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# Surface runoff simulation for part of Yewa basin

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**Abstract** PUB provides a scientific means of addressing water related problems in a data-scarce basin like Yewa drainage basin in Nigeria. This study focuses on surface runoff simulation through the generation of geomorphologic instantaneous unit hydrographs using digital terrain modelling. The simulation is necessary, in order to provide relevant information needed towards water resources assessment within the basin.

**Key words** digital elevation model; prediction of ungauged basin; synthetic hydrology; ungauged basin

## INTRODUCTION

The unabated increase in water demand and its fluctuation constitute issues of concern in the planning and development of water resources, most especially in the area of water production and water utilization in the developing world (Shiklomanov, 1998). Thus, a search towards developing a sustainable water resources management scheme in any environment requires a thorough assessment of the water resources of such an environment. This is necessary, if a sound science-based policy on sustainable protection and use of available fresh water resources is to be attained for the growing population and their increasing water demands.

Unfortunately, water resources assessment has been greatly affected by pressure of economic stringency through insufficient budget allocation and varied neglect of water resources assessment infrastructure. This is more prominent in the developing world, where cases of station neglect and the resultant poorly gauged and ungauged stations are common. Station neglect entails abandonment of the ill-equipped gauged staff and raingauges, faulty inappropriate rating curves and deplorable gauging equipment. It should be noted that in most cases, algae and sediment encrustation usually deface the equipment due to lack of maintenance.

The need to develop poorly gauged/ungauged basins to the benefit of all, makes a compelling case for synthetic hydrology. Synthetic hydrology involves estimation of hydrological parameters using appropriate coefficients related to various physical features of a drainage basin. Such estimation is usually carried out in order to generate appropriate data needed for hydrological information of a basin. Also, this need can easily be met by the application of tested and proved scientific procedures and techniques like the Predictions of Ungauged Basin (PUB) initiative of the International Association of Hydrological Sciences (Sivapalan *et al*., 2003).

PUB involves extracting and quantifying hydrological information in a poorly gauged/ungauged basin with a supportive intention of bridging the gap between theory, knowledge, research and practical applications of water resources information. This initiative was undertaken in order to resolve the ubiquitous ungauged basin incidence since running water problems like too little, too much and too dirty have to be addressed in a technical-scientific way (Shuttleworth, 2002; IAHS, 2003).

This study examines the value that could be added to basin studies by employing technology-enhanced synthetic unit hydrographs for Predictions of Ungauged Basin (PUB) through digital terrain modelling for a dynamic, operational hydrological practice in the data scarce Yewa drainage basin.

## STUDY AREA

The Yewa River is a transboundary (international) river between the Republic of Benin (source) and Nigeria. It lies approximately within latitudes 6.25°N and 7.75°N of the equator and longitudes 2.70°E and 3.00°E of the Greenwich Meridian and has a total catchment area of about 5000 km$^2$ (Fig. 1).

Climatologically, the Yewa River basin is located within the tropical rainy climate (Af) in accordance to Koppen's climate classification. The region is under the influence of the tropical continental (cT) and the tropical maritime (mT) air masses. Associated with the tropical maritime air mass are the southwesterly winds, while the

