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Hydrology of the Vemaband Wetland System

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ABSTRACT: The Vembanad wetlands of Kerala State in India has many mutually conflicting water and land use functions like flood control, pollution control, biodiversity, agriculture, inland navigation and tourism. A number of artificial interventions on the water system lead to the environmental degradation of wetlands; increased flood proneness and water pollution are two major adverse impacts. Water depth, flow patterns, and duration and frequency of flooding, which are the result of all the hydrologic inputs and outputs, influence the wetland processes. In this study, hydrology of Vembanad wetlands is characterized in terms of the river flow patterns to the system and its variability, sediment loads, seasonal water level variations, and overall water balance of the system. The study shows that the floods in the region are slow rising and attain peak in a few days. River flows are the major water inputs to the wetlands and thus contribute major part of the outflows to the Arabian sea.. Storage and optimal utilization of the river flows is essential for future water resources development in river basins and to sustain the different functions of the wetlands.

INTRODUCTION

Wetlands are transitional between the terrestrial and aquatic environments where the water table is usually at or near the surface or the land is covered by shallow water (Cowardin *et al*., 1979). The Vembanad wetland (Figure 1) located on the south west coast of the India is a complex aquatic system which include the Vembanad lake connected to the Arabian Sea and the lower reaches of the Achencoil, Pamba, Manimala, Meenachil, and Muvattupuzha rivers draining to the lake and their deltaic regions. The fertile tract of flat low lands located on the south and east of the Vembanad water body, known as *Kuttanad* is characterized by the groups of polders formed for rice cultivation. Large-scale reclamation of water bodies and unscientific construction activities has been the human interventions in the wetland since the beginning of the 19th century. Operation of the Thanneermukkom (TM) salinity barrage located across the Vembanad lake divide the lake into two different water regimes; a freshwater dominant southern zone and the saline water dominant northern zone. After the construction of barrage in 1975, several environmental and ecological problems cropped up in the wetlands, the major issues being; increased flood proneness, concentration of pollutants in the lake, increase in weed growth and reduction in fish catches.

In a wetland system, the seasonal flow patterns, water levels, and duration and frequency of flooding are the result of all the hydrologic inputs and outputs and these factors influence the various processes in the wetlands (Mitsch and Gosselink, 1986). The Vembanad wetland has several functions and values like flood control, pollution control, agriculture, fisheries, inland navigation, tourism etc. Hydrology of this wetland is influenced by precipitation, river flows from upper basins, tides penetrating from Cochin sea mouth and the operation of hydraulic structures. Knowledge on the hydrology of wetlands is essential for the scientific planning of its water management, but, only very few studies have been conducted on these aspects. In a case study, Balchand (1983) highlighted the adverse impacts of human interventions to moderate floods and to regulate salinity intrusion in the system. Various constrained faced for rice cultivation in the wetland are analyzed by the Indo-Dutch Mission (1989) and some engineering measures are proposed for flood control and low flow augmentation and for improvement of its environmental conditions. In a case study, James *et al.* (1997) highlighted the importance of an integrated management approach covering the Vembanad wetlands and its river basins for optimal utilization of the benefits of wetland. The study presented in this paper deals with the characterization of hydrology of the Vembanad wetland based on the analysis of the available hydrologic data. The study area and its associated river basins are delineated from the Survey of India (SOI) topographic maps. Hydrology of the wetlands is characterized in terms of; rainfall, river flow patterns and its variability; sediment loads, pattern of water level variations, duration and frequency of floods and overall water balance of the system.

WATER SYSTEM OF VEMBANAD WETLANDS

The complex water system of Vembanad wetlands consist of the discharges from five major rivers and the semi-diurnal tides penetrating from the Cochin Sea mouth through the Vembanad backwater lake. The rivers draining into the wetlands (Figure 1) originate from the hilly Western Ghats, flow down the highland over steep slopes, and traverse their midland stretches with much flatter slopes before entering the deltaic region, where the rivers join and branch and finally drain to the Arabian Sea through the Vembanad lake. The Achencoil, Pamba and the Manimala rivers enter the deltaic region from southeast and join together on the southern side before joining the Vembanad lake in many branches covering the upper and lower Kuttanad regions.

