Setting up an experimental basin in Sri Lanka for PUB studies

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Abstract In order to enhance the knowledge base through increased observations and measurements in different hydrological regimes, the present study proposes to set up and model a mountainous catchment in Sri Lanka as a part of the PUB initiative. A comprehensive GIS at 1 km spatial resolution is being prepared. Rainfall data would be available on a daily scale, with a few stations having measurements at higher temporal resolutions. Different scaling techniques would be adopted to prepare a cascading database at increasing spatial and temporal resolutions. For modelling and monitoring purposes the catchment is divided in to three areas: relatively virgin head water area with limited stream flow and rainfall measurements, one upstream segment with comprehensive rainfall and flow measurements, and finally the inflow records at the outlet of the catchment defined by a hydropower reservoir. This paper describes the catchment, the planned experiment, and some preliminary analysis of the rainfall and discharge trends of the catchment.

Key words experimental basin; hydrological modelling; PUB; rainfall trends

INTRODUCTION

Hydrological measurements available for understanding catchment responses are almost always insufficient to uniquely define the hydrological status of the catchment. In order to discuss them adequately it is necessary to enhance the knowledge base through increased observations and measurements in different hydrological regimes. In the present study we propose to set up and model a mountainous catchment in Sri Lanka as part of the PUB initiative. In particular, the study is geared to address the question: "how much information is required to estimate a required hydrological response, specifically the flow discharge at a gauging point, with a required accuracy?"

Sri Lanka is heavily dependent on water flowing from the major rivers originating in the central mountains. Hydropower has been the main source of cheap power for Sri Lanka and will continue to be the most economical and important power source in the future. As almost all the major streams have been dammed with little or no potential for major power generation, recently, the emphasis has been shifting to mini-hydro plants to alleviate the country's chronic power shortage. However, most of the streams in the country are ungauged and there is little or no information on the reliability and the quantity of stream flow in many of the mountain streams that abound the central hills. Developing the ability to predict the flow in these basins would be of importance to evaluate mini-hydro potential as well as design and deployment of mini hydro plants. In addition to the need for assessing water resources, there is also an urgent need in the country to assess the impact of climatic change. Past studies have also identified that Sri Lanka shows clear evidence of climatic change associated with global warming, especially a decline of rainfall in the central mountainous region. The present study is expected to contribute towards solving these problems.

CATCHMENT DESCRIPTION

The upper Kothmale basin, situated in the central hills of Sri Lanka, is selected as the study basin. The main stream of this basin, known as the Kothmale Oya is the major upstream tributary of Mahaweli Ganga, the most important water resources source in Sri Lanka. The drainage area of the basin is 555 km^2 and the elevations vary from around 650 m to over 2500 m a.m.s.l. The terrain is generally mountainous, with the highest elevations covered with virgin forests and grasslands. This upper part of the basin is a plateau bearing the springs that originate this river. Being situated in the wettest parts of the country it receives an average rainfall of greater than 2800 mm. A major portion of the basin is located above 1000 m and is largely planted with tea. The steeper slopes of the mountains are not utilized for tea plantations and are either covered with virgin forests or re-grown pine plantations. Rock outcrops can also be seen on the steeper slopes. At the top of the ridges small patches of trees, scrub and grassland prevail. Areas surrounding the steeper drainage paths are also covered with forest patches.

A reservoir for hydropower development is built at the outlet of the catchment. In the upstream parts a few small reservoirs and diversions are located, but they do not have a significant regulating effect on the river flow. These smaller reservoirs and diversions mainly serve for irrigation and mini-hydropower generation. A noticeable portion of the basin is also used for commercial vegetable cultivation.

As described above, considering the land use and land cover, the catchment can be divided in to three major zones. The southern and eastern areas in the first zone have higher elevations and a major portion belongs to plain terrain predominantly covered with virgin forests with some grasslands and pasturelands used for dairy. The second zone is the central part of the basin and mainly used by tea plantations. The eastern parts of the central basin are mainly used for vegetable cultivations. The third zone consists of the lowland valleys generally covered with tropical trees and bare lands. The population is distributed within both the second and third zones. In the second zone population is concentrated to settlements within plantation estates, whereas in the third zone population is distributed with many house gardens.

