METHOD OF FLOOD HAZARD MAPPING IN UNGAUGED MARKHAM RIVER BASIN IN PAPUA NEW GUINEA

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ABSTRACT

During last decade, flood disaster events were experienced throughout Papua New Guinea (PNG). Markham river basin in Morobe province is one of the areas that encountered considerable damages to properties and infrastructure during these flood events which have led to disruption of everyday activities and affected the economy of the country. Though it is an important river basin that supports extensive commercial and agricultural activity of PNG, there had been very little studies on flood and other water related disasters. This study attempts to provide a means of useful flood information such as hazard map to the residents of the basin. Rainfall runoff and associated inundations are computed by means of a rainfall runoff model (RRI model) for specific rainfall data such as 25, 50 and 100 years return periods. Based on the predicted inundation areas, a flood hazard map is proposed. However, the proposed hazard map is not tested for its validity because there are no observed data.

Keywords: Markham River basin, flood disaster, RRI model, Flood Hazard Map

INTRODUCTION

Markham River basin (Figure 1) in Morobe Province is one of the five largest river basin in PNG that is located between longitudes: (145° 58’ 00’’ to 146° 58’ 30’’) and latitude: (-5° 51’ 30’’ to -7° 31’ 00’’). Having an area of 12,750 km^2, its large fertile flat lands have encouraged agricultural and economic activities to boom rapidly. Large plantation of agricultural products such as peanuts (groundnut) and vegetables are grown and sold to local markets. Large cattle farms producing 70 to 80 % of beef products are established in the basin. For the last 10 years the basin encountered several extreme rainfall events

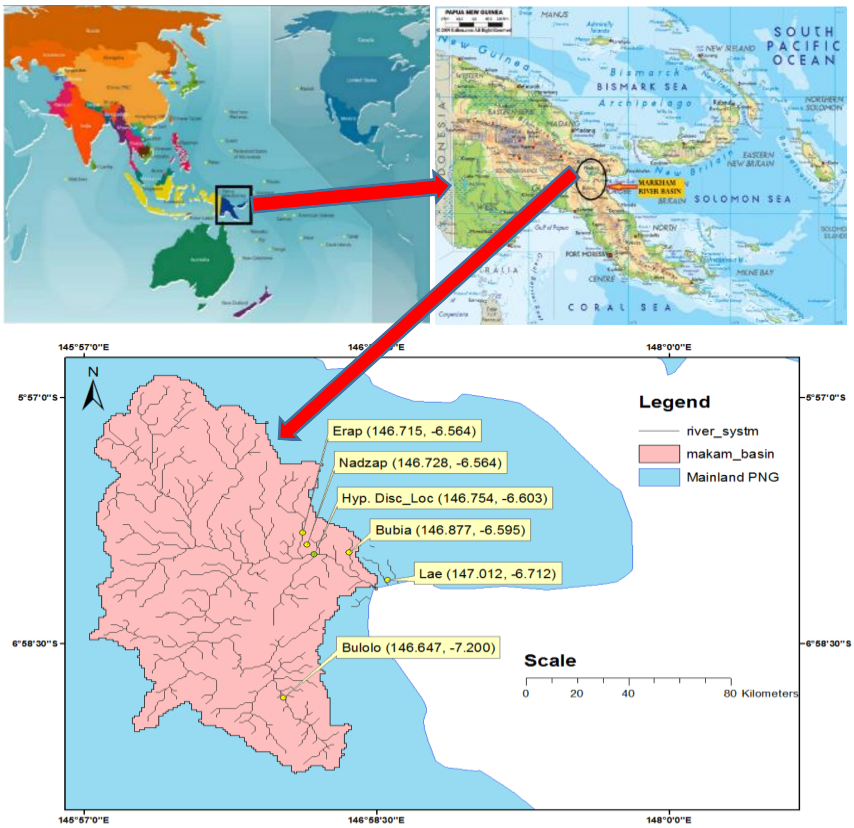

Figure 1: Location of Markham River Basin

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that caused flooding, destroying properties, infrastructure and even losses of lives. Table 1 shows some of those events.

