Asian Journal of Water, Environment and Pollution, Vol. 3, No. 2, pp. 63-69.

Hydrological and Nutrient Budget Modelling of Surface Water of the Achankovil River, Western Ghats, India

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Received March 15, 2005; revised and accepted November 10, 2005

Abstract: An attempt has been made to develop a hydrologic and nutrient budget for Achankovil river watershed (area 1484 km^2) in Western Ghats of India. The work was carried out in the year 2002 during three seasons i.e. pre-monsoon (February), monsoon (June/July) and post-monsoon (October). The water budget was determined using the formulae $dm/dt = \Sigma$ input $- \Sigma$ outputs $+ \Sigma$ (sources – sinks). The inflow (precipitation, tributary and Achankovil river baseflow) and out-flow (evapo-transpiration and discharge from tributaries and Achankovil river) segments were measured following the standard procedure for three seasons. The result indicates that significant amount of water leaving (60.35×10^8 m^3) the watershed to the adjoining Vembanad lake and ultimately into the ocean, which exceeds the water, entering (54.83×10^8 m^3) the basin. The outgoing water ($\cong$ 9%) surplus may be due to overestimation of transpiration and the lack of estimation of the water input from the intermittent streams in the present study. Nitrogen and phosphorus balances are also calculated by LOICZ–CABARET budget model. $20,976.86 \times 10^6$ m mol/yr and $19,655.1 \times 10^6$ m mol/yr of nitrogen and phosphorus were lost or utilized within the Achankovil river basin during the study period. More detailed study on short term and variation will certainly help us in dealing with the various sources and the contribution by main stream as well as intermittent streams.

Key words: Achankovil river, budget modelling, evapo-transpiration, base flow, nutrients.

Introduction

The preliminary objective of a hydrologic budget is to determine the percentage of the incoming water that evapotranspirates and exits the watershed through groundwater flow, emerges as stream flow and provides supply for the domestic needs.

The basic components that are highly required to calculate the hydrologic budget include measurements of surface water run off, precipitation, groundwater flow, stream discharge, evaporation and transpiration.

The runoff is an important component because it is the integrated value of all meteorological and hydrological processes (Moldan and Cerny, 1994). Runoff can be separated into components of overland flow, inter flow and channel interception (Brooks et al., 1997). Precipitation is another important segment of a hydrologic budget. The problem with rainfall measuring is that it is not evenly distributed throughout the year and even over a watershed area. Many methods have been developed to measure rainfall accurately, including the arithmetic mean, the isohyetal method and construction of Thiessen polygons (Dawdy and Landbein, 1960; Thiessen, 1911).

The evapotranspiration component in the hydrologic budget is output from the pool. It plays an important role in water quality, nutrient transport, vegetative growth and development (Black, 1996). This can be calculated indirectly by using climatic data. Thornthwaite equation is widely accepted empirical formula to calculate the evapotranspiration (Thornwaite and Mathur, 1957).

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The nutrient budget is important to understand various biogeochemical processes taking place in the aquatic system. Inputs include atmospheric deposition, weathering, direct anthropogenic flow and lateral groundwater flow from another aquifer system. The outputs include runoff into streams, groundwater seepage, gaseous emissions from the soil, and harvest and removal of vegetation. Important problem with this nutrient flux calculation is that environmentally important nutrients such as nitrogen, carbon and sulphur can have significant gaseous components, making a precise budget assessment much more difficult (Moldan and Cerny, 1994).

There has been some works on nutrient budgets on various ecosystems (Campbell, 1978; Denmend, 1990; Kohn, 1997; McKee and Eyre, 2000). This study is important for two reasons. Firstly, this appears to have been no nutrient budget made on a small Western Ghats river, Achankovil river and secondly, no such tropical homogeneous reverine budget has been found in the literature either for a single year or that consider inter-annual variations.

The main objectives of this study were to develop:

1. A hydrologic budget for Achankovil river watershed in Western Ghats, South India.
2. The biogeochemical modelling of nutrients (N and P) in the Achankovil river is by LOICZ-CABARET (Gordon, 1996).