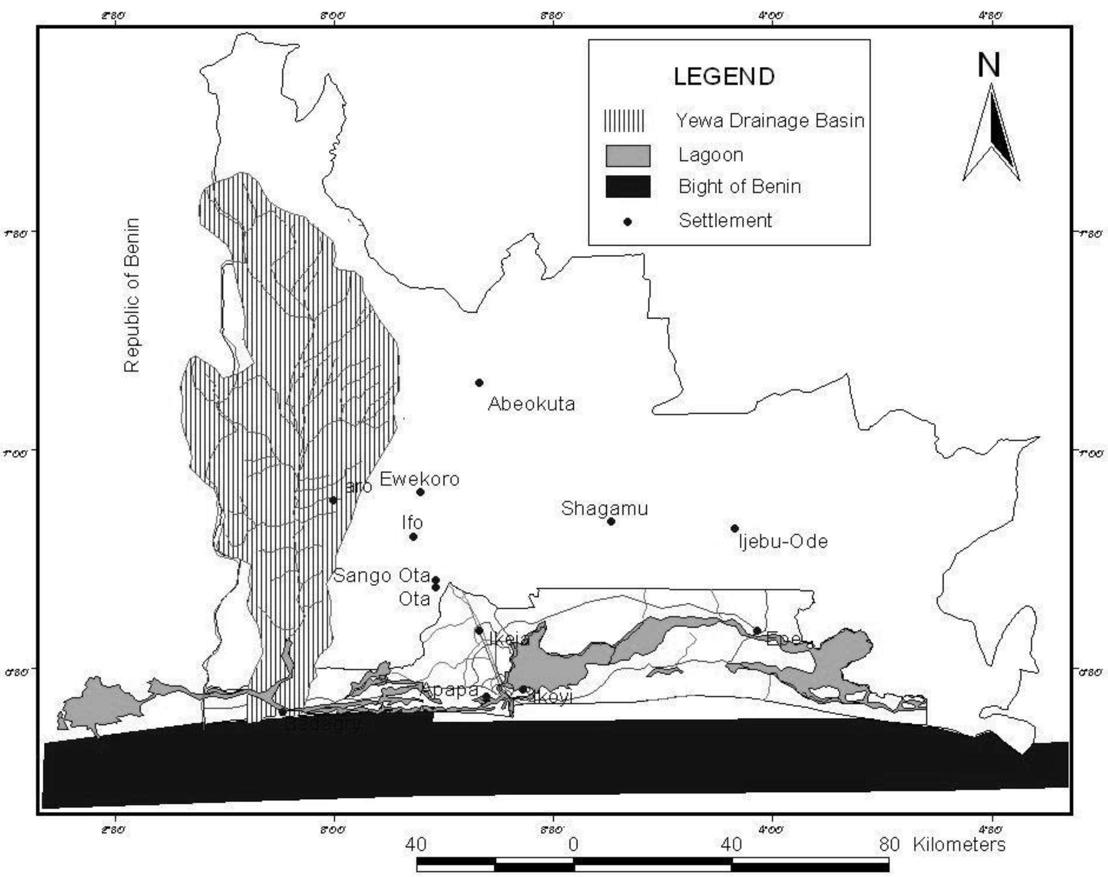


**Fig. 1** Yewa Drainage basin and major settlement in Lagos and Ogun State.

northeasterly winds are associated with the dry and dusty tropical continental air mass. The narrow zone of convergence of the two air masses is called the intertropical convergence zone (ITCZ) and it usually shifts seasonally with the pressure belts and isotherm (Iloeje, 1976).

The reliability of available hydro-climatological datasets in the Yewa basin since the mid 1990s is questionable, since the data is inconsistent and the present state of most of the gauging equipment and gauging stations is deplorable (Fig. 2). Cases of complete gauging station abandonment are therefore on the increase. Thus, the basin can be classified as a good example of an ungauged or at least, poorly gauged basin.

## METHODOLOGY

In the study a terrain based methodology was used to estimate the basin system response using the Demiurge Group of Digital Terrain Models (DTM) Version 3.11 (IRD, 1999) developed by Institut de Recherche pour Développement (IRD, formerly ORSTOM).

The estimation of the catchment system response was restricted to topographical sheets 278 N.E. and part of N.W. (scale 1:50 000), which was sourced from the Federal Surveys, Lagos. The sheet covers areas lying within latitudes 6.75°N and 7.00°N and longitudes 2.70°E and 3.00°E with total area of 936.29 $km^2$, where

**Fig. 2** Damaged gauging station at Ebute Igboro (Yewa catchment).

contours are reasonably close with a contour interval of 50 feet (15.24 m). The restriction was carried out in order to facilitate the achievement of a dense digital elevation model (DEM) with an acceptable logical surface representation (Weibel & Brandli, 1995). In this study, a cell dimension of 60 × 60 m was used as the spatial resolution for the raster model. This dimension is considered to be adequate for the purpose of this work while considering the available topographical map and nature of terrain of the region in question.

The method used involves digitizing of the iso-elevation (contours) in order to generate a digital elevation model (DEM) for the basin using the cubic spline interpolation technique. Cubic spline interpolation is a useful technique to interpolate between known data points due to its stable and smooth characteristics. The technique belongs to the Piecewise interpolation method, which involves constructing a polynomial of low degree between each pair of known data points and it is third degree polynomials.

From the interpolation of the DEM surface, a graph model was generated in order to delineate the watershed and sub-basins boundary and the D-8 method was used to define the landscape properties for each individual raster cell. The D-8 method involves evaluation of each cell and its eight neighbours. The direction of drainage between the central cell and one of its eight neighbours is also defined using the D-8 drainage model.