Table 1: Flood Disasters in the Basin

Year of Flooding	Description Damage
2004	Markham Bridge washed away
2008	Several houses washed away in a traditions village
2012	Highway over flooded blocking traffic
2013	Bulolo road wash away
2014	Inundation at villages along highlands highway
2016	Houses washed away, 7 casualties

Lae city being the second largest city in PNG with its port serving the six inland provinces, is located at the outlet of the basin. In the past years there were no issues faced by the city with regards to flooding because all the building infrastructures and residential homes were located at a safe distance away from the river floodplain. However with the increase of population, the city is expanding into these flood risk zones. Without any proper hydrological study of flooding in the area, information on flood risk zones to be disseminated to the residents is lacking, it has therefore become an important and vital need that flood hazard maps are being produced and distributed to the residents of the city and the population living along the Markham river basin as an awareness tool. This study involves hydrological simulations for flood scenarios and identifying flood risk zones on the basin area for the purpose of producing flood hazard maps. The knowledge and information gained in conducting the study are discussed with suggestions and recommendations proposed to authorities for implementation of policies for rivers and waters for flood disaster management.

THEORY AND METHODOLOGY

The study adopts the hydrologic modelling method which is one of the methods that uses results from hydrological model simulations to map out flood inundated areas. In this study, RRI model simulations of peak rainfall events for certain return periods causing inundation results were calculated to obtain the extent of water surface (Lastra et. al., 2008). Figure 2 shows the general flow of the study.

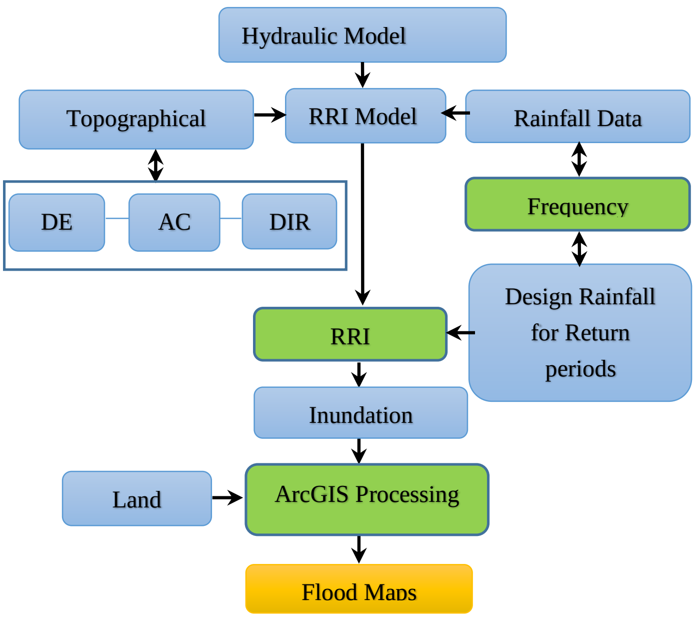

Figure 2: Schematic diagram of the Methodology

The Rainfall-Runoff Inundation (RRI) model as defined by Sayama et al., 2012, is a two-dimensional model that is capable of simulating rainfall-runoff and flood inundation simultaneously. It simulates flows on land and in river and their interactions at a river basin scale. The model treats slope areas and river channel separately. The flows on slope grid cells are calculated using 2D diffusive wave model while channel flow calculations uses 1D diffusive wave model. The governing equations (1.1), (1.2) and (1.3) describing the flows are based upon the mass balance equation and momentum equation for gradually varied unsteady flow, where h = height of water at local surface, q_x & q_y = unit width discharge in x and y direction respectively, v_x & v_y = flow velocity in x and y direction respectively, r = rainfall intensity, f = infiltration rate, H = height of water from datum, ρ_w = density of water and g = gravity (acceleration).