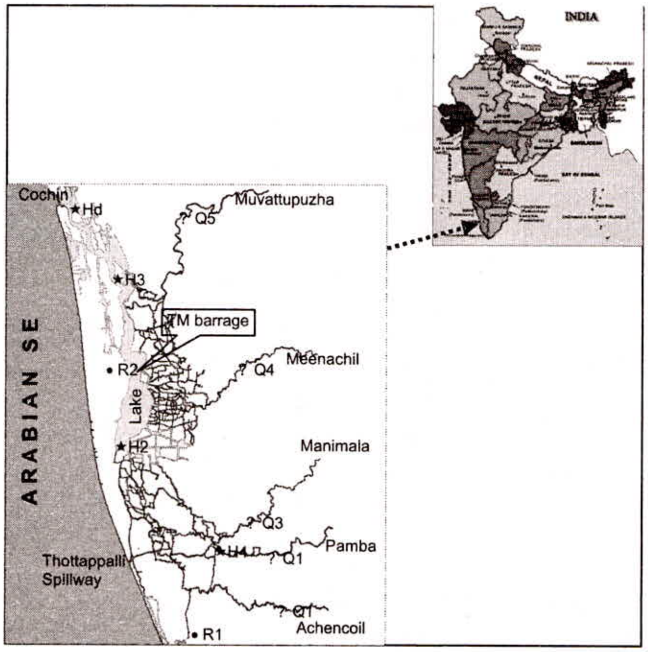


Fig. 1: Location map of Vembanad wetlands with monitoring stations (*filled circle*: Rain gauge. *filled triangle*: Discharge monitoring station. *filled star*: Water level monitoring station)

In the upper basins of the rivers, land use varies from evergreen forests and plantation crops like rubber and tea in the highland regions to crops like rice and coconut in the midland. TM salinity barrage built across the Vembanad lake and the Thottappalli (TP) flood spillway constructed to divert a part of the combined floodwaters of Achencoil, Pamba and Manimala rivers directly to the Sea are the major structures existing in the water system.

DATA USED FOR THE STUDY

The 1:50000 scale SOI topographic maps are used for generating the drainage basin boundaries of the rivers and the study area of the wetlands. Hydrologic data used for the study include; mean daily discharge data for the period from 1978 to 1999 from five gauging stations (Figure 1) one on each of the five major rivers draining to the wetland; and daily rainfall data for the period from 1992 to 1999 from two rain gauge stations located within the wetland. Tidal data is obtained from the gauging station located at Cochin port. Other data used for the study include the historic monthly rainfall data obtained from the Centre for Water Resources Development and Management (CWRDM), and water levels for extreme floods in the region as obtained from the records of Water Resources Department of Kerala.

DELINEATION OF STUDY AREA AND ITS LAND USE

Drainage boundaries of the Achencoil, Pamba, Manimala, Meenachil and Muvattupuzha rivers and a stream named Kariar that could be delineated based on the drainage pattern and topographic contours in 1:50000 scale SOI maps are digitized in GIS as vector datasets. The drainage areas of the rivers defined by the digitized boundaries are referred as the *upper basins*. Lower deltaic regions of rivers where individual catchments can not be distinguished is delineated into one single non basin unit titled "*Vembanad wetland*", with its western boundary defined by the shoreline of Arabian Sea. Northern boundary is extended up to the Cochin estuary and the southern boundary to 25 km south of TP flood spillway. The upper basins of five major rivers cover a total area of 6031.74 km^2. The Kariar covers a basin area of 94.74 km^2 and the Vembanad wetlands cover an area of 2033.02 km^2 (Table 1).

