash Floods on the Northern Basins of Afghanistan, May 2014 [10].

Minor river basin	Human fatalities	Domestic animals	Damaged houses	Agricultural land (hectares)
Balkh/Khulm	9	3678	2797	5317
SarePul (Juzjan province)	0	50	619	3064
SarePul (SarePul province)	32	2125	2300	2000
Shirintagab	43	14872	2926	9984

Balkh lies between 35.5 to 37.5 northern latitude and 66 to 68 eastern longitude. The climate of Balkh is strongly determined by its topography. On the left bank of Amudarya most parts of the plains are semi-arid with desert-like conditions. Rainfall is relatively low and uncertain, averagingfrom 25 to 40 cm per year. The rainy season extends from January to May. Due to the low-pressure zones prevailing outside the country, low humidity is present throughout the year. The summers are hot with an average temperature of about 40C during June through August. Winter is relatively cold with light snowfalls. All of the houses in the rural area are constructed in an unplanned area and most of them on the floodplain are under risk of damage by flood and other natural hazards. The fundamental materials of the houses are clay soil with raw brick and mostly slab made of wood sticks; these types of structures cannot withstand severe flooding events. Table 1 shows the fatalities and damages from a flash flood due to heavy rainfall that occurred on the northern river basin of Afghanistan in April 2014.

III. NUMERICALSIMULATION

A. Floods and Disaster

One of the most significant problems in Afghanistan is the shortage of drinking water; approximately 70 percent of Sholgara district has no access to clean drinking water, so the population uses the river water for drinking and cooking, at the risk of different types of disease[11]. The Nays 2D Flood solver is applied to a 7 km section of Balkhab River which is located in the northern part of Afghanistan.This river originates from Amir Dams in Bamian Province and flows into Mazar-e-Sharif City, with a total length of 400 km, an average discharge of 1689m^3/min, and covers an area of almost 18700 square km. The elevation of this river from its source is approximately 3300 m, then as it flows down to Mazar-e-Sharif it has an average elevation of 357m. The river flows to 17 canals, including the Ekshkamish Canals, to irrigates all the agricultural land in Mazar-e-Sharif. The special topographic conditions result in this area being vulnerable to flooding, with many people suffering and public facilities becoming damaged annually during the flooding season. On April 24, 2014 heavy rainfall caused flash flooding in this area,and according to information obtained fromSholgara district, 3 people and 520 livestock died, 100 houses were completely destroyed, and more than 400 houses partially destroyed, forcing the families to immigrateelsewhere.In addition, a large portion of agricultural landwas damaged in Kishindy district, Fig. 2[10], [12].

B. IRIC (Nays 2D Flood)

IRIC (International River Interface Cooperative) is a river flow and riverbed variation analysis software package which combines the functionality of MD_SWMS, developed by the USGS (U.S. Geological Survey), and RIC-Nays, developed by the Foundation of Hokkaido River Disaster Prevention Research Center.In this study, the Nays2DFlood solver is applied to the flood analysis of Balkhab River. Nays2DFlood is a flood flow analysis solver that relies on unsteady 2-dimensional plane flow simulation using boundary-fitted coordinates as the general curvilinear coordinates. This solver adopts the 2-dimensional plane flow simulation of the Nays 2D solver developed by Professor Yasuyuki Shimizu of Hokkaido University for flood flow analysis. This solver is easily utilized to set the inflow conditions of an arbitrary number of inflow rivers that enter from either the upstream end or sides of the river[13].

Fig. 2 Housesdestroyed by flash flood in Balkh Province.

Since this solver does not require river channel data, it can also be used for the flood process analysis of primitive rivers and rivers in developing countries such as Afghanistan.The data needed for an overflow calculation by Nays2DFlood are topographic data, discharge and roughness of each river and floodplain[14].

