INNUNDATION ANALYSIS AND DEVELOPMENT OF RAINFALL RUNOFF MODEL FOR TINAU RIVER BASIN IN NEPAL

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ABSTRACT

Climatic change, unplanned land use pattern, deforestation, socio-economic change and human intervention are affecting the hydrology of Tinau river basin in Nepal. In the absence of proper flood management, extent of flood damages is increasing in every extreme flood events. The existing structural counter measures in this basin will not be sufficient against probable extreme floods. So, it is necessary to develop non structural counter measures. The methodology in this study is to develop non structural counter measures for downstream reach of Tinau river basin so that losses and damages due to flood disaster could be minimized with the simultaneous application of structural as well as non structural measures. This paper presents the results of inundation analysis and flood forecasting models based on Tinau river basin data. Inundation maps for different return periods will be provided to the community level so that communities can easily identify the depth of inundation of their place of interest. In order to develop the relationship between rainfall and runoff and hence to develop flood forecasting model, simple statistical tools for hydrological analysis and least square methods of best fit technique are applied with the available historical data. The developed model will be useful for community level people to prepare themselves during extreme flood events to save their lives and properties as a part of flood disaster management approach.

Keywords: Trend analysis, flood frequency analysis, inundation analysis, rainfall runoff modelling

INTRODUCTION

The main hazards repeatedly occurring and causing heavy losses in terms of lives and properties in Nepal are floods, landslides, avalanches, hailstorms, windstorms, lightning strikes, earthquakes, fire, and epidemics. The overall impacts caused by water-induced disasters such as floods, landslides, and avalanches are the most severe. Between 1983 and 2006, on average, 309 people

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were killed annually by the water-induced disasters. Every year heavy damages of infrastructure and property worth NRs. 1242 million (≈ USD 16 million) causing negative impacts on the social and economic development of the country (DWIDP, 1999). It is observed that majority of flood disaster victims are poor and marginal people. This trend of destruction due to floods will continue unless the reliable coping mechanisms are well established in advance. It is realized that non structure measures, including flood forecasting and early warning, are important and effective tools in flood management in Nepal (Osti et al., 2008). Identification of inundation depth in the flood zone and establishing a flood forecasting system would enhance the effectiveness of all other mitigation measures by providing time for appropriate actions. In this study, inundation depths are identified for different scenarios based on rainfall and discharge data in Tinau watershed.

STUDY AREA AND PROBLEMS

The Project area is located between 27^0 49’ - 27^0 23’ North Latitude to 83^0 36’ - 83^0 15’ East Longitude, the western part of Nepal and approximately 260 km west from the capital, Kathmandu. It covers parts of Palpa and Rupandehi districts. The Tinau River is originating from the lesser Himalaya Mountain range with a length of 103 km. Its width in the Terai plain ranges from 100 - 940 m. The Basin area of the Tinau River is 1081 km^2 in total, consisting of 669 km^2 of mountainous area and 412 km^2 of plain area.