Recent land use information of the Vembanad wetland (Table 2) is extracted from an existing land use map for the region (NEERI, 2003) prepared using the LISS III sensor data of Indian Remote Sensing Satellites, IRS 1C and IRS 1D for February 1999. Maximum area of the wetlands (1284.154 km^2) is covered by mixed crops including coconut, banana, etc. During the period 1988–1999, area of cultivated polders reduced from 441.85 km^2 (Indo Dutch Mission, 1989) to 337.2 km^2 (Table 2) and therefore, total area of water bodies including the lake and unused polders increased from 236.45 km^2 to 341.02 km^2.

Table 1: Area of the River Basins and Drainage Unit Delineated as Vembanad Wetlands

Sl. No	*Basin/Unit*	*Area, km^2*
1.	Achencoil	1013.16
2.	Pamba	1705.34
3.	Manimala	793.79
4.	Meenachil	1030.94
5.	Kariar	94.74
6.	Muvattupuzha	1488.52
7.	Wetland region	2033.02
	Total	8159.51

Table 2: Land Use of the Vembanad Wetlands as on 1999

Sl. No.	*Land Use*	*Area, km^2*
1.	Built-up area	46.828
2.	Mixed Crops	1283.44
3.	Rice	337.281
4.	Rubber	23.786
5.	Water body	341.016
	Total	2033.06

HYDROLOGY OF THE WETLANDS

Rainfall

The Vembanad wetland region has sub-humid climate with temperature varying between mean minima of 22°C (in January) to mean maxima of 35°C (in March) and relative humidity varying from 80% to 95%. Out of a mean annual rainfall of 3000 mm, about 60% is received during the southwest monsoon (June–August), 30% during the northeast monsoon (September–November) and the remaining 10% during summer months. The average rainfall intensity is 1 cm/hour whereas during the monsoons, rainfall intensity is up to 5 cm/hour (Pisharoty, 1990). Within the river basins, mean monthly rainfall vary from a minimum of 2970 mm (in Meenachil basin) to a maximum of 4360 mm (in Manimala basin). Figure 2 shows the mean monthly rainfall of the wetland, computed using the average rainfall of stations R1 and R2 (Figure 1) for the period from 1985 to 1990. Mean annual rainfall for the wetland is estimated as 2517 mm.

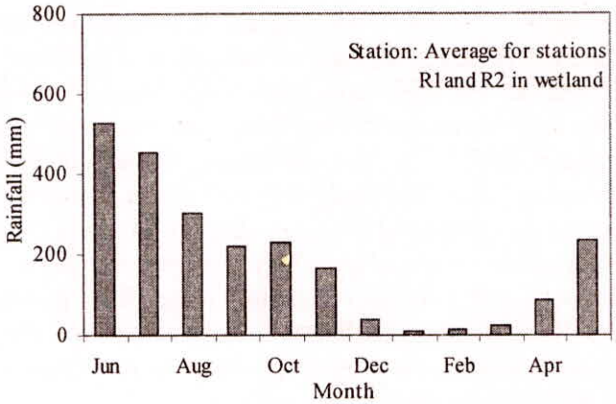


Fig. 2: Mean monthly rainfall within the wetland region (Data: CWRDM)