CURRENTLY AVAILABLE HYDROLOGICAL STATIONS AND PLAN FOR NEW STATIONS

The tea estates maintain most of the available rain gauging stations. The data are collected by the meteorological department of Sri Lanka, which archives them.

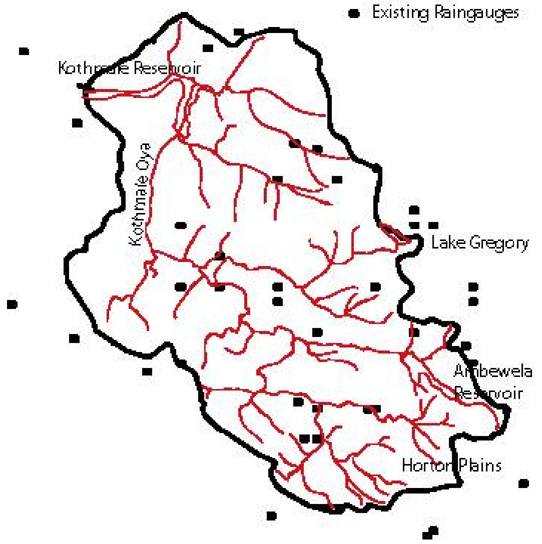

Fig. 1 Location of existing raingauges

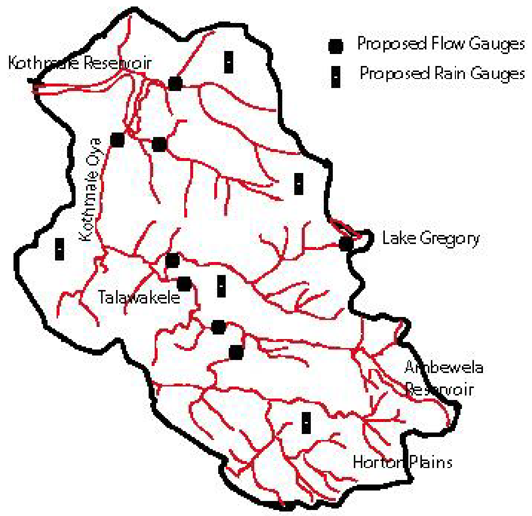

Fig. 2 Locations of proposed raingauges and flow gauges.

Locations of the stations from which the data were collected are shown in Fig. 1. Figure 2 shows the proposed stations where high resolution (0.1 mm) tipping bucket type raingauges will be installed. Also it shows the proposed flow gauging stations.

PROPOSED IMPROVEMENTS FOR AVAILABLE DATA SETS

It is proposed to carry out hydrological modelling in several stages. Starting with coarse data sets for meteorological and spatial data it is proposed to enhance the data resolution with extrapolation schemes and satellite remote sensing. Two such schemes, currently under study, are briefly described here.

Improving temporal resolution of rainfall data

Only daily rainfall data are currently available in the catchment at present. Although long time series of daily rainfall data are available at many tea estates, the raingauges are not of the same type and the funnel sizes vary. In the present programme a number of high resolution auto recording raingauges would be placed along with the existing raingauges so that some empirical method can be found to calibrate the gauge values.

Additionally, it is proposed to attempt rainfall disaggregation using a rainfall cascade model similar to that proposed by Olsson (1998). Here, the scaling behaviour of rainfall is modelled by a cascade process, as shown by Schertzer & Lovejoy (1987) and Gupta & Waymire (1990). The approach has been used successfully to derive hourly rainfall characteristics of Japanese rainfall series from daily rainfall data (Pathirana *et al*., 2001). In the disaggregation method proposed by Olsson (1998), a branching number of two is adopted, where a rainfall segment at a particular level of time resolution is divided into two segments of higher time resolution slots according to weighting factors w_1 and w_2, which are decided by a theoretical probability distribution, but expected to be dependent on the rainfall volume and the current resolution. Using the data from the newly established raingauges, as well as any existing data sets, the possibility of disaggregation of rainfall in the time domain will be attempted.