The basic governing equationsusing a rectangular coordinate system (x, y) are as follows:

$$\frac{\partial h}{\partial t}+\frac{\partial (hu)}{\partial x}+\frac{\partial (hu)}{\partial y}=q+r$$

$$\frac{\partial (uh)}{\partial t}+\frac{\partial (hu^2)}{\partial x}+\frac{\partial (huv)}{\partial y}=-hg\frac{\partial H}{\partial x}-\frac{\tau_x}{\rho}+D^x$$

$$\frac{\partial (vh)}{\partial t}+\frac{\partial (huv)}{\partial x}+\frac{\partial (hv^2)}{\partial y}=-hg\frac{\partial H}{\partial y}-\frac{\tau_y}{\rho}+D^y$$

The terms $\frac{\tau_x}{\rho}$, $\frac{\tau_y}{\rho}$, $D^x$and$D^y$are defined as follows:

$$\frac{\tau_x}{\rho}=C_f u\sqrt{u^2+v^2}$$ Type equation here.

$$\frac{\tau_y}{\rho}=C_f v\sqrt{u^2+v^2}$$

$$D^x=\frac{\partial}{\partial x}\left[v_t\frac{\partial (uh)}{\partial x}\right]+\frac{\partial}{\partial y}\left[v_t\frac{\partial (uh)}{\partial y}\right]$$

$$D^y=\frac{\partial}{\partial x}\left[v_t\frac{\partial (vh)}{\partial x}\right]+\frac{\partial}{\partial y}\left[v_t\frac{\partial (vh)}{\partial y}\right]$$

whereh is water depth, t is time, u is flow velocity in the x direction, v is flow velocity in the y direction, g is gravitational acceleration, H is water surface elevation, $\tau_x$is riverbed shear stress in the x direction, τ_y is river bed shear stress in the y direction,$C_f$is river bed friction coefficient, $v_t$is eddy viscosity coefficient, ρ is the density of water, q is inflow per unit area, and ris rainfall.

C. Data sets and pre-processing

The data required for flood inundation models falls into four distinct categories [15]:

- Topographic Data of the channel and floodplain to act as model bathymetry.
- Roughness coefficients for channel and floodplain.
- Time series of bulk flow rates and stage data to provide model inflow and outflow boundary conditions.
- Data for model calibration, validation and assimilation.

Elevation points on a proposed length almost 7 km of Balkhab River were extracted from a raster file using QGIS tools and the DEM data with a high resolution of 12.5 meters was downloaded from the Alaska Satellite Facility’s website[16]. Satellite data is available to users through ASF under NASA's open-access data policy.The basic topographic data requirement is the high-quality Shuttle Radar Topography Mission (SRTM) data, which represents the position of each point in a standard coordinate reference system (CRS). Despite the high level of accuracy, the spatial scale of this data is insufficient to represent the micro-topography of relict channels and drainage ditches existing on the floodplain that control its initial wetting. However, at higher flood depths inundation is controlled mainly by the larger scale valley morphology, and detailed knowledge of the micro-topography becomes less critical [1].

Important exceptions are features such as embankments and levees controlling overbank flow, for which a higher accuracy and spatial scale are required (10cm vertical accuracy and 2 m spatial resolution) [17].

Reference [18] shows that SRTM DEMs, globally and freely available data,can be used to extract surface water elevations and estimate a reliable surface water slope, provided that the river reach is long enough [19].The performance of X-band and C-band SRTM DEM also gives reliable water elevations for smaller river reach lengths. It has been previously found thatSRTM data is viable for hydrologic application as well.

A background image has been taken from Google Earth to overlay the extracted elevation points in Fig. X. An inflow point considered at station of Pul-i-Baraq, hence a flood with a peak flow discharge of 404m^3/swas recorded on May 9, 2014.Since the hourly discharge rate is not available,it is set according to the local news, as inwhat time the flood started, when it reached its peak flow, and when the flood stopped. In this study a Manning coefficient of 0.025 for the river and 0.035 for the flood plain is considered. The Manning coefficientswere chosen according to examples from previous research using Nays2DFlood [20].A Manning coefficient for a flood plain is made up of pastureland is commonly 0.035 which is applicable to the area of study as it is located in an agricultural sector of the river basin.The influence of rainfall and runoff are not considered in this study,as well as the rate of erosion. This is in part due to the complexity, as well as the lack of significant data for rainfall and infiltration processes for the area.

Fig.3. shows the daily discharge in Balkhab River at the station inPul-i-Baraq, with the model input as an assumed hourly discharge.

