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Reconstructing the tropical storm Ketsana flood event in Marikina River, Philippines

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Abstract

In September 2009, tropical storm Ketsana (local name: TS Ondoy) hit Metro Manila and brought an anomalous volume of rain that exceeded the Philippines' forty-year meteorological record. The storm caused exceptionally high and extensive flooding. Part of this study was a survey conducted along the stretch of the Marikina River, one of the major rivers that flooded. Hydraulic and hydrologic modeling was carried out to understand the mechanism that brought the flood. The study revealed that while there were anthropogenic factors that exacerbated flooding in Marikina, the observed flood heights can be simulated in the models generated. Peak floods occurred at different hours along the river resulting from the transmission of water from the main watershed to the downstream areas and the contribution of smaller tributaries entering the main river. Prediction of flood heights and the use of the known time lag between the peak rainfall and the peak runoff could be utilized to issue timely flood forecasts to allow people to prepare for future flooding.

1 Introduction

On 26 September 2009, Tropical Storm Ketsana (local name: Ondoy) hit the Metro Manila area and brought 347.5 mm rainfall in only 6 h, reached 413 mm in 9 h and totaled to 448.5 mm after 12 h. This rainfall amount was the highest in the country's forty-year record and surpassed the typhoons of 1970 and 1976 that brought 403.1 mm and 371.6 mm/day of rainfall, respectively. The volume of rainfall resulted in a flood that was exceptionally high and extensive which made it extremely devastating. An estimated worth of damages to property and infrastructure reached 2 billion pesos (US $43.5 million) and left more than a million Filipinos homeless.

The Marikina River Basin (MRB) is situated in one of the highly urbanized areas in Metro Manila. Its drainage area of 582 km^2 starts in the western slopes of the Sierra Madre Mountain Range (Fig. 1). Several rivers including Montalban, Wawa, Tayabasan, Boso Boso, Manga and Nangka feed into the 31-km Marikina River that flows southward. The Marikina River floodplain is in part defined by the Valley Fault System with the up thrown blocks comprising the high relief areas of Antipolo City to the east and the Diliman Plateau to the west.

The region experiences Type II climate over the year. November to April is typically the dry season while May to October is considered to be the wet season. The average annual rainfall is around 2405 mm with a monthly maximum of 504.2 mm usually during August and a minimum of 7.2 mm every February (PAGASA, 2009).

A significant factor in the damage brought by the floods can be attributed to the lack of preparedness of the populace. No warning or monitoring systems were in place. On hindsight, knowing that such a huge flood can take place in Metro Manila it is important to revisit the Ketsana flood event and understand its hydrologic details. This will hopefully minimize if not prevent much of the damage and loss of lives from a similar incident that may happen in the future.

2 Methodology

2.1 Interviews and field measurements

In the absence of any river gauging data along the river, local residents living along the Marikina River were interviewed two days after the flood event. The time of peak flood, estimated maximum height and rate of flood water increase were inquired. This is primarily to reconstruct the flood and determine the lag time between the peak rainfall and peak run-off as well as flood wave velocity. At least five respondents from eight stations were included in the survey. The stations chosen include areas from the upstream of Marikina River going downstream: Sitio Harangan, Wawa, San Isidro, Pacific Bridge, Rodriguez, San Mateo Bridge, Brgy. Nangka, and JP Rizal. Flood marks in houses, bridges and trees were also noted and measured with respect to the ground level (Fig. 3).

2.1.1 Basin and sub-basin delineation using GIS

The use of digital elevation models (DEM) in geomorphological analysis especially in regional scope is at the core of most environmental process modeling and disaster management (Schumann et al., 2008). The availability and globally available DEMs (e.g., SRTM) brought in a big step in hydrologic and hydraulic modeling. Geographical Information System (GIS) provides an ideal tool for environmental planning, and a well-established tool used for hydrologic modeling, because they make use of the capabilities of modern, high-speed computers to store large amounts of environmental data in geographical format, to manipulate these data according to some model of environmental processes, and to display material in pictorial form (Bhadra et al., 2009; Coroza et al., 1997).