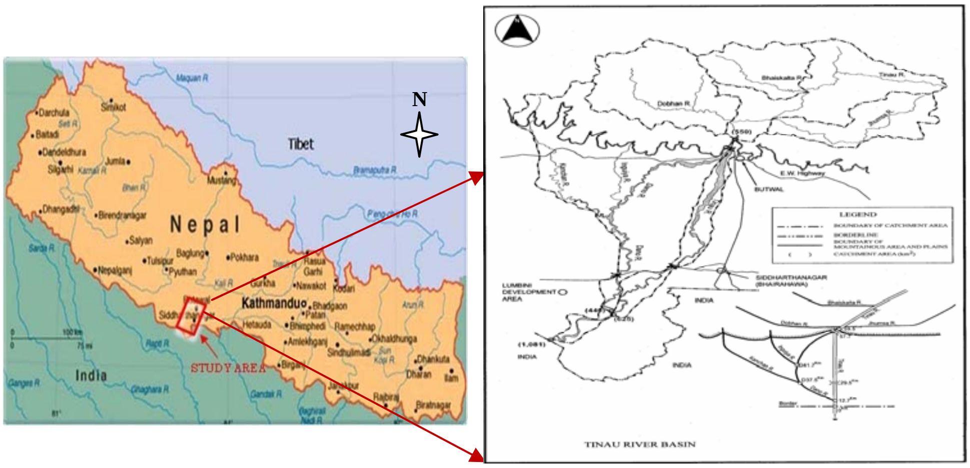


Figure 1 Map of Nepal and study area

Flooding is one of the major problems in this basin. Every year in the monsoon season, high floods in this river cause loss of lives and property. Major land erosion results in loss of agricultural lands in the middle reaches whereas the flooding in the lower reach causes inundation. The maximum 24 hour rainfall recorded was 320 mm in 1981. The most devastating floods occurred in 1970, 1979, 1981 and 1996. The flood of 1981 was more noticeable in magnitude and inundated area. In 1981, the flood swept away 70 lives, about 100 houses, irrigation intakes, agriculture lands along the river bank and also degraded a huge area of land due to sediment deposition. The cause of this flood was a landslide, which blocked the river flow for several hours before it breached (Bhattarai, 2001). Dano River bifurcates from Tinau River near the foot of the hill and again joins Tinau River at about 13 km upstream from the Indian border. The risk of hazard is increasing inside the two river boundaries as a result of improperly development of infrastructures and poor drainage system. Poor and marginal people are living near the bifurcation point of the river and they are most vulnerable against extreme floods. At the point of convergence and inside the two river boundary, inundation occurs every year but the local communities don't know about areas and depths of inundation.

METHODOLOGY

Hydrological analysis

The rainfall and discharge data are analysed statistically in order to obtain the annual average rainfall, monsoon average rainfall, annual discharge, maximum discharge etc. Trend analysis provides an idea about climatic variability in the watershed. Trend analysis is done with linear regression test, Kendall's method and Student's **t** test to check the significance of trend. Floods for different recurrence intervals are calculated with Gumbel and Normal distribution. Chi-square goodness of fit is adopted for determining how well model fits the observed data. It allows us to evaluate how close the observed values are to those which would be expected. The objective of flood frequency analysis is to get the discharge for different recurrence intervals (Jayawardena, 2008). Natural dam breach case is also performed as the worst scenario.

Inundation analysis

The flood plain visualization is carried out using one dimensional hydrodynamic numerical model HEC-RAS. It is capable of performing water surface profile calculation for steady and unsteady flow conditions. HEC-GeoRAS, an ArcView extension, is used as the interface between HEC-RAS and ArcView GIS for pre-processing and post-processing for the data. The geometric data of the flood plain and river are obtained from the digital elevation model. Water surface profiles for floods of different scenarios are computed with subcritical flow simulation. These profiles are exported to ArcView GIS and water surface Triangular Irregular Network (TIN) is generated. Intersections of terrain TIN and water surface TIN result in an inundation map.

Rainfall runoff modelling

Statistical method, the best fit technique, and least square methods of error minimization are chosen to set up the model based on available data sets.

RESULTS AND DISCISSIONS

Average annual and monsoon precipitation (June-September) in Tinau watershed are 1985 mm and 1637 mm respectively. Monsoon rainfall is 82.26% of annual rainfall. Average annual rainfall of Nepal is 1700 mm and 75-85% of rain falls in the monsoon period. Observed average annual rainfall data is analyzed by linear regression. The slope of the trend line 'b' is 2.20 positive. The result of Kendall's coefficient (τ) is 0.011 positive. Significance test for average annual rainfall is performed with student's **t** test and it is found that there is no significant trend at 95% confidence level ($\alpha = 0.05$).

