Hydrological Modelling Approach for Flood and Water Pollution Control in an Ungauged Catchment - A Case Study in Erewwala Catchment in Bolgoda River Basin, Sri Lanka

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ABSTRACT

The data scarcity is a widespread, global issue and unavailability of reliable hydro meteorological data is one of the major issues the hydrologists and researchers are facing in Sri Lanka when it comes to water resources planning and management. A significant increase in occurrence of flash flood incidents and water quality degradation in surface water bodies have been noted in the recent past. Hence, developing an approach to identify underlying causes and recommend mitigation or preventive measures for floods and water pollution is a timely requirement that planners, designers and researchers should attempt. The objective of this project is to formulate a hydrological modeling approach to recommend preventive or migratory measures for floods and water pollution in ungauged catchments based on the findings of a case study in Erewwala catchment in Bolgoda River Basin, Sri Lanka. The parameters of hydrological models for ungauged catchments can be estimated using regional information. For this case study, a rainfall-runoff model was developed in spreadsheet and graphical format where the monthly runoff coefficient and base flow were the model calibration parameters. The model was calibrated based on observed data for three years and validated for two years. Observed discharge data at Millakanda gauging station, basin rainfall obtained from Rakwana, Horagoda and Usk Valley rainfall stations and evaporation data from Colombo were used for the model developed for Kaluganga. The calibrated parameters of Kaluganga basin were used for the water resources assessment in Erewwala catchment (2.9 km^2). The catchment was divided into three sub-catchments for water pollution control purpose and the incremental runoff at the each sub-catchment outlet node was estimated using the rainfall- runoff model. The types of water uses were identified for each sub-catchment unit and the discharges due to each water use in individual catchments were calculated, subsequently deriving the contribution of each catchment to its overall water pollution. These values were compared with the stipulated permissible pollutant level in surface water bodies. For flood control measures, the HEC-HMS (US-ACE) software was used to estimate the peak discharge with 10 year return period storm event and the peak discharge in each catchment node was obtained. The required flood controlling measures were identified and recommended for the critical catchments which contribute to the highest discharge leading to flashflood conditions in the downstream areas. Based on the peak flow and pollutant source analyses, the sub-catchment No. 1 was identified as the most polluted catchment as well as the one which contributes the most to the flash floods in Erewwala catchment.

KEYWORDS: Data scarcity, Flash flood, Hydro meteorological data, Rainfall-runoff model, Water pollution.

1. Introduction

Runoff estimation for ungauged catchments is a typical issue in Water Resources Management. This paper aims to introduce a practically viable approach to establish flood mitigation and water quality control measures focusing on an ungauged catchment. This method will be more appropriate for the catchments with relatively uniform climate conditions and land use patterns.

1.1. Study Area

Erewwala sub catchment which is in the Bolgoda river basin spatially spreads over an area extent of 2.9 km2. A significant variation in land use pattern can be observed within this area and the dominant land use pattern amongst all is the homestead garden (Figure 1). This area can be categorized as a semi-urbanized area. Available soil group in the area is "Red-yellow podzolic soils with soft or hard laterite rolling and undulating terrain" (De Alwis & Panabokke, n.d.).

In terms of hydrology, this area receives rainfall during South-West monsoon and intermediate monsoon periods.

According to the Meteorological department data, annual rainfall in the study area is around 2500 mm and the annual evaporation is around 1500 mm.

Though there are multi-sector water users in the study area, none of them extract water from surface

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water bodies. Only rain-fed irrigation is being practiced in this area. The surface water bodies in the river basin ultimately drain into the Bolgoda Lake in which water quality is becoming gradually deteriorated (Illeperuma, 2001). This is an indirect indication that the surface water bodies are carrying pollutants to the Bolgoda Lake.