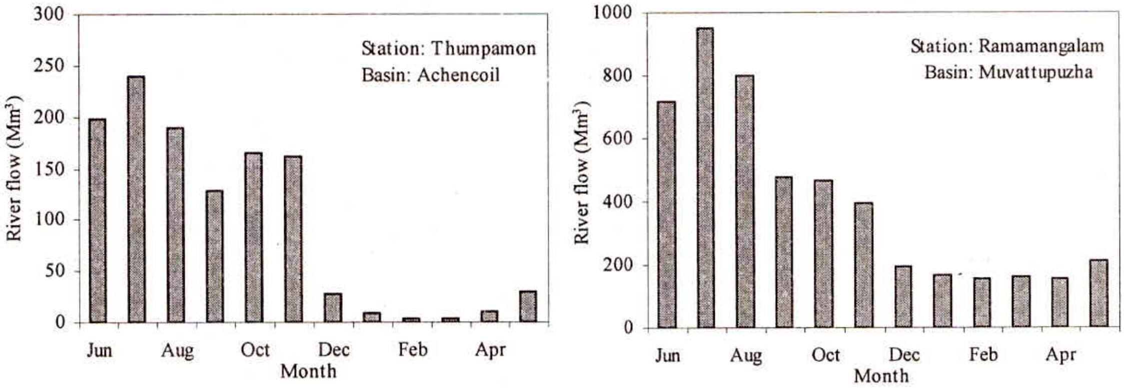
River Flows

The average seasonal and annual flows at the gauging stations, one in each of the five river basins are estimated based on the daily discharge data. Seasonal flows include the monsoon flows from June to November and the baseflow contributed from December to May of the following year. The average seasonal and annual discharges computed per unit area of the catchment of each gauging station are given in Table 3. Among the five rivers, Muvattupuzha contributes the maximum unit discharge both during the monsoon and non monsoon seasons. The Achencoil, Manimala and Meenachil basins contribute about 95% of their annual discharge as monsoon flows and remaining 5% as non-monsoon flows. The corresponding seasonal flows in; Pamba basin are 91.4% and 8.6% and Muvattupuzha basin are 82.4% and 17.6% respectively. The average monthly river flows at the gauging stations of the Achencoil and Muvattupuzha basins are presented in Figure 3.

Out of the total upper basin area of 6031.75 km^2 of the five major rivers, the gauging stations cover only 4957 km^2 area. Assuming that the seasonal and annual unit discharges computed for the catchment of each river gauging station is also valid for the remaining basin area downstream, river flows from each of the upper basins are estimated (Table 4). Since there are no discharge or rainfall monitoring stations in Kariar basin, its contribution of river flows is estimated by assuming unit discharge same as that of the contiguous Meenachil river basin where there are no storage reservoirs or inter-basin water transfer. Out of the total annual flow of 16609.47 Mm^3 contributed to the wetlands from the upper river basin areas (Table 1), 14875.80 Mm^3 (89.6%) occurs during the monsoons and the remaining 1733.64 Mm^3 (10.4%) is received as the base flow during the non-rainy months from December to May.

Table 3: Seasonal and Annual Discharges per Unit Area of the Catchment of Gauging Stations

River Basin	*Gauging Station*	*Drainage Area (km^2)*	*Monsoon Flow (Mm^3/km^2)*	*Base Flow (Mm^3/km^2)*	*Annual Flow (Mm^3/km^2)*
Achencoil	Thumpamon (Q1)	796	1.392	0.071	1.463
Pamba	Malakkara (Q2)	1644	2.217	0.206	2.424
Manimala	Kalluppara (Q3)	706	2.253	0.114	2.368
Meenachil	Kidangur (Q4)	603	2.632	0.151	2.783
Muvattupuzha	Ramamangalam (Q5)	1208	3.313	0.705	4.018



(a) (b)

Fig. 3: Mean monthly flows at gauging stations; *a* Q1 (Achencoil) and *b* Q5 (Muvattupuzha)

Table 4: Average Seasonal and Annual Discharges from the Upper River Basins

River Basin	*Drainage Area (km^2)*	*Monsoon Flow (Mm^3)*	*Base Flow (Mm^3)*	*Total Flow (Mm^3)*
Achencoil	1013.16	1410.63	72.00	1482.64
Pamba	1705.34	3781.50	351.94	4133.44
Manimala	793.79	1788.76	90.60	1879.37
Meenachil	1030.94	2713.78	155.24	2869.02
Muvattupuzha	1488.52	4931.77	1049.55	5981.34
Kariar	94.74	249.36	14.31	263.66
Total	6126.49	14875.80	1733.64	16609.47