The flow direction in D-8 drainage model is given in accordance to the principle of the maximum descent (steepest descent). The maximum descent method allows for the determination of flow direction in accordance with the drainage model while the Grid flow accumulation grid network is used to identify watershed and sub-basin outlet points for watershed delineation. In addition, the identified basins and their sub-basins with their slopes are classified in a descending order in accordance to the Bocqullion classification (Garbrcht *et al*., 1996). The Bocquillon method established the major topographical link between the main basin and its sub-basin as well as identifying the hydrological links between the upstream and downstream flow in a drainage system.

Also, for the exercise, a cell accumulation threshold value of 100 cells for thalweg (flow) occurrence was selected in order to achieve an adaptive sampling scheme, data structures and accurate surface interpolation method. Thalweg is the line of steepest descent along the stream.

In all, a total of three sub-basins were extracted from the larger basin (Ebute Igboro drainage basin) within the topographical sheet. The selection was based on the consideration of a basin with an area of 50 km$^2$ and above.

The flow simulation method used to obtain the system-response to input (rainfall) analysis is the morphological transfer function (Depraetere & Coste, 1999). An American engineer, Robert E. Horton, who investigated the relationship between morphometry, hydrology and landscape evolution in 1945, first drew the concept of morphometric analysis in fluvial geomorphology.

The technique used in this study is based on a physically satisfactory hydrographic network schematized transfer function of a D-8 model. This is necessary since according to Rodriguez-Iturbe *et al*. (1982) the geomorphoclimatic theory of the instantaneous unit hydrograph (IUH) interprets the response function of a basin as a stochastic structure, which varies according to the characteristics of the rainfall input. The IUH is therefore the frequency distribution of the times of arrival at the outlet of a drainage basin of water particles, given an instantaneous application of a unit volume of excess rainfall uniformly spread over the drainage basin at zero time

The simulation process involves calculation of all the morphological and hydrological indices using an assumed hydrographic network dimensional fractal of 1.1. The dimensions fractal quantifies the static geometry of an object and how to get an average number out of many different parts of a geometric object. The channel width was estimated in accordance to basin size and local channel slope.

The Morphological transfer function technique (IRD, 2000) is expressed as:

$$Q = \lambda VH \tag{1}$$

$Q$ is discharge, $\lambda$ is basin width, $V$ is flow velocity, $H$ is the basin depth, where $V$ ($ms^{-1}$) is defined as:

$$V = 4 * Sd^{0.144} * I^{0.382} \tag{2}$$

$Sd$ is surface drained and $I$ is slope.

$H$, (the basin depth) is defined as;

$$H = Q / \lambda V \tag{3}$$

The length of Channel flow (L) is quantitatively expressed as:

$$L = \psi * 8[D-1]/[D+3]*\{\psi 4D\ [1010\ .8*\psi - 7.6*\Delta H*n - 1.8]*D-1\}*1/[D+3] \tag{4}$$

where $\psi$ is DEM resolution, $D$ is dimensional fractal of the basin's banks layout.

The input data for the flow simulation include the use of the rainfall intensity-duration-frequency data obtained from Oyebande (1983) of effective rainfall input of 10 mm for 15 min duration. The daily-observed rainfall corresponding to the specified duration covered by the observed daily discharge data (April–November, 1971) of the River Yewa at Ebute-Igboro Station was used for the model verification. The data was obtained from the Lagos state Ministry of Works and Planning (Lagos state Ministry of Works and Planning, 1976).

## RESULTS

The main drainage area within the studied topographical sheet is Ebute-Igboro drainage basin. The basin has a total area of about 600 $km^2$ with area ratio of 0.89 and basin diameter of 32.66 km as well as a shape factor coefficient of 0.75. The selected sub-basins within Ebute-Igboro drainage basin are the River Igbun, Erimi and Oja-Odan drainage basins (Fig. 3). The basins total catchment areas are about 198 $km^2$, 43 $km^2$ and 51 $km^2$ for the River Igbun, River Erimi and River Oja-Odan drainage basins, respectively.