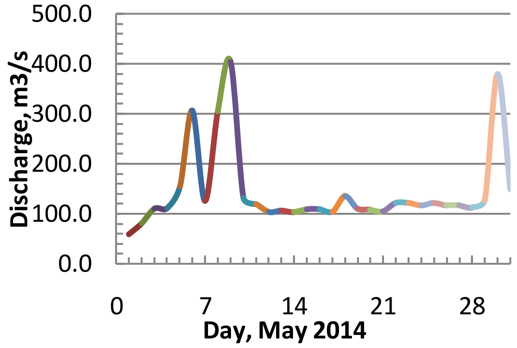

Fig. 3 Daily discharge in Balkhab River at station Pul-i-Baraq, used as inputfor the model as an assumed hourly discharge.

IV. NUMERICAL SIMULATION RESULTS

TheDEM data and inflow as described in the previous section were applied to the Nays2DFlood solver. The image maps were exported directly from the solver after the calculation successfully completed. The obtained resultsare shown in a maximum flood depth map, Fig.4, and a velocity vector map, Fig.5.A streamlines map is shown in Fig.6.

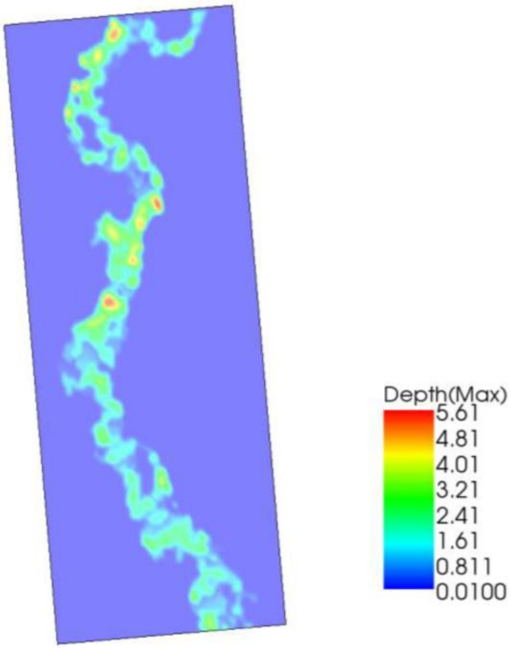

Fig. 4 Map of flood maximum depth.

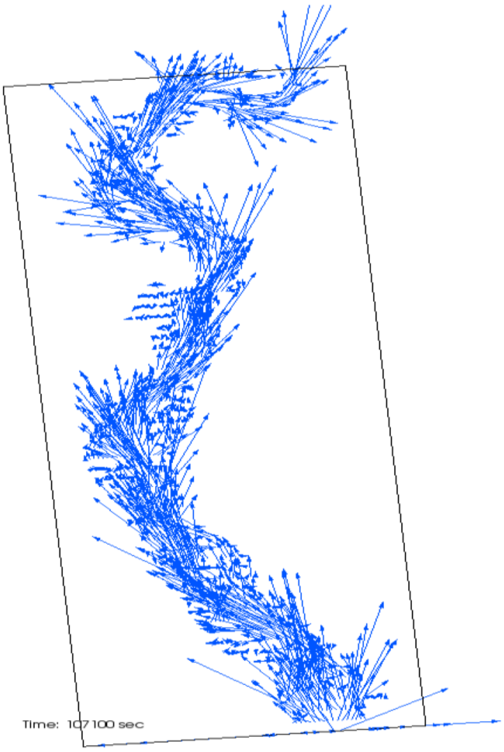

Fig. 5 Map of velocity vectors.