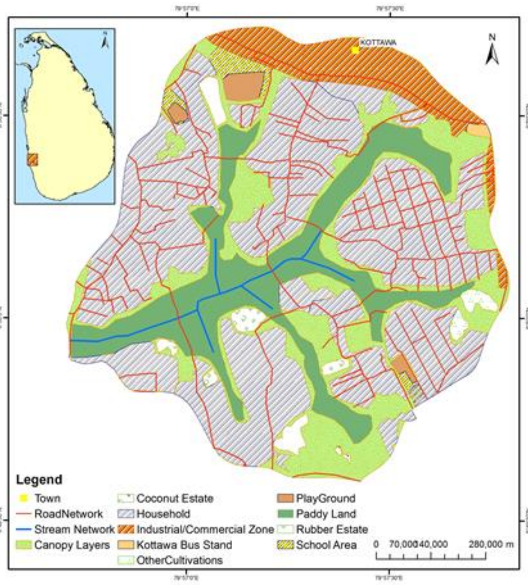

Figure 4: Location Map

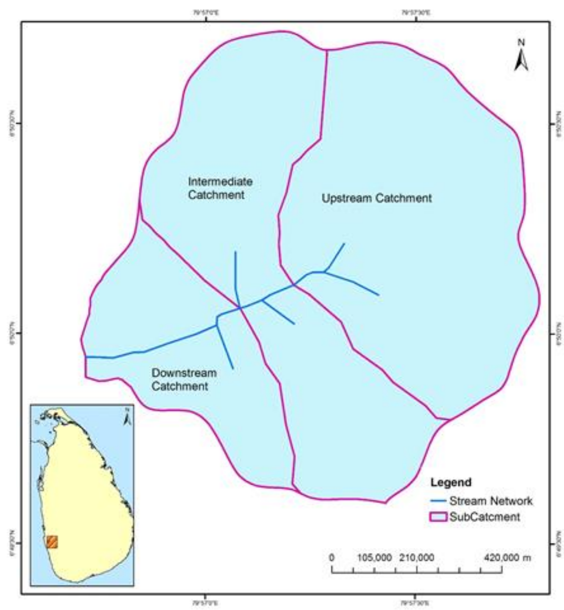

Figure 2: Delineated Sub-catchments in Study Area

Though the lake is situated outside of the study area, it is a part of the interconnected surface water bodies in the study area and ultimately drains into the Bolgoda Lake. In the environmental and social point of view, it is a vital requirement to avoid such possibilities of getting the surface waterbodies polluted. Further, the groundwater level in the study area is shallow. Hence, there is a high risk of associated groundwater pollution if the surface water is affected.

The frequent flooding during monsoonal periods is another critical issue in the downstream settlement areas while the paddy lands and the roads are the most prone areas to inundation during such periods. Therefore, immediate action should be planned and implemented to avoid aforementioned adverse situations.

2. Approach and Methodology

2.1. Data Collection

As the preliminary step for the study, a social survey was carried out to identify the issues related to water sector in the area. The interviewees for the survey were selected representing all groups of stakeholders including farmers, residents, business and industrial owners, etc. The individual personals for the survey were however arbitrarily selected.

Table 2: Social Survey- Issues Related to Water Sector

Category	Response
Farmers	Inundation of paddy lands during rainy season
Residents	Inundation of roads during rainy seasons

Once the social survey was completed, next objective was to quantify the available water in the area. There is no way to quantify the groundwater in the area. The information available related to groundwater is very limited in Sri Lanka (Panabokke & Perera, 2005). Therefore, the objective was narrowed down to quantify only the surface water resources in the intended area. Accordingly, it was decided to develop a spreadsheet based rainfall runoff model based on water balance concept. The next challenge was to collect hydo-meteorological data for the rainfall runoff model. There were no any established hydo-meteorological monitoring stations within the study area. Hence, it was decided to develop a hydrological model for an area in which the functioning hydo-meteorological stations are available (Mwakalila, 2003). The model with the calibrated parameters was then used to generate discharge for the intended area. Further, the area was selected in such a way that the topography, land use pattern and climate in the selected area is similar to those of the Erewwala sub catchment.

After a careful study, the observed hydro-meteorological data in Millakanda sub catchment in Kaluganga basin was selected to develop the rainfall-runoff (RR) model for Erewwala area. The collected data for this analysis are shown in Table 2.

Table 2: Hydro-meteorological data- Kalu Basin

Station	Data type	Duration
Millakanda	Daily discharge	01/10/95 ~ 30/09/98
Rakwana	Daily rainfall	Do -
Horagoda	Do -	Do -
Uskvally	Do -	Do -
Colombo	Do -	1/01/95 ~ 31/12/14
Colombo	Evaporation data	Monthly average data

2.2. Data Checking and Pre-Processing

The raw data was checked for outliers, inconsistencies and missing values and pre-processed in accordance with the Dahmen and Hall (1990).