The Study Area

The Achankovil river basin is one of the important river systems flowing through the Western Ghats. The basin (76°.25' – 76°.75' E and 8°.75' – 9°.5' N) extend over an area of 1484 km^2 and has a total length of 128 km (Figure 1). The principal tributaries of the river are the Pamba and Manimala. The river is originated at Pasukidamettu. 55.54% of the watershed land is forestland, 39.85% used for agricultural activities and remaining portion used for other activities. The climate of the area is characterized by humid tropical climate with mean temperature of 23° C. The area receives an annual rainfall of 2000-5000 mm. The river discharges into the Vembanad Lake extends from Cochin (Kochi) to Alleppey (Alapuzha) for a distance of 83 km and is the largest estuary in Kerala (Bala Krishna Prasad and Ramanathan, 2005).

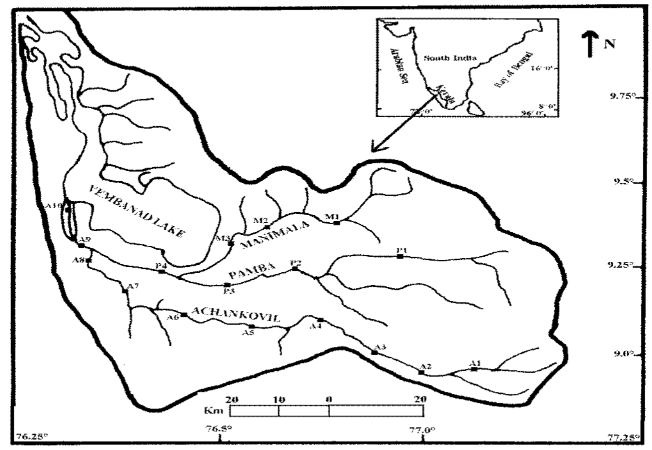


Figure 1: Map of Achankovil river watershed in Western Ghats of South India.

Materials and Methods

Sampling Sites

12 sampling sites were identified on Achankovil river system, four on Pamba and three on Manimala. These were gauged for stage height and discharge once in ten days for one month for each season, beginning February 2002 (pre-monsoon), June/July 2002 (monsoon) and October 2002 (post-monsoon). All the measurements were taken as close as possible to the point of the tributaries into the main watershed.

Methodology

To determine stream discharge (Q), the cross sectional area (A) of the stream was multiplied by its velocity (V):

$$Q = V \times A \qquad (1)$$

The cross sectional area of each tributary was divided into three segments for which the width and the depth were measured. The depth was measured at the middle of each segment by using a Water Mark graduated steel measuring tape. The steel measuring tape was sprayed with red chalk and dipped into the river at the middle of each segment. Once it reached the bottom, it was quickly reeled up to mark up to the point where the chalk was absent, thereby indicating the depth of the water. The stream velocity was measured using a float method (Martin and Mc Cutcheon, 1992). Estimating current velocities from floating objects is relatively straight-forward. The velocity of the floating object v_f (L T^1) is determined from the distance the object travels L_f (L) during some time t (T) as $v_f = L_f / t$. The distance the float travels provides a measurement of the water velocity for the depth at which the float is suspended. The secondary data were collected from Indian

Meteorological Division (IMD) and Central Water Commission (CWC).

Budget Calculations

For hydrologic budget calculations, mass-balance equation was modified to fit the area of investigation as follows:

$$\textit{Inflow} = \textit{Outflow} \pm \textit{Storage} \quad (2)$$

Precipitation + Total Base flow
= Total Stream out flow + Evapotranspiration (3)

The relationship between total base flow and total stream flow can be represented as:

Precipitation + (Total Tributary Base flow + Achankovil River Base flow)
= Total Tributary Discharge + Achankovil River Discharge + Evapotranspiration (4)

Precipitation was calculated for the entire system 29.45 × 10^6 m^3 and reported as the effective uniform depth (EUD). EUD was calculated using the Thiessen polygon method (Thiessen, 1911). The evapo-transpiration for each season were determined by using full sun day period, temperature and used in Thornwaite formula (Thornwaite and Mathur, 1957). The nutrients N and P were determined by using standard procedure (APHA, 1985).