### Hydrodynamic simulation characteristics of catchment

The logical approach to basin system response using topographical information involves application of the principal hydro-geomorphometric functionalities of a DEM and its derived indices. The approach is based on the drainage model of a basin,

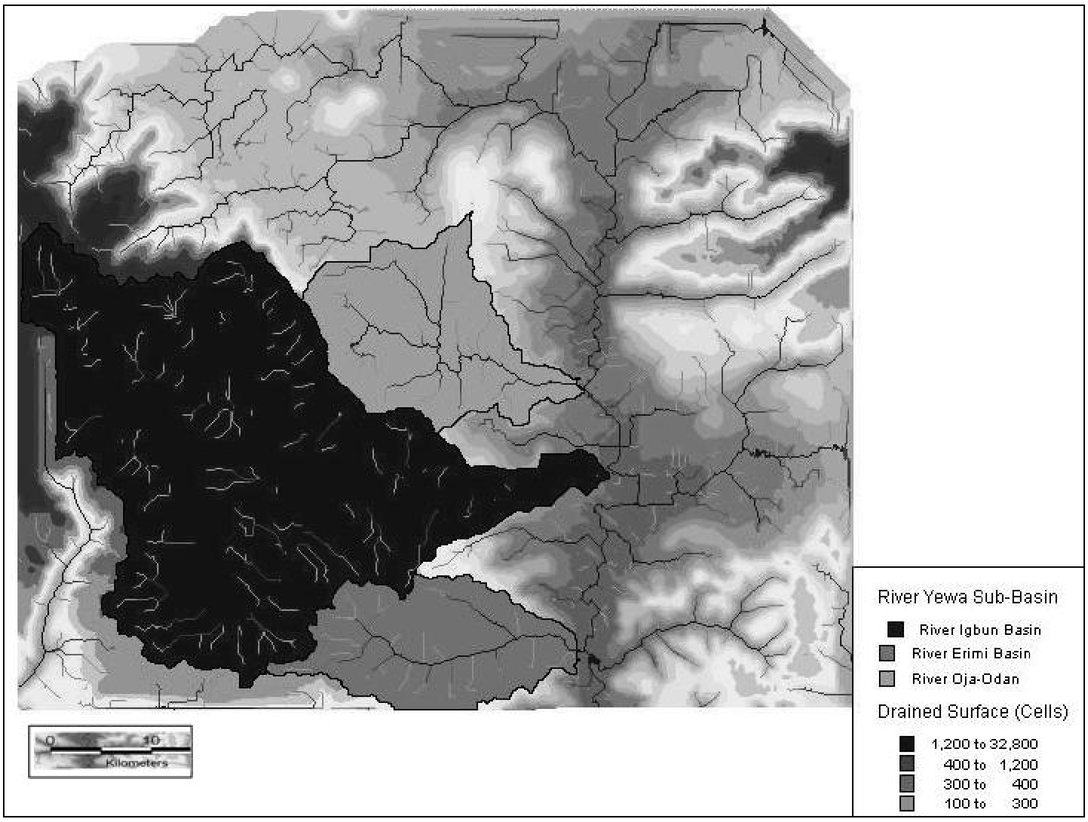


**Fig. 3** Selected Sub-Basin within Ebute Igboro (Yewa Catchment).

which is becoming increasingly common in hydrological studies. In this study, the geomorphological and hydrological indices used in the measurement and classification of drainage properties within the drainage basins include drainage model, basin slopes, orientation, length of drains, surface drainage and distance to the drainage system.

The geomorphological unit instantaneous hydrographs (GUIH) analysis for River Igbun catchment (Fig. 4(a)) shows a steady rise along the approaching limb and the rising limb with some delay, probably due to the need to satisfy the storages. The hydrograph shows a double peak flow, the first peak (6.67 $m^3 s^{-1}$) was attained at 8.6 h and the second peak (5.88 $m^3 s^{-1}$) was obtained at 11.4 h. Thereafter the flow reduced gradually in a fairly smooth with irregular decline in discharge pattern along the falling limb. Such a pattern might be due to different surges that come through from different parts of the drainage basin and the contribution from rapid interflow.

The hydrograph of River Erimi catchment (Fig. 4(b)) depicts an abrupt rise along the approaching limb as well as a rapid rise along the rising limb. This might be due to the rainfall intensity, which far exceeds the infiltration rate at this period. A multi-peaked flow pattern is depicted by the hydrograph. The first peak was attained at 4.2 h with a flow of 2.27 $m^3 s^{-1}$. The second peak flow (2.13 $m^3 s^{-1}$) was obtained at 5 h and the third and fourth peaks were attained at 5.6 and 6.2 h, respectively. The corresponding flows were 2.12 $m^3 s^{-1}$ and 1.98 $m^3 s^{-1}$. The falling limb depicts a fairly rapid receding flow pattern. This might probably be due to little contribution from rapid interflow after the rain had receded.