Elevation information improvement through drainage forcing

In addition to the global GTOPO30 (USGS, 1997) digital elevation data set, the national digitization scheme is under way to provide the 1:50 000 contours. Additionally 1:10 000 scale maps have been recently released, covering most of the area under consideration. Once this additional data integration is complete, the digital river network and a drainage-forcing algorithm (Hutchinson *et al*., 1991) can be used to adjust the elevation data set so that the elevation data set could correctly produce the river drainage network. A few pilot studies are planned to be carried out with a Kinematic GPS survey to establish the adequacy and accuracy of the adjusted elevation maps.

PRELIMINARY ANALYSIS OF RAINFALL OF THE CATCHMENT

In order to assess the hydrological climate change in the basin, daily data for 30 years were collected from about 60 rainfall-gauging stations from the central part of the country surrounding the basin under consideration. The selected stations lie on both sides of the central mountains and can therefore represent the spatial distribution of the rainfall trend variation in both of the predominant wind directions.

The rainfall was first investigated by examining the cumulative rainfall trend. Figure 3 shows this change for station number 60 (Wewelthalawa). Preliminary analysis of the data showed that a trend change has occurred during the period from 1975 to 1980. Therefore, the collected data series were divided into two sectors from

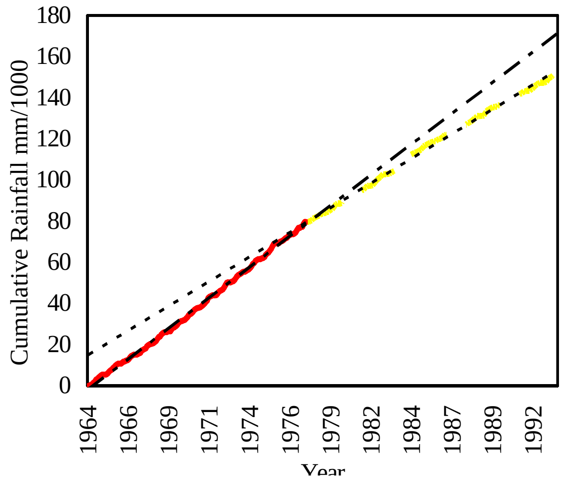

Fig. 3 Trend variation of cumulative rainfall for station no. 60

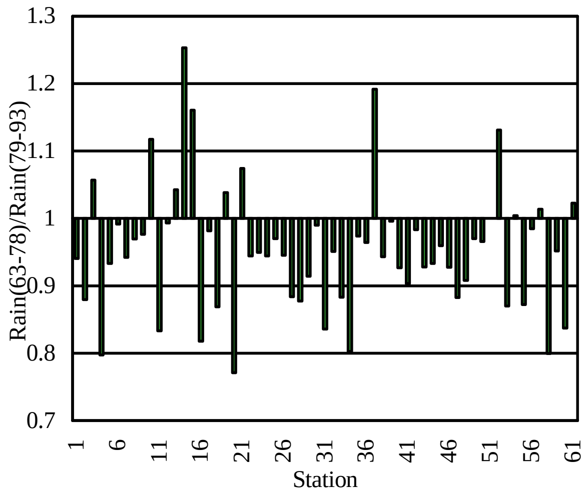

Fig. 4 Trend variation of cumulative rainfall of each station.

1964 to 1978 and 1979 to 1993 and the ratio of the two linear trends of these sectors was used for the comparison.

Figure 4 shows this ratio for all the raingauges considered which shows a variation from 1.25 to 0.77. A value of 1 indicates no change in rainfall trend. An increasing trend is seen for a few stations while the majority of stations showed a decreasing trend, and it can be concluded that rainfall is decreasing in most of the areas.

In order to find the change in the characteristics of rainfall occurrence, two different time series giving the lengths of wet spells and dry spells were calculated. The length of a wet spell was defined as the consecutive number of days with a significant rainfall. The minimum length of a wet spell was taken as one day. Similarly the lengths of dry spells were calculated. Most of the stations showed a negative trend variation in the cumulative lengths of wet spells and a corresponding majority of stations showed a positive trend change in the cumulative lengths of the dry spells. Combining with the previous results it can be said that both the rainfall and the number of rainy days show a decreasing trend. This poses the question whether there has been a change of rainfall intensities.