In conducting the study, the 25, 50 and 100 years return period rainfalls were determined using frequency analysis on the historical rainfall records (1917 to 1995) of four stations in the basin. Maximum daily rainfall for each years were sorted out and used in the frequency analysis. A probability distrubution curve, comparing Gumbel and General Extreme Value (GEV) distributions to values of observed daily maximum rainfall was being plotted. The return period values for Gumbel or GEV that was best fitting to the ground observed rainfall were chosen for design rainfall. The design rainfall was then determined from three different rainfall patterns (Figure 3). After running simulations with all three patterns, the pattern producing maximum results for inudation depths, inundation areas and discharge at the hyptothetical point was selected and used in producing the flood maps. These inundation results were overlaid with land used maps using ArcGIS to produce the Flood Hazard Maps.

Governing Equations

$$\frac{\partial h}{\partial t}+\frac{\partial q}{\partial x}+\frac{\partial q_y}{\partial y}=r-f \tag{1.1}$$

$$\frac{\partial q_x}{\partial t}+\frac{\partial v_x q_x}{\partial x}+\frac{\partial v_y q_x}{\partial y}=-gH\frac{\partial H}{\partial x}-\frac{\tau_x}{\rho_w} \tag{1.2}$$

$$\frac{\partial q_y}{\partial t}+\frac{\partial v_x q_y}{\partial x}+\frac{\partial v_y q_y}{\partial y}=-H\frac{\partial H}{\partial y}-\frac{\tau_y}{\rho_w} \tag{1.3}$$

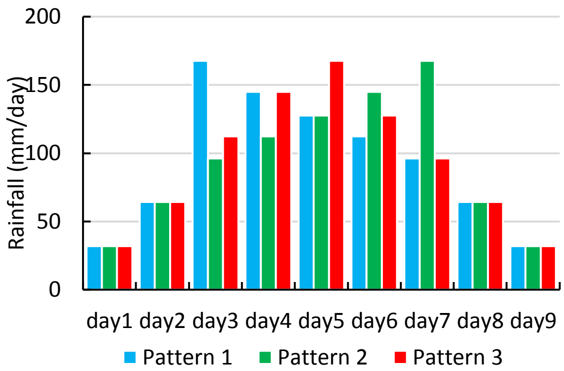

Figure 3: Rainfall Patterns

DATA

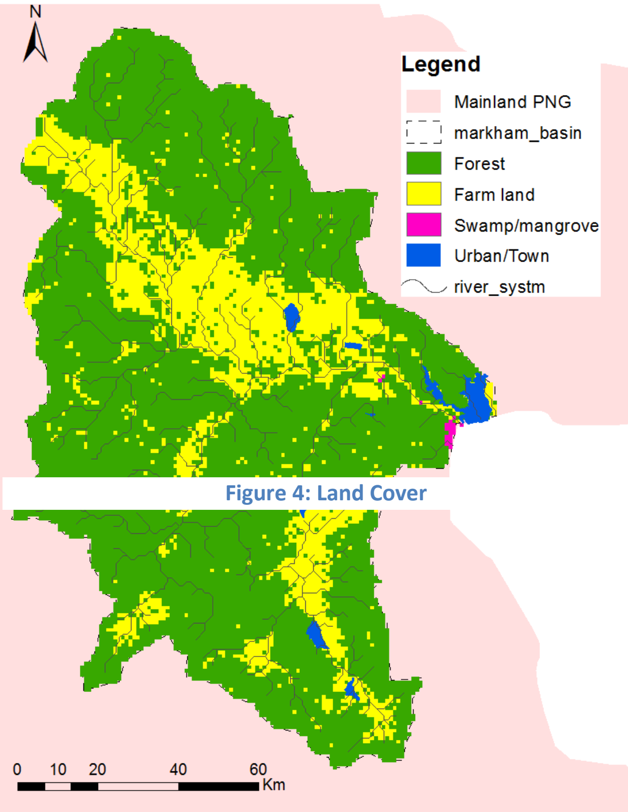

Figure 4: Land Cover

Global Land Cover Characterization (GLCC version 3) map for South East Asia was downloaded which PNG is included in there. Generally the land cover of Markham river basin consist of three major classes. Forest was dominant followed by cropland and water bodies (Figure 4). Little information is known about the soil type distributions thus model calibration did not include land use types. The land use types was only used in overlaying the simulation result for flooding on to it to identify inundation areas.