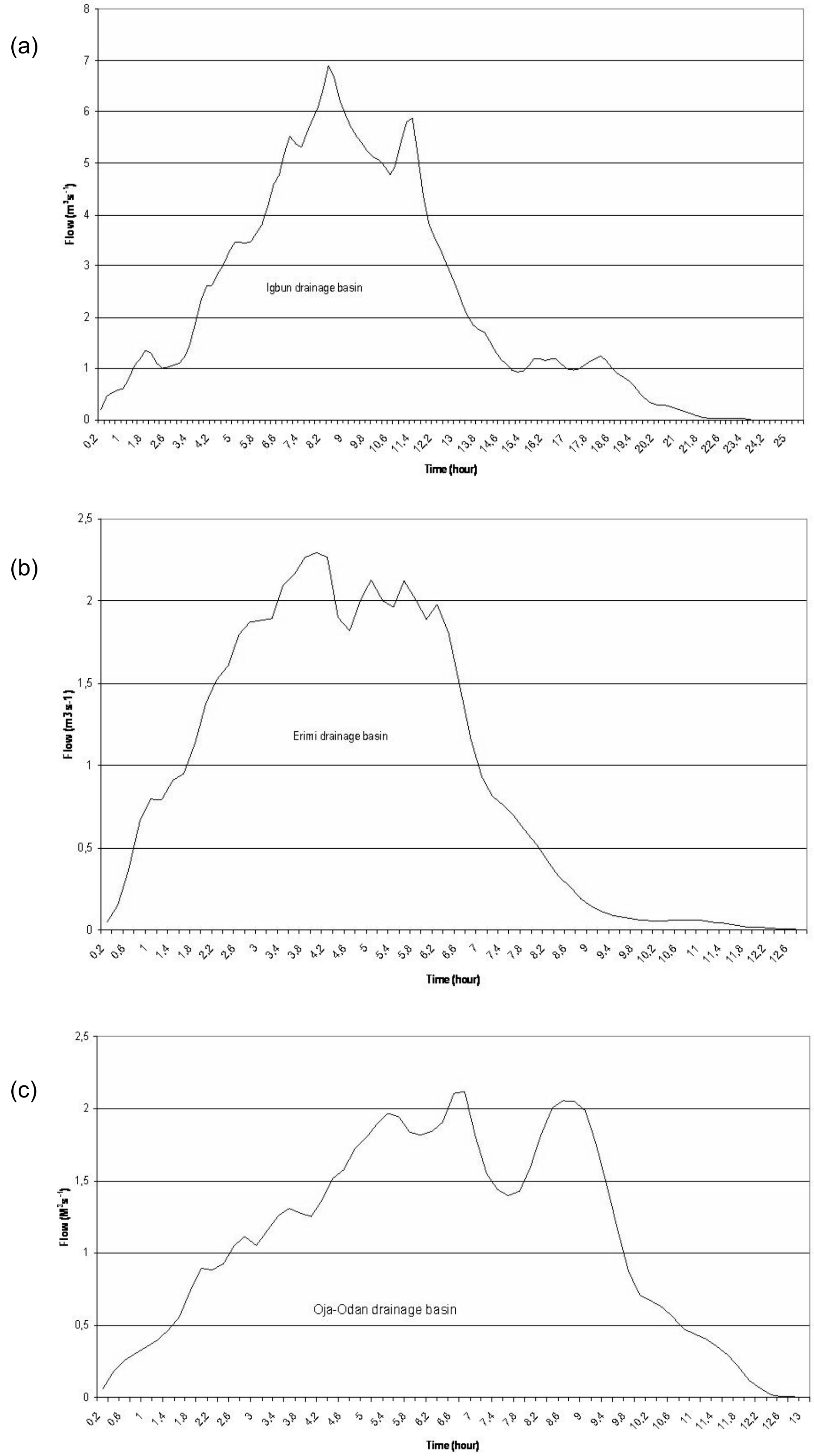


**Fig. 4** Geomorphological Instantaneous Unit Hydrograph for: (a) River Igbum; (b) River Erimi; and (c) River Oja-Odan.

The GUIH at River Oja-Odan (Fig. 4(c)) depicts a steady rise both at the approach and rising limb. This is probably due to the need to satisfy depression storages. The hydrograph rises to reach its first peak at 5.6 h with flow magnitude of 1.94 $m^3 s^{-1}$. The second and third peaks were attained at 6.8 and 8.8 h, respectively. The corresponding flow magnitudes were 2.12 $m^3 s^{-1}$ and 2.05 $m^3 s^{-1}$. Thereafter the flow shows a fairly smooth receding pattern along the receding limb.