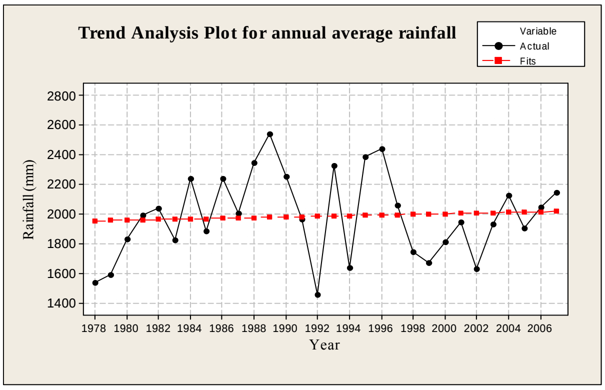


Figure 2 Annual average rainfall trend

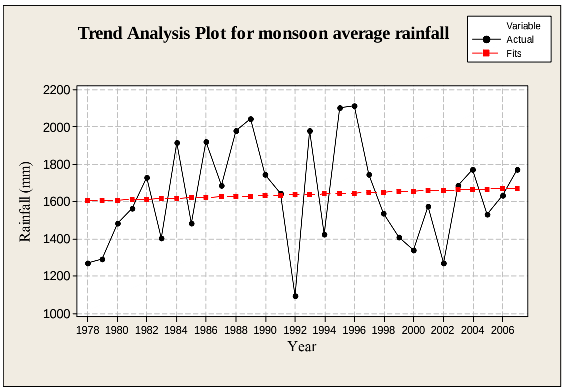
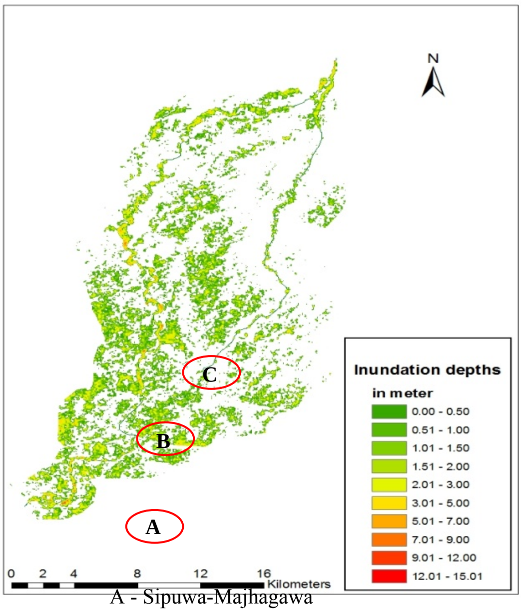


Figure 3 Monsoon average rainfall trend

To find the chi-square (χ^2) value for the estimated frequencies of different flood events with an application of Gumbel and Normal distribution, the return period for particular value of plotting position discharge were calculated. Chi-Square at (9 - 1) = 8 degree of freedom (n-1, degree of freedom for error) at probability level P = 0.05 is 15.5. Since both the calculated Chi-Square values are less than the values at P = 0.05, Null hypothesis (Fit of distribution with the Gumbel and Normal distribution) is not rejected. Gumbel distribution is best fitted for the observed data and discharges for different return periods are calculated as in Table 1.

Simulated inundation depth of 1996 flood (Fig. 4) shows many of the areas inside the two river boundaries are inundated. The depth of inundation is more in the downstream area compared to upstream area. The mean depth of inundation is 1.05 m during 1996 flood.

Natural dam breach analysis is simulated for a 20 m high dam. It is assumed that the natural dam will fail by overtopping and collapse fully within 0.3 hours. Obtained hydrograph is used for unsteady flow inundation analysis. The peak flow of dam breach



A - Sipuwa-Majhagawa
B - Kamahariya
C - Amuwa-Dayanagar

Figure 4 Inundation map of 1996 flood

hydrograph is 9260 m^3/s. Inundation analysis result shows that Bhairahawa city will be inundated up to 3.08 m in case of dam breach.To protect the Bhairahawa city, height of levee required is 3 m in case of usual flood scenario and 5 m in case of natural dam failure.

Table1 Flood discharges for different return period

Return period (Tr) yr	2	4	10	20	50	1996 flood	100	200	500
Discharge (m^3/s)	659	1053	1503	1826	1928	2485	2556	2868	3280

Inundation depth for different scenarios are identified at three points (Sipuwa-Majhagawa, Kamahariya and Amuwa-Dayanagar) and plotted between flood magnitude (log Q) and average inundation depth. In the plotting graphs, logarithmic curve is best fitted. Fitted curve has good average coefficient of regression, R^2 = 0.943 (excluding dam breach) and R^2 = 0.971 (including dam breach). Figure 5 is an example of plot between discharge and average inundation depth at Kamahariya. With this plot, local community people can easily identify the inundation depth for corresponding forecasted discharge.