First, the collected rainfall data for the three stations were plotted in one graph. The trend, variation of the rainfall pattern and the missing data were checked. Then the outlier test was carried out for all the stations. Once the outlier test was carried out, data consistency for each station was checked using single and double mass curves.

The Thiessen polygon method was used to calculate the basin rainfall. Further, the calculated basin rainfall was plotted with the observed discharge in order to check whether any mismatch available with the two data sets (Figure 3).

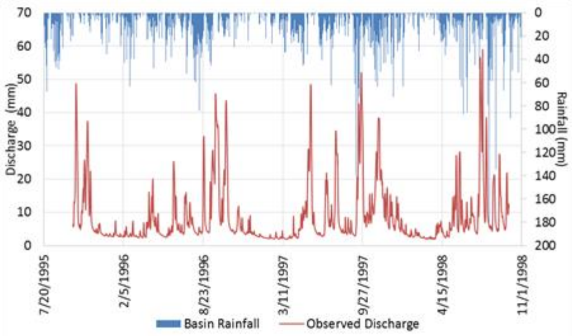

Figure 3: Observed discharge Vs Basin Rainfall in Kalu Ganga Basin

2.3. Catchment Delineation of the Study Area

The most widely practiced method for catchment delineation is to use a Digital Elevation Model (DEM) in the area. For this study area, there is no such DEM available except for the 30 m and 90 m resolution digital elevation models from the Shuttle Radar Topography Mission (SRTM) which are available in United State Geological Survey (USGS) website. As the study area is relatively small, such low resolution DEM will not accurately represent the actual elevation profile in the area. Hence, the catchment delineation was carried out manually after careful observation of the topography in the area during the site visits and with the use of 1: 50,000 topographic maps (Survey Department, Sri Lanka). The Erewwala catchment was delineated into three (03) sub-catchments as shown in Figure 2.

2.4. Sub-Catchment Contribution to Net Outflow

The net flow to each catchment outlet node was simulated using the aforementioned spreadsheet based rainfall runoff model. The runoff for each catchment was calculated by using the calibrated parameters and using the rainfall data collected from Colombo rainfall station and by changing the catchment area.

2.5. Spread Sheet based Rainfall- Runoff Model

The developed spreadsheet based rainfall-runoff model consists of two calibration parameters as listed below.

i. Monthly runoff coefficient
ii. Base-flow

The inputs for the model were daily basin rainfall and daily evaporation (derived from monthly evaporation), while output was the daily discharge. The model calibration was carried out for the period of 01 Oct 1995 - 30 Sep 1997. Model validation was checked for the period of 01 Oct 1997 - 30 Sep 1998.

2.6. Peak Flow Calculation

The peak-flow estimation for each sub-catchment was carried out for a 10 year return period storm event, by considering the severity of the possible damages and based on the information collected during the reconnaissance and subsequent field surveys. During the social survey, it was identified that the most downstream area of the catchment is vulnerable to damages due to flood.

The HEC- HMS model was used for peak flow estimation. The Intensity-Frequency-Duration (IDF) curves prepared for Colombo rainfall was used for designing the relevant 2 hr storm event (Ranatunga, 2001).

2.7. Central Environmental Authority (CEA) Recommendation

According to the guideline stipulated by the Central Environmental Authority of Sri Lanka (CEA) for discharges into waterways, there should be a minimum permissible dilution of 1 is to 8. Thus, based on the recommended dilution factor, the maximum permissible grey water discharge volume for each catchment node was calculated.

3. Results

The extent of the delineated catchments are listed below.

i.Upper catchment (U/S) - 1.20 km^2
ii.Intermediate catchment (IM) - 1.09 km^2
iii.Downstream Catchment (D/S) - 0.53 km^2

The Table 3 shows the data collected during the social survey as well as from the 1: 50,000 topographic base maps (Survey Department, Sri Lanka) for each sub-catchment shown in Fig. 2.

Table 3: Land Use in Erewwala Catchment

	Catchments		
	U/S	IM	D/S
Canopy Layers (m2)	216,936	270,675	44,578
Population	5,584	3,648	1,788
Other Cultivation (m2)	19,045	-	-
Paddy Land (m2)	175,277	238,008	105,484

The spreadsheet based hydrological model calibration plot for Kaluganga- Millakanda sub-catchment is shown in Fig. 4. The calibration period was selected from 01 Oct 1995 to 30 Sep 1997. The correlation between the observed and simulated flows during the wet season has indicated a better agreement (R2=0.74) compared to that of the dry season (R2=0.62). The variation of cumulative observed and simulated discharges are shown in Fig. 5.