Principles of the LOICZ Approach

The LOICZ approach is a budgeting procedure describing the rate of material delivered to the system (*inputs*), the rate of material removed from the system (*outputs*) and the rate of change of material within the system (*internal sources or sinks*). An important feature of the LOICZ approach is the simultaneous tracking of several material (specially N and P) allowing derivation of conclusions that would not follow from analysis of a single nutrient. The relationship between the different budgeting components is given by the following equation:

$$dm/dt = \Sigma \text{ inputs} - \Sigma \text{ outputs} + \Sigma\,[\text{sources} - \text{sinks}] \quad (5)$$

dm/dt = the change of mass of any material with respect to time.

In this study, we calculated river discharge (V_Q), precipitation (V_P), evaporation (V_E) and groundwater flow (V_G). For this study we assumed that V_G is negligible. Based on these data, residual flow (V_R) is calculated by the following equation:

$$V_R = V_Q + V_P + V_E + V_G \quad (6)$$

In the above equation the value of V_E is negative, implying that water leaves from the watershed by evapo-transpiration. V_G, V_P and V_Q are positive, implying that water enter the watershed by discharge, precipitation and groundwater flow.

To conserve the nutrients in the river watershed, the amount of nutrient leaving the river with residual flow (V_R) is balanced by an amount of nutrient entering the river with horizontal exchange flow (V_X) caused by winds, small tides and river and lake water flow, yielding:

$$0 = V_R N_R + V_X N_{Lake} - V_X N_{River} \quad (7)$$

In Equation (7) the nutrient concentration residual flow of nutrient (V_R) is defined as:

$$N_R = 0.5\,(N_{River} + N_{Lake}) \quad (8)$$

where N_{River} and N_{Lake} are nutrient concentrations of river and lake respectively. After rearranging Equation (6) horizontal exchange flow (V_X), which is critical in calculating nutrient budgets, can be calculated as:

$$V_X = \frac{V_R\ N_R}{N_{Lake} - N_{River}} \quad (9)$$

V_X is critical because it is the last unknown component in the nutrient budget of the river watershed and estuary. This nutrient budget is formulated as:

$$\Sigma[\text{sources} - \text{sinks}] = \Sigma \text{ inputs} - \Sigma \text{ outputs} = \Delta F \quad (10)$$

Inputs and outputs are calculated as products of input or output of water (V) and appropriate concentrations of the nutrient or material (Y):

$$F = V \times Y \quad (11)$$

So, ΔF is given as:

$$\Delta F = V_Q Y_Q + V_P Y_P + V_G Y_G + V_X (Y_{Lake} - Y_{River}) + V_R Y_R \quad (12)$$

where $Y_{River,}$ and Y_{Lake} are the concentration in the river and the lake respectively. The concentration Y_R is in anology of Equation (8) given by:

$$Y_R = 0.5\,(Y_{River} + Y_{Lake}) \quad (13)$$

in case of $\Delta F = 0$. In case of non-conservative behaviour such as P uptake by the biological systems for its production, ΔF will have a non-zero value. A positive value for ΔF indicates uptake within the system, while a negative value indicates release within the system.

Results and Discussion

The precipitation, effective uniform depth (EDU) and evapotranspiration are given in Table 1. In all seasons, the amount of water leaving the Achankovil river watershed exceeded the water input. However, in monsoon (June/July 2002) its difference in output is only

8.72% when compared to the remaining two seasons (pre-monsoon—14.8% and post-monsoon—32%). The base flow for each of the tributaries was calculated by examining the hydrographs in rainfall and non-rainfall periods (Tavener and Iqbal, 2003). The magnitude of base flow water was considerably comparable (Table 2). Input into the Achankovil river watershed from precipitation accounted for 65% of the total input. The main channel (Achankovil river) and tributary base flow components were 8% and 27% respectively (Figure 2a).