The rainfall intensity trend was investigated by dividing the rainfall seiries by the rain spell series and an analysis similar to that described in Figs 3 and 4 was performed. The results of this analysis are shown in Fig. 5 where it can be seen that the rainfall received per length of wet spell has increased for most stations. This means while both the rainfall and the rainy days have decreased, the rainfall intensity has increased in most of the locations. Next we investigate how these changes in rainfall are reflected in river discharge.

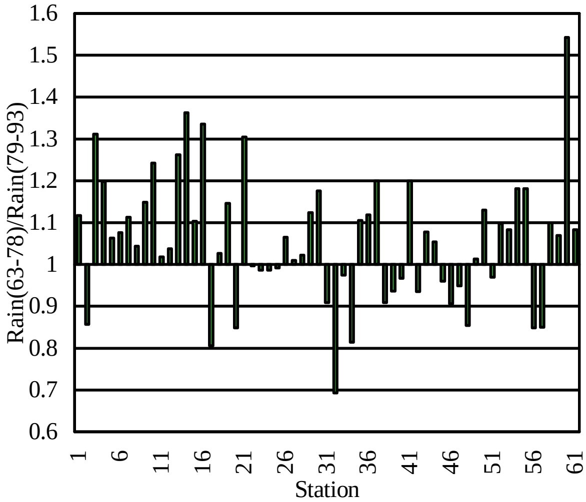

Fig. 5 Trend variation of rainfall per length of rain spell.

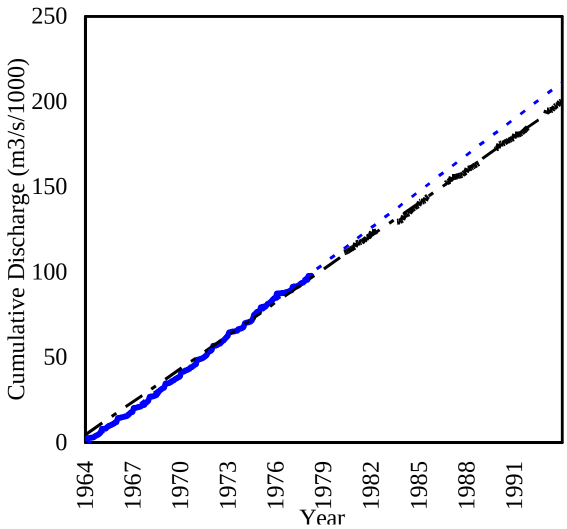

Fig. 6 Trend variation of cumulative discharge at Talawakele.

The runoff generated from the upper portions of the catchment during the same period, where the land use and land cover has not shown any significant change, was analysed to compare the trends with that of rainfall. The total runoff in the sectors from 1963 to 1978 and from 1979 to 1993 is shown in Fig. 6 and shows a slight decreasing trend. The annual maximum discharge and the average annual discharges are shown in Fig. 7, where peak discharge shows a deceasing trend, while the mean annual discharges do not show a significant trend. It is difficult to explain these results with only the rainfall trend, as one would expect the peak discharges to increase and the mean discharge to decrease in accordance with the rainfall distribution. This observation reinforces the need to carry out a detailed modelling exercise to understand how the rainfall trends translate to river discharges.

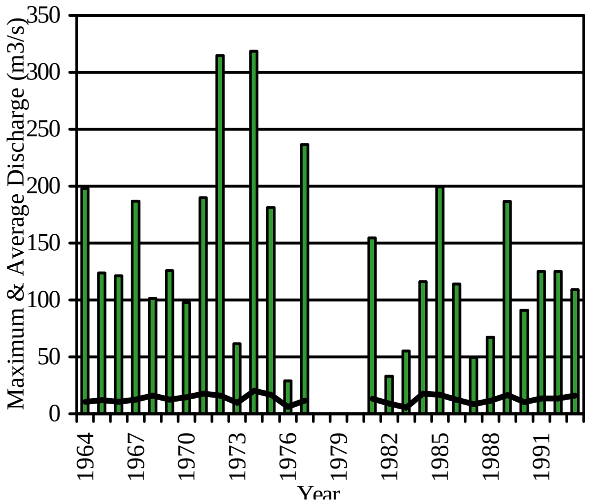

Fig. 7 Maximum and average discharge at Talawakele.