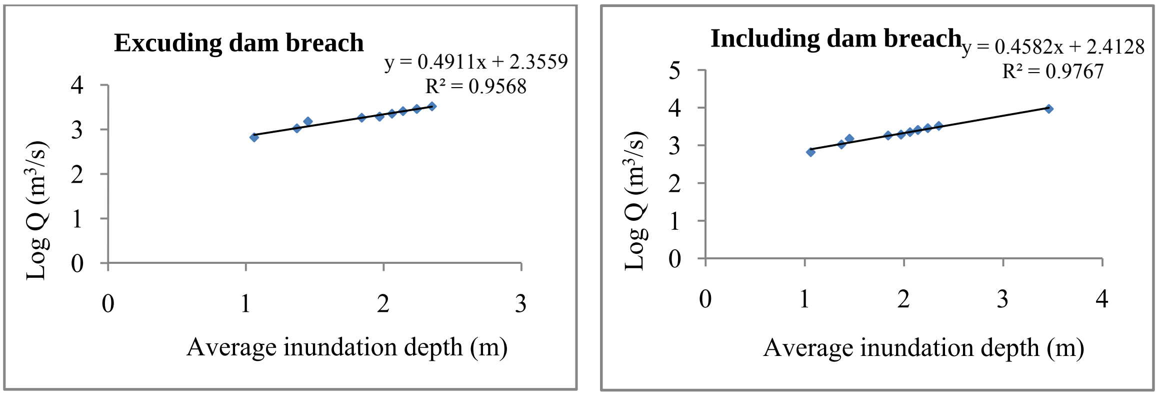


Figure 5 Plot of discharge Vs average inundation depths at Kamahariya

The rainfall runoff modelling is done for different cases and it is found that the best result is the one considering last 24 hours observed rainfall and the discharge in the river in previous 24 hours.

$$Q_p = K_1 * Q_{t-1} + K_2 * B_t + K_3 * T_t$$

Where,

Qp = discharge at forecasting time t in m^3/s

Qt-1 = observed discharge at time (t-1) in m^3/s, i.e. previous day

Bt = observed rainfall at station Butwal in *mm* during last 24 hours

Tt = observed rainfall at station Tansen in *mm* during last 24 hours

Table 2 Model coefficients and errors of model (calibration - validation)

Model coefficients			Calibration (1984-2002)			Validation (2003-2007)		
K_1	K_2	K_3	R^2	MAE	RRMSE	R^2	MAE	RRMSE
0.208	5.933	5.403	0.95	7.52	0.1762	0.94	5.97	0.1430

This model is best fitted for the Tinau river basin based on available hydrological data. Using this model as flood forecasting and early warning could save the life and property to some extent at lower watershed of Tinau River. This model is simple one and using this model even the community level people can forecast the probable flood. Every day the rainfall on Butwal and Tansen rain gauge stations is forecasted by communication media. So, next 24 hours expected rainfall of that region is known. If the community level people get information about the discharge in the previous day at Butwal station, knowing all the parameters and coefficients, the probable flood could be easily forecasted.

CONCLUSIONS

The study area has suffered from various types of hydrological disasters, and flood is one of the major. Inundation analysis and flood forecasting is a very useful tool for flood risk management for Tinau river basin. Decision makers and communities are often concerned with extend of inundation areas and flood depths at specific locations. Flood maps were prepared for various return periods and corresponding inundation areas and depths were computed. Once the probable discharge is predicted, with an application of rainfall runoff model, community people can identify the inundation areas and depths from discharge inundation depth relationship. Once the depth of inundation is identified, they can make evacuation plan to save their lives and properties against coming flood in time. The inundation maps can be used as flood forecasting, awareness raising, development planning, emergency services and post disaster rehabilitation aimed at reducing flood damages and economic impacts in future. As this model is based on 24 hours observed data, it will be updated with hourly observed precipitation data in future.

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