Table 1: Precipitation, EUD and Evapotranspiration for all Three Study Months

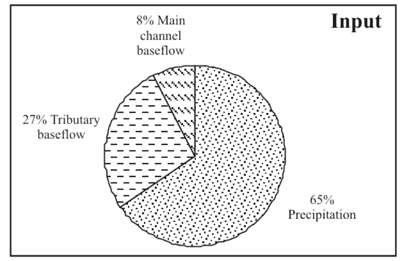
Month	*Precipitation (m^3)*	*EUD (m)*	*Evapotrans-piration*
February	2.54×10^6	0.04	1071.2
June	16.29×10^6	0.256	975.6
October	10.62×10^6	0.167	1081.2

Table 2: Channel Base Flow and Monthly Discharge from Main Channel for the Three Study Months

Tributary	*Feb (m^3)*	*June (m^3)*	*Oct (m^3)*
Channel base flow			
Achankovil	23.32×10^6	851.5×10^6	332×10^6
Pamba	32.03×10^6	4550×10^6	365×10^6
Manimala	59.63×10^6	2997×10^6	380×10^6
Monthly discharge			
Achankovil	31.17×10^6	1726×10^6	538×10^6
Pamba	28.4×10^6	4189×10^6	393×10^6
Manimala	31.3×10^6	2632×10^6	405×10^6

The output from the system includes the components of the discharge from each tributary channel to the main channel and the discharge from the main channel to the receptive Vembanad lake. In addition to this, output segment includes potential evapotranspiration from the watershed area. The monthly discharge from each river system from the watershed area is given in Table 2. The discharge of two tributaries account for 40% of total and the remaining two output segments were from the main channel (Achankovil river) and by evapo-transpiration processes which accounts for 27% and 33% (Figure 2b). Once all the parameters of the hydrologic budget had been determined, they were substituted in the equation to calculate the total monthly and the average budget for the desired period. The hydrologic budget for three seasons has been combined and is given below:

Precipitation + Tributary Base flow + Main Channel Base flow = Tributary Discharge + Main Channel Discharge + Evapotranspiration



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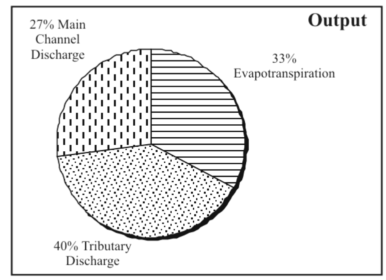


2b

Figure 2a and 2b: Distribution of input and output segments of the Achankovil river watershed.

$$2.54 \times 10^6\,m^3 + 91.66 \times 10^6\,m^3 + 23.32 \times 10^6\,m^3 = 31.17 \times 10^6\,m^3 + 59.7 \times 10^6\,m^3 + 1071.2\,m^3$$

$$117.52 \times 10^6\,m^3 \neq 90.87 \times 10^6\,m^3$$

From the above results it is clear that the tributary base flow accounted for higher contribution ($\cong$ 50%) than the remaining two segments (main channel base flow $\cong$ 15% and precipitation $\cong$ 35%). Tributary discharge accounted for $\cong$ 40% loss of water from the river system. This may be due to the tributaries having more intermittent channels than the main channel. The magnitude of output segments was given as tributary base flow > evapotranspiration > main channel discharge. The total input into the Achankovil river watershed was 117.52×10^6 and output was 90.87×10^6. The difference between these two flux values was 22.67%. Even though there is a good balance in the budgeting for the three seasons, there could be a number of reasons why the budget did not balance in the individual months. There might be errors in the measurements of budget components like over estimation of evapo-transpiration, underestimating precipitation and ignoring the soil moisture storage components in the budget calculation (Tavener and Iqbal, 2003).