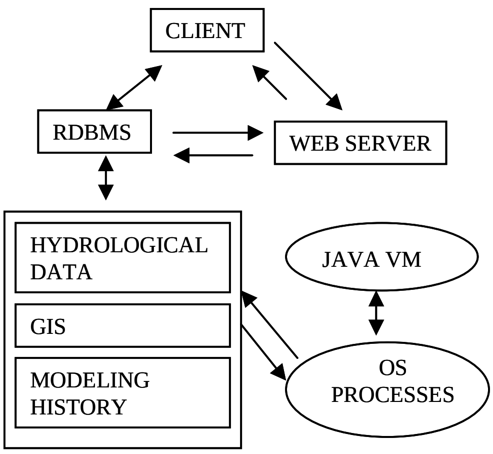

Fig. 8 Configuration of data dissemination system.

DATA DISSEMINATION PLAN

A dedicated www server is being set up for the dissemination of catchment hydrological data as well as for the archiving and verification of modelling experiments. The skill of predictions would be automatically calculated and the modellers would have the ability to update the information on the www server. The basic configuration of the dissemination system is shown in Fig. 8, which was designed previously for hydrological data dissemination (Herath & Pathirana, 1998). The main component of the system is a relational database, which would store catchment hydrological information as well as different modelling strategies and prediction skill of the modelling exercises.

The hydrological database consists of two components: the meta data structure that describe the data; and the actual data values. Table 1 shows the main categories of meta data and main attributes in each category. In the case of actual data all time series data are recorded as *data id, date, value* fields for each record. The *data id* is unique to a particular station and from the meta data a user can select the appropriate data set through the *data id*. Spatial data are stored as catchment units in the GIS and are retrieved using the meta data and *data id*. The attributes corresponding to each spatial data set is implemented through a link table, where for example, a soil map is linked to a soil data type table that describes each soil contained in the map, and each soil attribute is linked to its value.

Table 1 Meta data categories and main attributes.

Category	Main attributes
Geographical classification	Country, region, province, basin, latitude, longitude, etc.
Type classification	Rainfall, soil type, temperature
Source based classification	Observed, computed
Statistical classifications	Based on data quality, missing data
Data accessibility	Authorization levels, access mechanisms, alternative locations
Data management	Contact person, processing software, organization
Data coverage	Point or regional references, period covered

DESCRIPTION OF MODELLING EXPERIMENT

The modelling experiments are designed so that modellers can use data sets of increasing high resolution. For the first level of modelling, use of available 1 km data sets covering elevation (GTOPO30), land cover (USGS, global land cover) and soil data (derived from IGBP data set) is proposed. As for the meteorological data sets: (a) daily rainfall data from the available gauges; (b) weekly pan evaporation data from available gauges; and (c) meteorological data covering temperature and humidity for selected basins would be made available. However, the discharge records would not be made available, but it would be possible to compare the predicted outputs with the observations to obtain several indices.

The second stage of information would consist of interpolated rainfall, adjusted elevations with drainage forcing, and improved land cover maps and soil characteristics. Also the users would be urged to develop applicable data sets using other global and regional models as well as satellite observations, and to share them through the dedicated www server.

CONCLUDING REMARKS

Water resources play an important role, not only in the irrigation and municipality sectors of Sri Lanka, but also in the country's power sector, which is heavily dependent on hydropower. Stream flow forecasting in many ungauged catchments in the country is therefore an important national need. Analysis of the rainfall observations shows that there is a clear decline of rainfall in the central mountainous area. Furthermore, the rainfall analysis shows that not only has the total rainfall decreased, but also that the number of rainy spells (rainfall duration) has decreased. However, the average rainfall intensity has increased for most of the rain station locations but the discharge records do not show such a clear trend as could have been expected from the rainfall trend change. The maximum discharge has reduced while the mean has more or less not changed. In order to understand this behaviour, it is necessary not only to look at the change of the total rainfall value, but also to look into the rainfall duration and intensity changes, which may require higher resolution rainfall data. In addition, the effect of land use changes, and maintenance practices, especially those associated with changing the tea estate ownership and population growth, would have to be looked into. The treatment of the catchment in three different segments with varying degrees of intervention and complexity, is expected to clarify the challenges associated with modelling poorly gauged and ungauged catchments. In addition, the new discharge and raingauge stations are expected to help investigate the amount of information required for adequately modelling the catchment responses.

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