The availability of public domain GIS platform to process these free DEMs are essential especially when finances are a limitation. Needless to say, DEM and GIS are increasingly becoming important in hydrological research. The incorporation of hydrologic modeling in GIS redefines the model in spatial context by giving new possibilities in understanding the fundamental physical processes underlying the hydrological cycle and the solution of mathematical equations representing those processes (Castrogiovanni et al., 2005; Liu et al., 2005; Correla et al., 1998; Coroza et al., 1997). Moreover, the results can be presented visually, which is exceptionally useful for non-technical people and to disaster managers (Usul et al., 2006; Wolski et al., 2006; Zerger et al., 2004; Chubey et al., 2004).

Several studies have confirmed that the overall quality of SRTM DEM is sufficient for hydrologic model applications and flood risk analysis (Schumann et al., 2008; Demirkesen et al., 2007; Ludwig et al., 2006; Valeriano et al., 2006). A finished 3-arc second (90 m resolution) SRTM (Shuttle Radar Topography Mission) DEM (Digital Elevation Model) was processed in a GIS platform – Integrated Land and Water Information System (ILWIS version 3.2) to ultimately delineate the basin and the sub-basins of the area for the hydrologic modeling. ILWIS is open access software that can perform various image processing. The DEM hydro-processing also generated maps showing the topography, the flow direction, flow accumulation, river networks and stream order. Arcview which is likewise a GIS platform was used to make necessary adjustments of the sub-basin delineation done in ILWIS.

2.2 Hydrologic modeling: HEC-HMS

The hydrologic modeling method was employed to generate peak flows and hydrographs for different areas along the Marikina River for TS Ketsana. With this, the amount of lag time between the peak rainfall and peak run-off can be determined as well as the timing of peak run-off of different points along the stretch of the Marikina river.

The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS), version 3.2 was used to develop the hydrologic model. The model is developed by the US Army Corps of Engineers, designed to simulate the precipitation-runoff processes of dendritic watershed systems (USACE 2008). The inputs include information from the basin model, the meteorological model, time-series data and paired data, and control specifications. A range of well-known cumulative loss models in HEC-HMS include initial and constant-rate loss model, deficit and constant rate model, SCS-CN (Soil Conservation Service-Curve Number) loss model, and Green-Ampt loss model.

The sub-basin map previously generated was used as a guide in creating the basin model of the Marikina River Basin. The SCS-CN loss method was employed. This method is one of the most popular and widely used methods in hydrologic modeling and hydrologic forecasting (e.g., Van Dijk et al., 2010; Maharjan et al., 2009; Geetha et al., 2008). In the study of Lastra and others (2008), they chose the SCS method for it is commonly used in different environments and deliver good results. Its calculation is easier because it requires only few variables, and despite its simplicity, it gives results as good as the more complex models. In the study of Baltas et al. (2007), they used the SCS-CN method to determine the initial abstraction ratio in a watershed using various rainfall events. This method also works well on rainfall-runoff data of high magnitude

(Mishra et al., 2005).

The SCS-CN method calculates precipitation excess as a function of cumulative precipitation, land use, soil cover and antecedent moisture given by the equation (Singh, 1994):

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} \quad (1)$$

where, P_e=accumulated excess rainfall or direct runoff, P=accumulated amount of rainfall, I_a=amount of initial abstraction, and S=storage or the potential maximum retention of the watershed. Analysis of the results of the numerous experiments, the SCS developed an empirical relationship between I_a and S as I_a=0.2S. The cumulative excess at time t is thus given as:

$$P_e = \frac{(P - 0.2S)^2}{P_a + 0.8S} \quad (2)$$

The SCS Unit hydrograph (SCS UH) was used to transform rainfall excess into direct surface run-off. This method is appropriate for determining the timing of the rainfall excess with respect to the peak of the direct run-off. The UH peak (U_p) and time of UH peak (T_p) are given as:

$$U_p = C\frac{A}{T_p} \quad (3)$$

where, A=watershed area; and C=conversion constant (2.08 in SI). The time of peak is related to the duration of the unit excess precipitation as:

$$T_p = \frac{\Delta t}{2} + t_{lag} \quad (4)$$

where Δt=the excess precipitation duration and t_{lag}=the basin lag or the time difference between the center of mass of rainfall excess and the peak of the direct run-off.

The land-use classification map was derived from existing satellite imagery. Type II soil condition and Antecedent Moisture Condition II (AMC II) were chosen as the conditions of the basin and the weighted curve number (CN) of each sub-basin were calculated using the empirical formula for CN calculation. The parameters for the hydrologic model are given in Table 1.