The RRI model uses topographical dataset which includes ground elevation data, flow direction data and flow accumulation data. The data can either be prepared by a user in Arc-GIS or downloaded from a global scale dataset offered by United States Geological Survey (USGS) (Sayama et al., 2015). In using the downloaded global dataset, the users must clip out the original data to the target basin (ibid).

This study uses 30 arc-second dataset for the Asia region, downloaded from USGS HydroSHEDS website and clipped out in the RRI model according to Markham river basin. For suitable simulations the DEM and the flow direction on the clipped out dataset was adjusted using a program included in the RRI model package (Sayama et al., 2015).

Historical daily rainfall data from 1971-1995 from four (4) rain gauge stations within Markham river basin was obtained and used in frequency analysis for determining certain return period rainfall. The maximum daily rainfall observed during each year were extracted and used in the frequency analysis where 25, 50 and 100 years return period rainfall values for each station were determined. A multiplying factor was then obtained by dividing the return period rainfall value with the observed maximum daily rainfall. These factors were then used to adjust values of a 5-days-extreme-rainfall-event to which new values of the same 5-days-extreme-rainfall-event that is equivalent of the corresponding return periods was produced. The adjusted values were then arranges in 3 different orders which gave the three rainfall patterns.

There is no discharge station located within the river channel therefore no discharge could be obtained for use in this study. Instead a hypothetical point was chosen for the purpose of viewing the hydrograph of the simulation discharge and comparing it to the inundation to make some coloration.

RESULTS AND DISCUSSION

Table 2: Corresponding Value of Flood area, Max inundation depth and Max discharge at hypothetical point to rainfall patterns

Rainfall Pattern	Flooded Area(km^2)	Inun Depth(m)	Disc Q(m^3)
25 years- Pattern 1	758	15.836	13191.76
25 years – Pattern 2	784	16.314	13829.33
25 years – Pattern 3	784	16.322	13837.94
50 years – Pattern 1	818	16.574	14170.07
50 years – Pattern 2	867	17.057	14834.53
50 years – Pattern 3	865	17.089	14877.29
100 years – Pattern 1	919	17.305	15165.77
100 years – Pattern 2	961	17.804	15876.63
100years – Pattern 3	961	17.86	15939.57

With additional two days at the start for initiating the flow condition and two days at the end, the simulation period was nine days (216 hours). The results for RRI simulations with the three different rainfall patterns is as shown in Table 2. It was observed that for each return period, simulation with case 3 rainfall pattern produced maximum values for discharge and inundation areas (Table 2). Rainfall pattern 3 was therefore used for simulations to produce inundation and hazard maps.

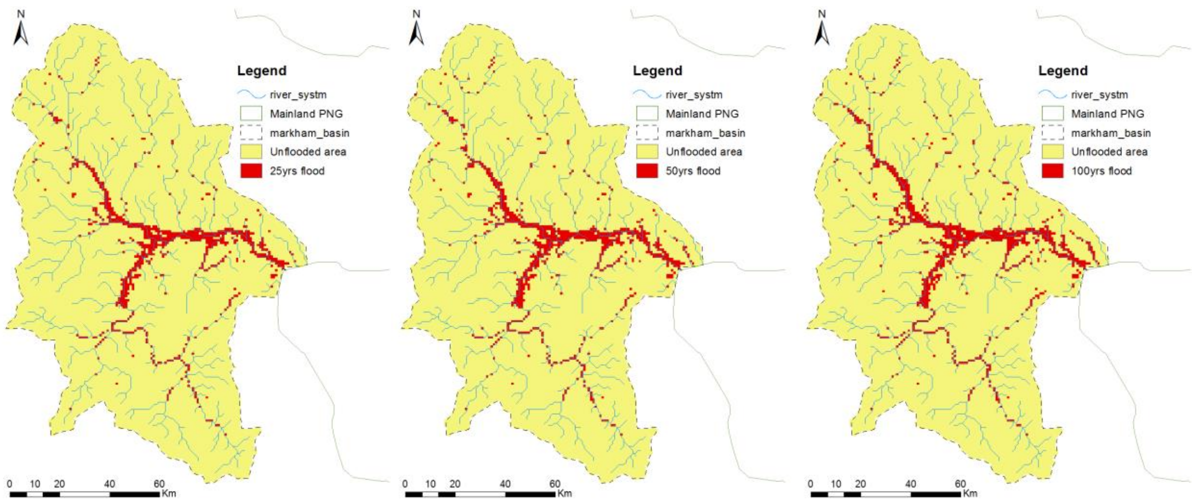

Figure 5: Inundation Maps for (25, 50 and 100 years return period rainfall)