Further, the model verification was carried out for the period of 01 Oct 1997 to 30 Sep 1998 and the correlation of the observed and the simulated discharge is shown in Fig. 6.

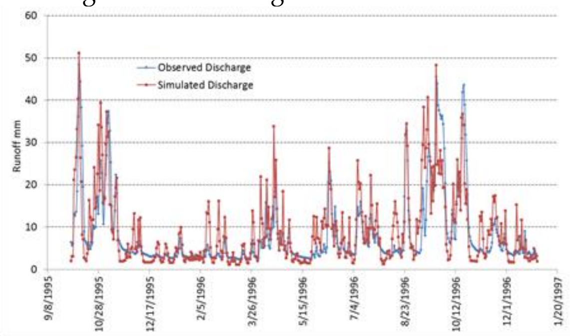

Figure 5: Model Calibration (Observed Vs Simulated Discharge in Kalu basin)

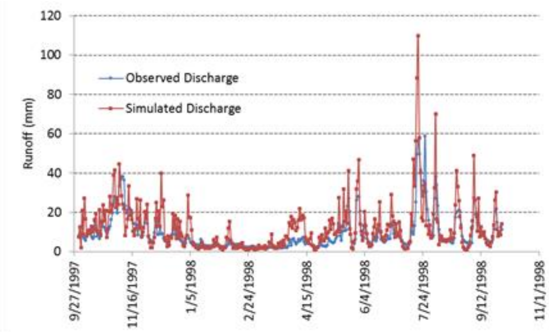

Figure 6: Variation of Cumulative Observed and Simulated Discharges

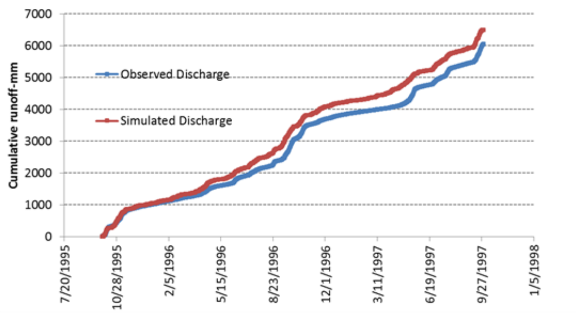

Figure 7: Model Verification

The calibrated parameters used for the spreadsheet model are shown in Table 4. The runoff coefficient was selected based on the land-use pattern and the average slope of the area (Chow, Maidment, & Mays, n.d.). The monthly runoff coefficient during the dry season of the year is less than that of the wet season as the soil moisture content is lesser during the dry season.

Table 4: Calibration Parameter

Month	Runoff Coefficient
January	0.30
February	0.30
March	0.30
April	0.35
May	0.35
June	0.40
July	0.40
August	0.40
September	0.40
October	0.51
November	0.45
December	0.35
Initial flow 4.5 mm	

The Fig. 7 to Fig. 9 illustrate comparison of the total flow, permissible greywater volume and the actual greywater volume each catchment outlet node. The greywater component consist with the return flow from paddy cultivation and the domestic water users. None of the return flows are measured figures.

Irrigation return flow was calculated based on the demand calculation procedure following Irrigation guideline (Ponrajah, 1984).

In the domestic return flow calculation process, it was assumed 80% of the demand will be discharged as the grey water component. Both National Water Supply and Drainage Board (NWS&DB) consumers and the water users fromdug wells were taken into account. Consumer data for potable water demand calculation was carried out based on the data collected from NWS&DB and the Water Resources Board, Sri Lanka. The per capita demand for domestic water was considered as 120 l/day.