3 Results and discussion

3.1 Interviews and fieldworks

Across interviews very similar data on flood height and peak flood timing for each station were gathered. This proves that first-hand accounts of flood characteristics are sufficiently accurate. The interviews revealed that the time of peak flooding along the Marikina River varies significantly (Fig. 2). Significant rain in the watershed started around 08:00 to 10:00 LT. The recorded floods in the most upstream station started at 10:00 LT while the highest floods downstream were recorded between 20:00 to 22:00 LT. This means that the lag time between rainfall and flooding is anywhere from 0–10 h. The peak flood heights also ranged from one meter up to 12 m with respect to the riverbed. The highest flood heights were recorded in San Mateo Bridge and JP Rizal stations.

3.2 Basin and sub-basin delineation using GIS

Basin delineation using the SRTM DEM was accomplished using the GIS software ILWIS 3.0. The outputs are various maps necessary for the development of the hydrologic model. Figure 4 shows the different maps generated from the DEM hydro-processing.

The catchment extraction delineated more than 400 sub-basins in the MRB which were merged into 19 basins. Still, the river network map shows a distinctly high

drainage density typical of dendritic systems and reflecting a highly dissected basin. Small basins will respond rapidly relative to rainfall input and will likely have a faster hydrologic response compared to a single large basin.

3.3 Hydrologic modeling: HEC-HMS

The rainfall data used is the record in Philippine Atmospheric Geophysical and Seismological Administration (PAGASA), Science Garden Quezon City which is southwest of the study area. Considering that the tropical cyclone moved from east to west, it should be noted that rainfall occurred slightly earlier (1–2 h) in the watershed compared to where the weather station is located. Figure 5 shows the results of the discharge simulation run in HEC-HMS. As expected, the arrival of peak discharge varies in six stations as what was gathered from the interviews. In Station 1 the calculated peak discharge is 2197 m^3/s and arrived at around 12:30 LT; 2197.5 m^3/s at 13:00 LT in Station 2; 3771.8 m^3/s at 13:30 LT in Station 3; 4666 m^3/s at 14:00 LT in Station 4, 5598.8 m^3/s at 14:10 LT in Station 5; and 5921.6 m^3/s at 15:00 in Station 6. The lag time between the peak rainfall and runoff range in the upstream stations coincided well with the interview data. The discrepancy in peak runoff in downstream MRB between observed (interview data) and model results is likely due to the other sources of flood waters which were not taken into account in the model. The observed peak floods (20:00 LT) in the downstream floodplains may be considered as inundation or flood water accumulation from other sources as well as backflow from the filled up river conduits downstream.

The maximum discharge calculated from the HMS model is 5921 m^3/s which is comparable to the preliminary computations done by the National Hydraulics Research Center (NHRC) (*unpublished report*) which is 5770 m^3/s peak discharge at the Sto.Niño station using a different hydrologic model. This range of values is the highest in the 42-year record (1958–2000) of the country and largely exceeded the projected 100-year flood discharge of 3440 m^3/s.

4 Conclusions and recommendations

Anecdotal accounts showed that the time lag between the peak rainfall and peak flood in Marikina River Basin vary with distance from the watershed. The lag time increases downstream from 2 h in Station 1 (Brgy.Wawa) up to 10 h in Station 6 (JP Rizal). These were consistent with the results of the hydrologic model except in the downstream stations where more factors come into play. Nevertheless, the lag time observed between rainfall and flooding could have been enough to get the communities prepared of the impending floods. The model developed in this study can be further refined with actual data and integrated in early warning systems. Future studies should include mapping of the extent of flood inundation to determine how this amount of discharge translate into flood spatial extent and distribution. The results of this study can be used to generate flood risk maps when integrated with channel model and digital elevation data with sufficient resolution. In the absence of gauging stations to be used for the hydrologic modeling, interviews and flood markers showed to be potentially helpful in reconstructing flood events.

Many cities like Marikina City are located in floodplains and will be constantly affected during times of high precipitation events. It is therefore imperative to install hazard mitigation programs to lessen the effects of flooding. One way is to implement a communication system that will alert the downstream communities once a threshold level is achieved upstream. As shown in this study, enough lag time between upstream and downstream floods is usually present such that flood preparation is possible. Lastly, predicting flood heights through modeling can be done with meager resources and such data will only contribute to the success of any early warning system.