The simulation results for inundation areas with rainfall pattern 3 for 25 years, 50 years and 100 years return period rainfall are as shown in Figure 5. A minimum water depth of 0.5 meters was used as cutoff for non-flooded areas. Areas above 0.5 meters are shown as being flooded. Maps showing flooding of areas in the basin were generated with inundation results from RRI simulations and the land cover map of the basin. For each return period rainfall simulation (25, 50 and 100 years), a map showing flooded areas was produced by overlaying the land cover map of the basin with RRI inundation results files. This was achieved in the Arc-GIS Program. A composite map (Figure 6) showing flooding of all three return period was produced by superimposing inundation of all three return periods onto the land cover map off the basin area. All these maps show extent of flooding and land areas that will be covered with water above 0.5 m in the event of the rainfall intensities equivalent to the return period values. It can be seen that in the composite flood map, urban, town and villages areas including cattle & commercial farming, plus the two main highways were introduced into the land use map then over laid with the inundation map to come up with the Composite Flood Map. These features were not included in the

Global Land Cover Characterization (GLCC version 3) map, however they were extracted from the Google Earth Application and added to the land cover map.

The unavailability of discharge data and limited rainfall records for the river basin has greatly affected outcome of the study. Almost all river basins in PNG are poorly gauged or not been gauged at all. Markham river basin alone has only 4 rain gauge stations and no river discharge station at all. Rainfall data from these 4 stations however were historical records from 1971 to 1995 which is about 20 years ago. Further, the basin is very large and the location of these 4 stations is poorly distributed thus area of influence is poorly represented. In addition the simulated discharge results cannot be validated because of no discharge stations. It is therefore important that such hydrological data be available so that flood studies are carried out accurately for proposing countermeasures that will reduce flood damages in future.

The results produced in this study is from rainfall derived from frequency analysis of historical rainfall data. The use of remote sensing technology such as satellite based rainfall is another option that can be considered in limited availability of ground observed data. This study however cannot incorporated satellite based rainfall because the recent rainfall data were missing. For obtaining a near to real values of satellite rainfall for the event, at least ground observed data from a few rain gauge station in the area should be available for carrying out bias correction on the satellite rainfall.