Due to lack of daily observations, rainfall corresponded to the specified duration covered by the observed daily discharge data for the selected Ebute-Igboro sub-basin (River Igbun, River Erimi and River Oja-Odan drainage basins). The model verification was based on the only available data (April–November, 1971) of the River Yewa at Ebute-Igboro Station. The simulated flow was based on specific discharge estimation for the entire Ebute-Igboro drainage basin.

The degree of relationship between the observed and the average simulated flow at Ebute-Igboro station using flow data for the year 1981 is 0.69 with coefficient of determination ($R^2$) of 0.48 (Fig. 5). This indicates a direct relationship and about 48% of the information contained in the variance in simulated flow is explained by the linear relationship. This might be due to the level of accuracy and the mode of collection and recording of the observed data and the estimated rainfall-intensity-duration data used. It should be noted that at comparatively low flows the model adequately simulates the flow to a reasonable level with the degree of relationship being 0.88 with coefficient of determination ($R^2$) of 0.78.

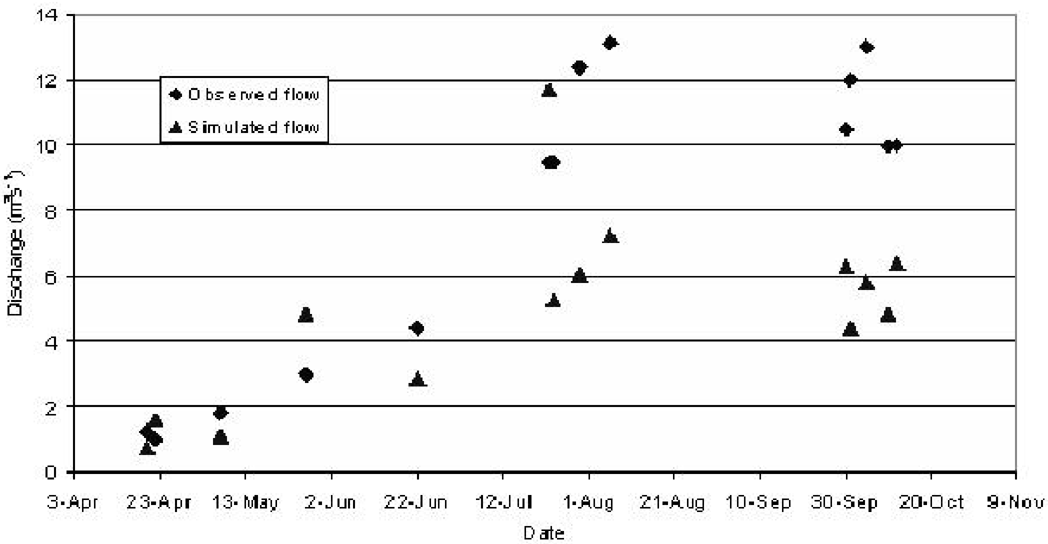


**Fig. 5** Relationship between observed and the average simulated flow at Ebute-Igboro Station (1981)

## CONCLUSIONS

The obsolete equipment and deplorable state of gauging stations within Yewa catchment call for adoption of the PUB initiative. This is necessary if adequate water resources assessment is to be carried-out within the basin. The GUIH in the three sub-basins display a non single peak. This shows that flows within the basins were irregular and there are discrepancies in the rate at which flow is being distributed with a high probability of intermittent floods. Hence, it is evident that the basin is experiencing a lot of flow irregularities. Such irregularities might be due to the basin geometry, poor drainage network and longer time of concentration and lag time.

For accurate digital elevation model (DEM) estimation of flat regions and areas with distant contours, there is a need to source contour information from other sources like the Shuttle Radar Topography Mission (SRTM) satellite imagery. Also, terrain based software with the capability of handling point data with an appropriate interpolation technique. In addition, there is a need to revamp the existing gauging stations within the basin with modern equipment for real-time oriented consistent hydrological data.

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