References

Baltas, E. A., Dervos, N. A., and Mimikou, M. A.: Technical Note: Determination of the SCS initial abstraction ratio in an experimental watershed in Greece, Hydrol. Earth Syst. Sci., 11, 1825–1829, doi:10.5194/hess-11-1825-2007, 2007.

Bhadra, A., Bandyopadhyay, A., Singh, R., and Raghuwanshi, N. S.: Rainfall-Runoff Modeling: Comparison of Two Approaches with Different Data Requirements, Water Resour. Manag., 24(1), 37–62, doi:10.1007/s11269-009-9436-z, 2009.

Castrogiovanni, E. M., La Loggia, G., and Noto, L. V.: Design storm prediction and hydrologic modeling using a web-GIS approach on a free-software platform, Atmos. Res., 77, 367–377, 2005. 6084

Chubey, M. S. and Hathout, S.: Integration of RADARSAT and GIS modeling for estimating Red River flood risk, GeoJournal, 59, 237–246, 2004. 6084

Coroza, O., Evans, D., and Bishop, I.: Enhancing runoff modeling with GIS, Landscape Urban Plan., 38, 13–23, 1997. 6084

Correla, F. N., Rego, F. C., Saraiva, M., and Ramos, I.: Coupling GIS with hydrologic and hydraulic flood modelling, Water Resour. Manag., 12, 229–249, 1998. 6084

Demirkesen, A. C., Evrendilek, F., Berberoglu, S., and Kilic, S.: Coastal flood risk analysis using landsat-7 ETM + imagery and SRTM DEM: a case study of Izmir, Turkey, Environ. Monit. Assess., 131, 293–300, 2007. 6084

Geetha, K., Mishra, S. K., Eldho, T. I., Rastogi, A. K., and Pandey R. P.: SCS-CN-based continuous simulation model for hydrologic forecasting, Water Resour. Manag., 22, 165–190, doi:10.1007/s11269-006-9149-5, 2008. 6085

HEC: Hydrologic Modeling System: Technical Reference Manual, US Army Corps of Engineers Hydrologic Engineering Center, Davis, C. A, 2008.

Lastra, J., Fernandez, E., Diez-Herrero, A., and Marqueinez, J.: Flood hazard delineation combining geomorphological and hydrological methods: an example in the Northern Iberian Peninsula, Nat. Hazards, 45, 277–293, 2008.

Liu, Y. B. and De Smedt, F.: Flood modeling for complex terrain using GIS and remote sensed information, Water Resour. Manag., 19, 605–624, 2005. 6084

Ludwig, R. and Schneider, P.: Validation of digital elevation models from SRTM X-SAR for applications in hydrologic modeling, ISPRS J. Photogramm. Remote Sens., 60, 339–358, 2006. 6084

Maharjan, M., Pathirana, A., Gersonius, B., and Vairavamoorthy, K.: Staged cost optimization of urban storm drainage systems based on hydraulic performance in a changing environment, Hydrol. Earth Syst. Sci., 13, 481–489, doi:10.5194/hess-13-481-2009, 2009. 6085

Mishra, S. K., Jain, M. K., Bhunya, P. K., and Singh, V. P.: Field applicability of the SCS-CN-based mishra-singh general model and its variants, Water Resour. Manag., 19, 37–62, 2005. 6086

Philippine Atmospheric Geophysical and Seismological Administration (PAGASA), http://kidlat.pagasa.dost.gov.ph/, 2009. 6083

Schumann, G., Matgen, P., Cutler, M. E. J., Black, A., Hoffmann, L., and Pfister, L.: Comparison of remotely sensed water stages from LiDAR, topographic contours and SRTM, ISPRS J. Photogramm. Remote Sens., 63, 283–296, 2008. 6084

USACE: Hydrologic Modeling System: Technical Reference Manual, US Army Corps of Engineers Hydrologic Engineering Center, Davis C.A., 2008.