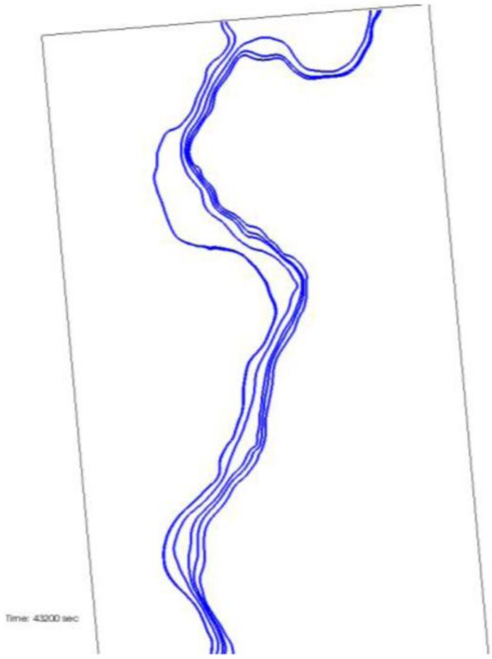

Fig. 6 Map of velocity streamlines.

Next, overlaying these mapswiththe background image of the study area, Fig. 7, it is determined that the solver verified the flood inundation and vulnerable areas with reasonable accuracy. The overlay map results are shown in Fig.s 8-10.

In addition, comparisons were made with photos and videos that were taken during and after the flooding to further validate the results qualitatively. As there is no available measured data from the flash flood on Balkhab River to validate the result quantitatively, the simulated results must be compared with information from the news reports and narration from the local people to validate the model. Even though iRIC Nays2DFlood cannot quantitatively show the river flow due to the shortage of accurate data for flood events in this region, the simulated resultscan be considered to be in agreement with the photos and news report from the observed flooded area. From local video footageit is observed that of the people attempting to cross the river, some of them fall down and swim, so it is not unreasonably to predict thatthe flood depths are similar in proportion to the results in the above figures,to maximums flood depths around 5 m.

Using these maps, information as to the most serious areas at risk to flooding in the river basin and expected inundation levels can be determined. By examining the results of these simulations, the most at risk areas can be focused on. Furthermore, this method can be applied to other rural river basins prone to flooding in order to gather information and develop detailed flood hazard maps.

Fig. 7 Background image of study area.

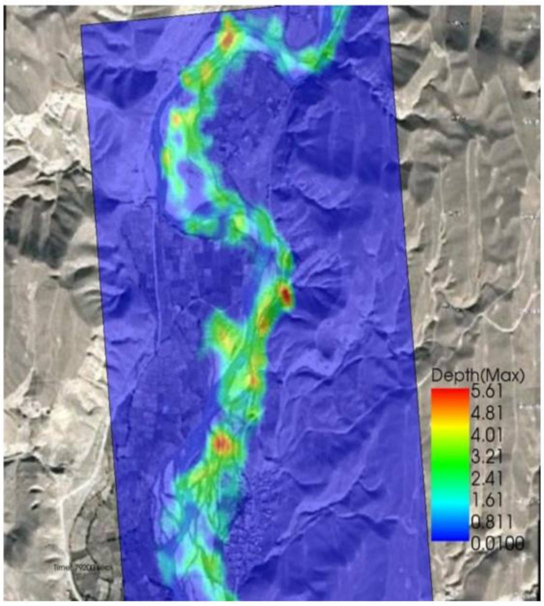

Fig. 8 Background image of study area.

Fig. 9 Background image of study area.

Fig. 10 Background image of study area.

CONCLUSION

In this study, a simplified flood inundation simulation model wasdeveloped by applying globally available data. The model calibration results demonstrate that the overall model performance is acceptable, providing a feasible modeling tool to simulate the flood inundation that can be utilizedin flood vulnerability assessment.This study generated an inundation map of the Balkh river basin, showing potential areas and depths of flooding. In the inundation results, velocity vectors show the direction and intensity of the flooding. The iRIC Nays 2D Flood tool can be used to study areas of interest in northern Afghanistan in order to determine flood zones and risk assessment for flooding hazards.

In conclusion it is shown thatiRICNays2DFlood is a useful model for flood prediction capabilities, especially the ability to delineate potential flood inundation areaswhich is one of the most important requirements for the study of flood hazard maps. The accuracy of model simulation not only depends on the resolution of DEM data, but it is essential to consider hydrologic and hydraulic model structure as well. In order to improve the model accuracy and its applicability for the future, there is a need for more information on hydrologic environments, such as the surface and subsurface flow,as well as other detailed data such as rainfall, runoff, and infiltration process.

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