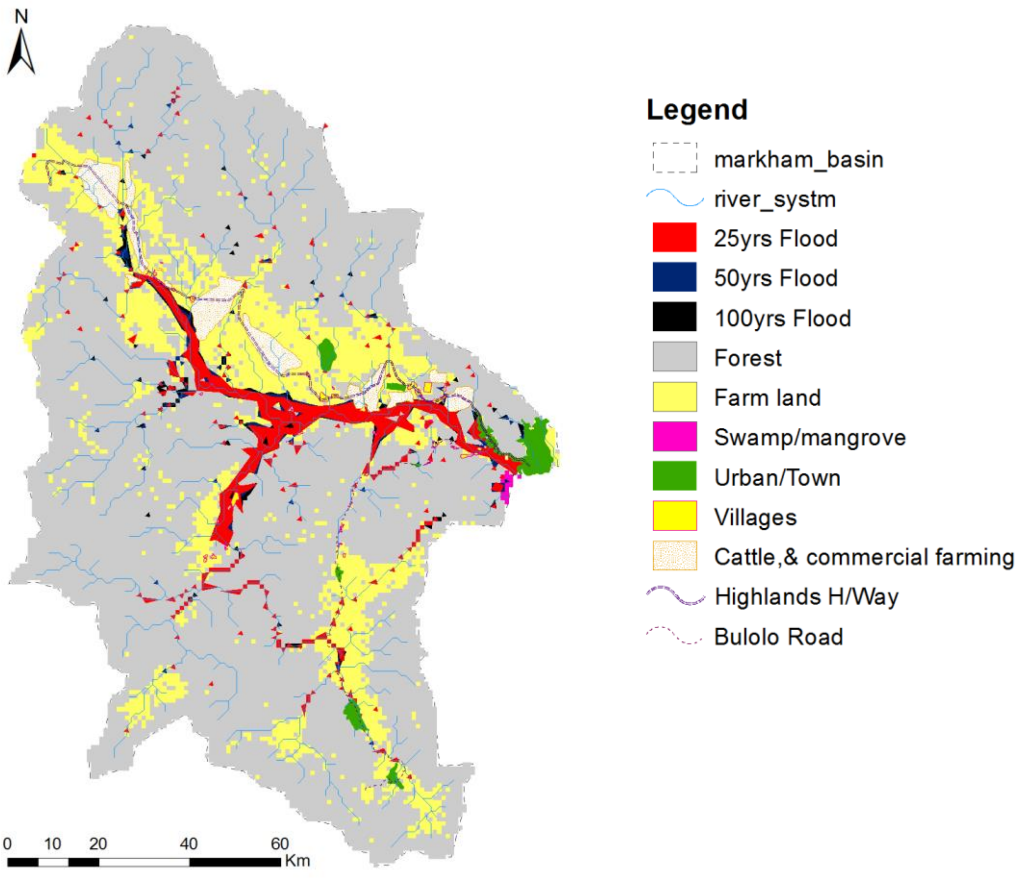

Figure 6: Composite Flood Map

CONCLUTION AND RECOMMENDATIONS

This study aims to study the flood hazards at Markham River basin in PNG. The limitations in the data availability made the study to conduct rainfall frequency analysis and inundation simulations only. Based on the available rainfall data, frequency analysis was conducted to estimate 25, 50 and 100 year return period rainfalls. RRI model simulations were carried out for the aforementioned return periods under different rainfall patterns to identify the probable flood hazards. Based on the simulation results, flood hazard maps for 25, 50 and 100 year return periods' rainfalls were prepared. The results were useful in identifying the flood risk areas in the basin aiming to propose counter measures in future. Up to now, flood hazard maps of the basin were not prepared and this study was able to fill that gap under the limited data availability. Those maps will be beneficial for the local flood control authorities to envisage possible floods in future and initiate actions towards a safe community with a minimum flood risk in future.

There are a few recommendations made in these study. The outcomes of this study were achieved without a verification due to insufficient data at time of completing the study. Therefore it is recommended that result of this study should be further revised and verified in future after collecting field observations.

Secondly, in recommending ways to address the limitations of this study which will be of benefit to any future studies involving flooding and other water related issues in PNG, the establishment of ground observed hydrological dataset collection systems must be seriously considered. It was observed in this study that a good and up-to-date hydrological datasets is a key factor that will allow studies involving flood and water related issues to be properly researched, verified and concluded with results that are near to in situ conditions. It is evident in the study that almost all of the river basins in PNG are poorly gauged. This brings to the point that any future studies of flooding and other water related issues on any river basins in PNG will continue to face restrictions and difficulties unless something is being done. It is therefore recommended that responsible authorities should install more data collection systems such as rain gauges and discharge measurement stations in important river basin such as Markham river so that hydrological database are collected to facilitate studies of flooding and or other water related issues, if the government is serious about addressing flood and water related disasters in the country. Further, the application of satellite based rainfalls is also another option, the authorities may consider in future to minimize the gap of observed rainfalls.

Finally, but not the least, PNG's policies relating to disaster management is basically being generalized. The revised 2012 National Disaster Management Plan did identify some areas of disaster management policies that were being delegated down to the local government, yet it is still being generalized to only responses after disaster strikes. Each type of natural disaster should have a detailed policy that identifies preparedness and countermeasures for managing and mitigating them. It is therefore recommended that for flooding and water related disasters policies, the government should look into establishing policies that should give directions and authority to existing responsible bodies to take charge of river and water managements. This bodies will then concentrate and come up with sound ideas which will facilitate detailed policies for flooding and other water related disaster.

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