Usul, N. and Burak, T.: Flood forecasting and analysis within the Ulus Basin, Turkey, using geographic information systems, Nat. Hazards, 39, 213–229, 2006. 6084

van Dijk, A. I. J. M.: Selection of an appropriately simple storm runoff model, Hydrol. Earth Syst. Sci., 14, 447–458, doi:10.5194/hess-14-447-2010, 2010. 6085

Valeriano, M. M., Kuplich, T. M., Storino, M., Amaral, B. D., Mendes, J. N., and Lima, D. J.: Modeling small watersheds in Brazilian Amazonia with shuttle radar topographic mission-90 m data, Comput. Geosci., 32,1169–1181, 2006. 6084

Wolski, P., Savenije, H. H. G., Murray-Hudson, M., and Gumbricht, T.: Modelling of the flooding in the Okavango Delta, Botswana, using a hybrid reservoir-GIS model, J. Hydrol., 331, 58–72, 2006. 6084

Zerger, A. and Wealands, S.: Beyond modelling: linking models with GIS for flood risk management, Nat. Hazards, 33, 191–208, 2004. 6084

Table 1. Hydrologic element parameters.

Sub-basin	Minimum	Maximum
Area (km^2)	11	30.25
Curve Number (CN)	65	90
Time of Concentration (h)	2.3	5.8

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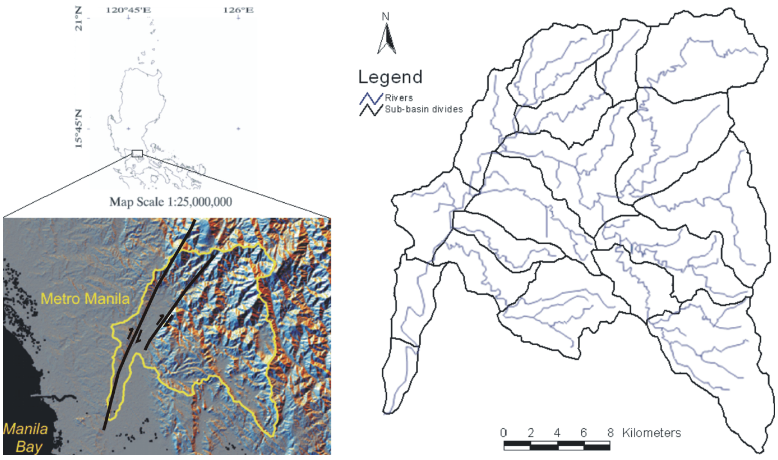

Fig. 1. The Marikina River Basin transverse by the East and West Marikina Valley Faults (black lines).

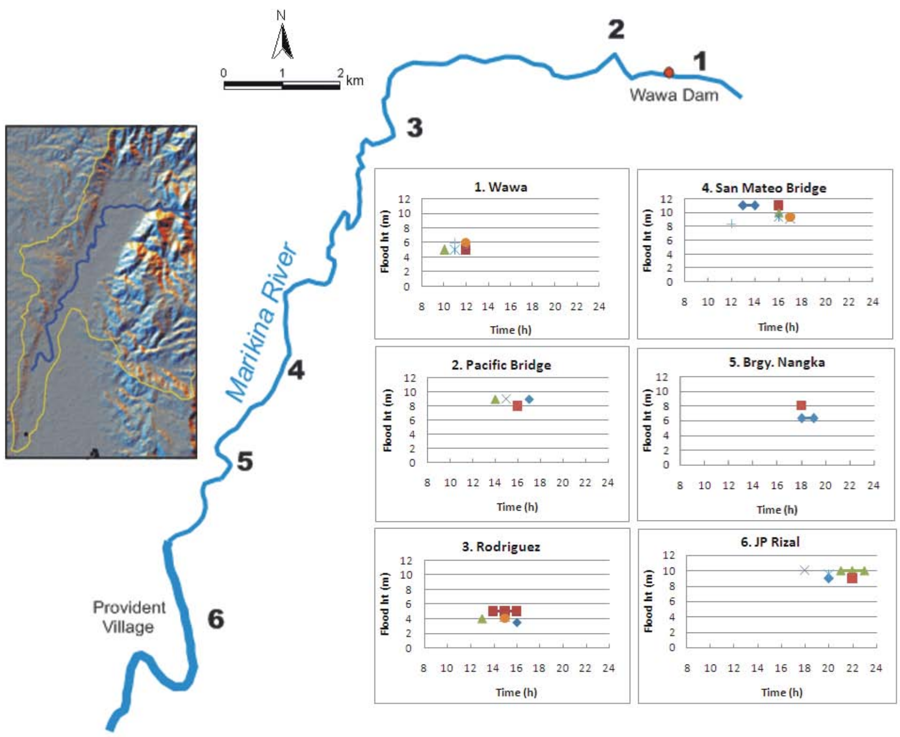

Fig. 2. Anecdotal accounts of the time of peak flooding in various points along the Marikina River.