The lack of balance in the model is probably due to the combined effect of all these factors. Underestimation of precipitation is frequently considered as a source of error in the hydrologic budget calculations. Underestimation of precipitation is largely due to wind induced turbulence at the gauge stations and wetting losses on the internal walls of the gauge (Groisman and Legates, 1994). This difference is usually high for mountainous regions; it is not significant for lower regions (Tavener and Iqbal, 2003). The deposition of water by dew formation as input was not considered in this study, which could also contribute significant amount of water. Dew formation and its accumulation are dependent on many factors, some of which include radiate loss of heat from the leaf surface, air temperature, humidity and wind speed (Luo and Goudriaan, 2000).

The surplus of outflow for the study period may be due to an overestimation of the evapo-transpiration and the small intermittent channels within the watershed that were not measured. The individual intermittent channels contribute only little amount, but the combined effect of all these intermittent channels may alter the balance of the hydrologic budget. Moreover, to determine exact volumes of water discharge from the watershed area, measurements must have been taken at the confluence with the Achankovil river at Viyyuvaram, which will be done in subsequent studies.

Nutrient Balance

A clear temporal and spatial variation of dissolved nitrogen and phosphorus fluxes were observed and this is mainly due to the intensive biological activity taking place in the watershed area, which may be responsible for variations. The average annual nitrogen concentration was about 0.289 mg/l and phosphorus was 0.592 mg/l (Bala Krishna Prasad and Ramanathan, 2005). The flux of nutrients into and out of the river watershed was calculated by multiplying the discharge by the amount of nutrient (Mc Lee and Eyre, 2000). The average annual concentrations of nitrogen and phosphorus were multiplied by the sum of the tributary discharge and the main channel base flow to calculate the loss of these nutrients from the watershed area. Nitrogen and phosphorus losses are 20,926.29 and 19,155.17 respectively on annual basis (Figure 3).

The total amount of nitrogen added to the watershed every year, approximately 9.24% of nitrogen and 12.84% of P are going out of the watershed to the next system (Figures 4a and 4b). The watershed is consuming huge amount of nitrogen for its biological productivity than phosphorus. Approximately 76.9% of nitrogen (153,736.3 × 10^6 m mol/yr) and 48.8% of phosphorus (61,054.2 × 10^6 m mol/yr) are retained within the watershed. Tributaries contributing 9.4% of nitrogen, residual concentration between the main stream and the tributaries (V_R DIN_R) 18,811.3 × 10^6 m mol/yr, and

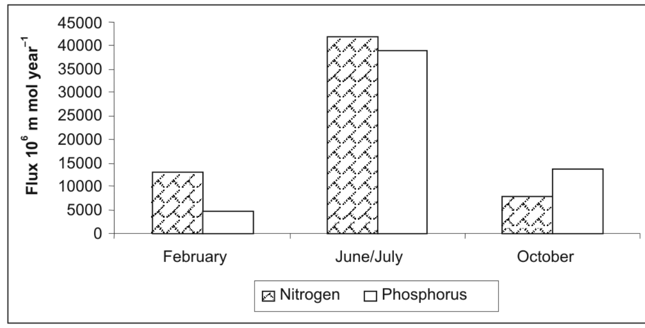
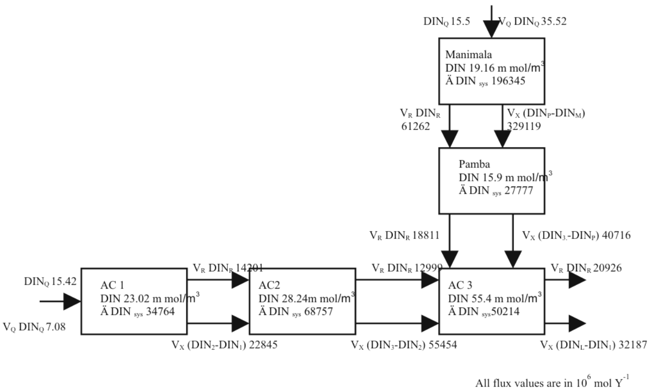


Figure 3: Fluxes of nutrients lost from the Achankovil river watershed.