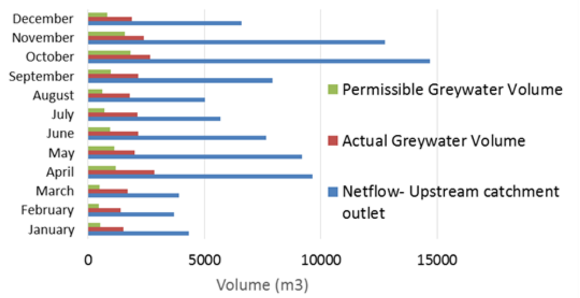

Figure 7: Volume Comparison at Outlet of Upstream Catchment

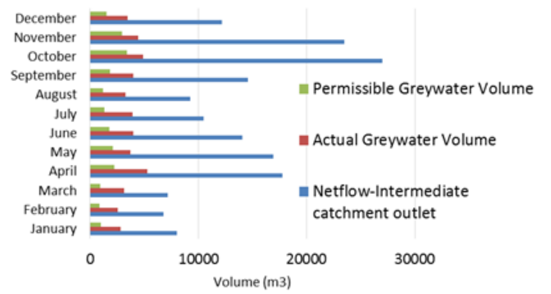

Figure 8: Volume Comparison at Outlet of Intermediate Catchment

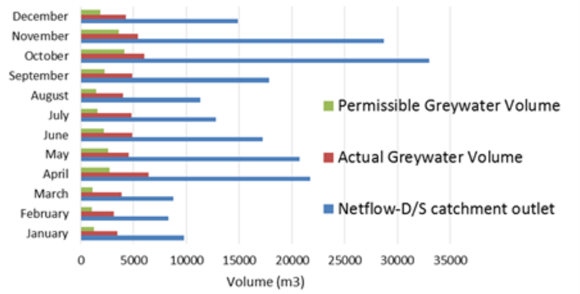

Figure 8: Volume Comparison at Outlet of Downstream Catchment

The Fig. 10 shows the generated 2 hr storm event as mentioned in Section 2.6. In peak flow generation, the flow loss method was set as Initial and constant method (Initial loss- 0.1 mm, Constant rate 0.05 mm/hr and Impervious – 10%) while the transform method was specified as SCS Unit hydrograph .The generated peak flow at the catchment outlet is shown in Fig. 11. Peak discharge in 10 year return period event is 71.9 m3/s.

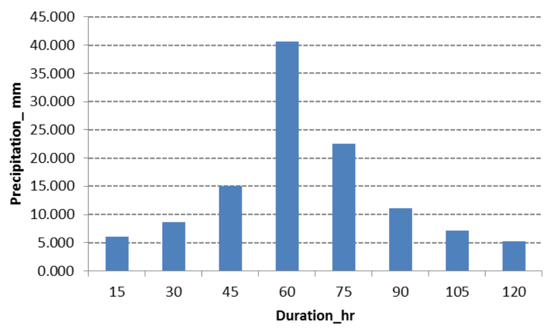

Figure 10: Design Storm - 10 year return Period

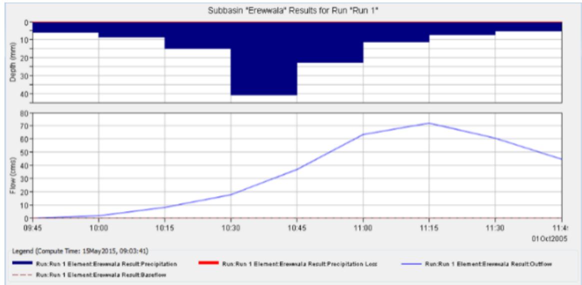

Figure 11: Generated Hydrograph for the Catchment outlet

4. Conclusion and Recommendation

In each catchment, the actual grey water content is higher than the maximum permissible levels stipulated by the Central Environmental Agency (CEA). Therefore, it is recommended to construct a separate grey water collection channel and direct it to a treatment plant. In this particular case, the upstream catchment contribution to water pollution is more significant compared to the other two catchments.

The most downstream catchment is vulnerable to the flood hazard. The highest contribution to the runoff is from the upstream most catchment. The estimated flow to the catchment outlet for 10-year return period event is 0.25 MCM. Hence, it is recommended to have detention ponds within the catchment to retard and regulate the flow. Further, most of the farmers mentioned that if water is available during the dry season, they can continue their crop cultivation without limiting it only to monsoon periods. Therefore, having detention ponds would facilitate soil moisture replenishment and continuous irrigation water supply in the area. Further, it is recommended to setup a hydro meteorological station either within the catchment or in a nearby area, if this basin is intended to be developed as a pilot research area for further improving the rainfall runoff model.

5. Acknowledgement

The author would like to extend her sincere gratitude towards the UNESCO Madanjeet Singh Center for South Asia Water Management for selecting her for the Post-graduate Study Programme in Water Resources Engineering and Management.

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