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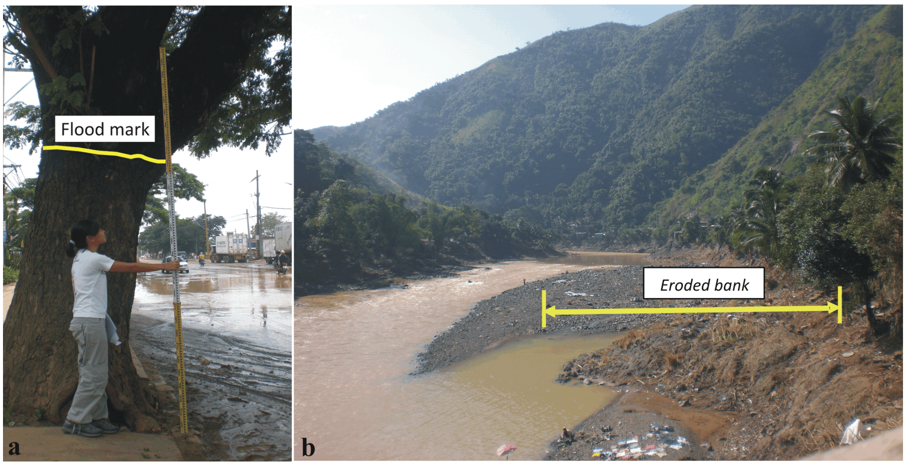


Fig. 3. **(a)** Photo taken along JP Rizal Avenue showing mud (stain) deposits on the bark of the tree indicating flood height and; **(b)** photo of upstream Marikina River showing extensive bank erosion.

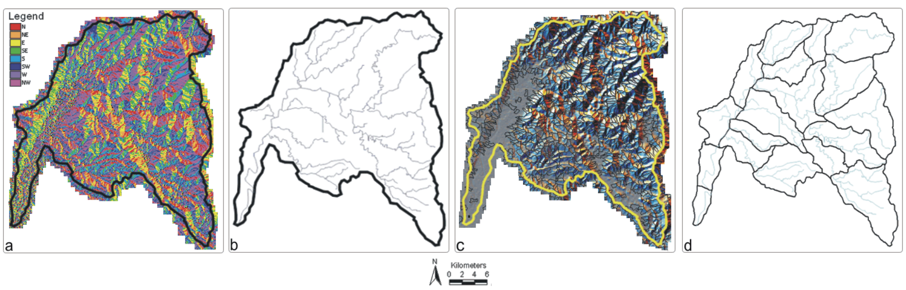
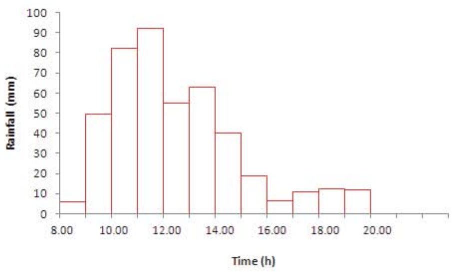


Fig. 4. Maps generated from DEM-Hydroprocessing **(a)** flow direction map, **(b)** drainage network map, **(c)** sub-basin map and **(d)** merged sub-basin map.



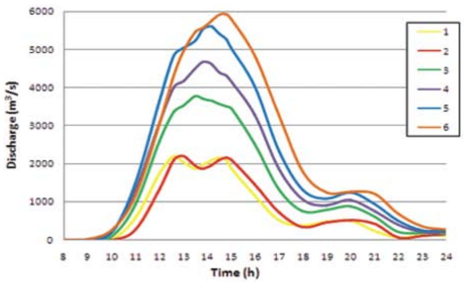


Fig. 5. The rainfall data used in the hydrologic model simulation and the resultant hydrographs. The different colors represent the corresponding station as the interview stations.