30.8% of phosphorus residual concentration between the main stream and the lake (V_R DIN_R) 38,640.2 × 10^6 m mol/yr to the overall watershed nutrient budget. The horizontal mixing concentration of DIN (V_X DIN_3-DIN_P) and DIP (V_X DIP_L-DIP_3) between the tributaries and the main channel and the lake were 40,716.56 × 10^6 m mol/yr, 32,187.16 × 10^6 m mol/yr, 19,655.8 × 10^6 m mol/yr, and 4,516.8 × 10^6 m mol/yr respectively. There was a negative balance between input and output nutrient components of the river system (Table 3). Generally rivers are mainly meant for the transport of the nutrients and metals in dissolved and particulate form (Meybeck, 1998). So, most of the times output component may dominate the input component (Table 6). But in pre-monsoon and post-monsoon DIP balance is higher than the monsoon. This may be because, due to the undistributed conditions, biological systems may consume nutrients for its growth. A high concentration of DIP in monsoon period is due to contribution from the rock weathering. Due to the high discharge of the water in the stream in monsoon, huge amount of DIP is transported to the Vembanad lake system. In pre-monsoon, perhaps due to the intensive denitrification, huge amount of DIN is going out from the system. In general, tributaries are playing a dominant role in phosphorus budget rather than nitrogen budget. Rigourous data collection is the main task in the hydrologic and nutrient budget studies. Eliminating the areas of uncertainties should be the primary objective. This is quite difficult task and will be attempted in our future study.

Conclusions

The following conclusions can be drawn from the study:



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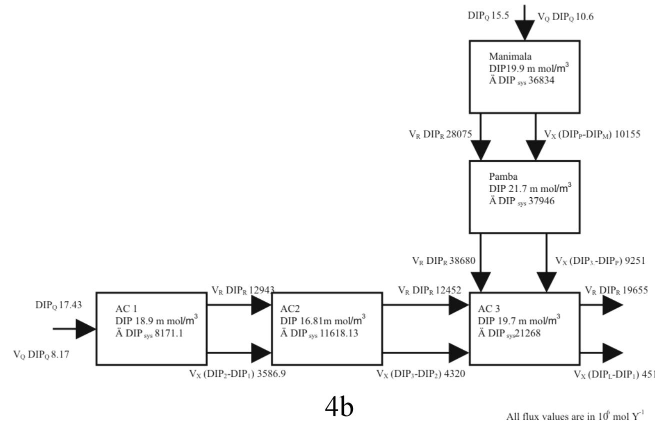

4b

Figure 4a and 4b: Nitrogen and phosphorus budget for the Achankovil river basin.

Table 3: Calculated DIN and DIP Flows and Daily Input to the River System and Daily Output from the River System

Nutrient	*Season*	V_R	V_X	V_Q	*Daily input*	*Daily output*	*Balance*
DIN	Annual	20926	32187	50.9	0.14	145.52	-145
	Pre-monsoon	13146	60744	36.4	0.10	202.44	-202
	Monsoon	41773	31468	94.3	0.26	200.66	-200
	Post-monsoon	7859	4348	27.1	0.07	33.45	-33
DIP	Annual	19655	4516	28	0.08	66.22	-66
	Pre-monsoon	4784	8609	29.2	0.08	36.70	-36
	Monsoon	40455	5110	47.4	0.13	124.84	-124
	Post-monsoon	13725	4279	38	0.1	49.33	-49

- During the study, the total outflow of water from the Achankovil river watershed was more than the inflow into the river system.
- Precipitation accounted for about 65% of the total inflow, the tributary baseflow component contributes approximately 27%. Of the total outflow, the tributaries contribution is 40%, evapo-transpiration contribution is 33% and main channel discharge contribution is 27%.
- The total amount of nitrogen and phosphorus that were lost from the watershed were 20,976.86 × 10^6 m mol/yr and 19,655.1 × 10^6 m mol/yr during this study period.

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