Variability of River Flows

Variability of the river flows to the wetland is studied at the five selected river gauging stations. The daily discharge data of each station involving a total of *n* values for the total length of record are sorted and a rank (M) assigned to each discharge value starting with 1 for the largest daily discharge (Patra, 2001). To plot the flow duration curves, exceedence probabilities (P) of the flows are calculated as,

$$P = 100 \times [M/(n+1)] \qquad \ldots (1)$$

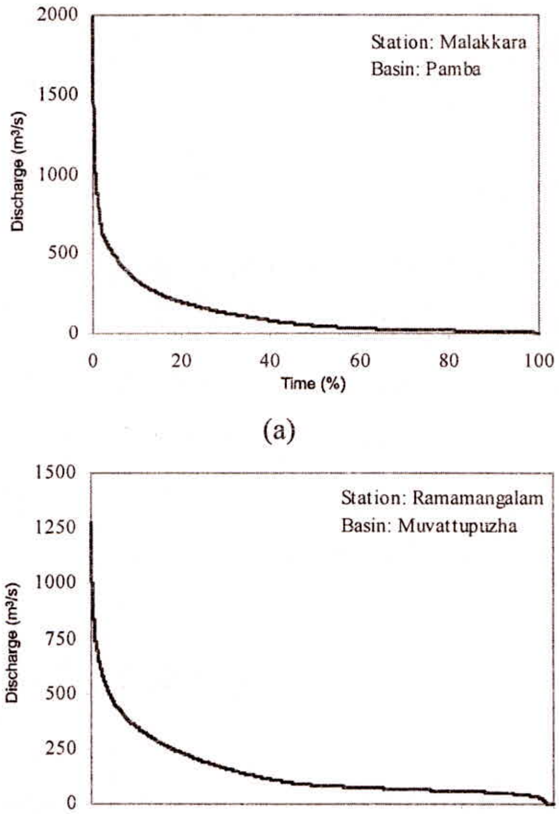
Where;

P = the probability that a given flow will be equaled or exceeded (% of time)

M = the ranked position on the listing

n = the number of events for period of record

The upper regions of the flow-duration curves of all the five stations are found to have similar steep shape indicating the same type of flood regime in all the river basins with very high flows occurring for a very short period of time. The lower regions of the curves characterize the ability of the basins to sustain low flows during dry seasons. For about 50% of time of the year, Achencoil, Manimala and Meenachil rivers have negligibly small flows (Table 5), whereas the Pamba (Figure 4(a)) and Muvattupuzha (Figure 4(b)) have slightly improved low flow regime with median flows of 49.1 m^3/s and 83.75 m^3/s respectively. Improved low flow conditions in the Pamba is due to two reservoirs with a total storage capacity of 493.5 Mm^3, whereas the low flows in the Muvattupuzha is maintained by the tailrace discharge received from the Idukki hydro-electric project located in adjacent Periyar river basin. Unit discharge contribution (Table 4) and the variability of river flows from the basins indicate that the reservoir operations play a significant role in sustaining the low flow regime in Pamba and Muvattupuzha rivers.



(b)

Fig. 4: Flow duration curves for gauging stations (a) Q1 (Pamba) and (b) Q5 (Muvattupuzha)

Table 5: Median Daily Flows at the Gauging Stations of the Five Major Rivers

River basin	*Station*	*Median flow (m^3/s)*	*10% dependable flow (m^3/s)*
Achencoil	Thumpamon (Q1)	11.29	103.60
Pamba	Malakkara (Q2)	49.10	331.90
Manimala	Kalluppara (Q3)	13.85	161.50
Meenachil	Kidangur (Q4)	15.90	143.90
Muvattupuzha	Ramamangalam (Q5)	83.75	349.95

Sediment Load

Excessive sedimentation has been highlighted as one of the major threats to the wetlands (e.g. James *et al.*, 1997). In this study, the total annual sediment load entering into the wetlands from the upper basins is estimated using the available observed sediment concentration data for the river gauging stations. For each of the five gauging stations, the average annual suspended sediment load is calculated and the estimate proportioned for the total area of the respective river basin (Table 6). Sediment load per unit basin area varies from a minimum of 0.49 tonnes/ha in Meenachil basin to a maximum of 1.27 tonnes/ha in Muvattupuzha basin. The mean annual sediment load from the total upper basin area of 6031.75 km^2 is 0.575 million tonnes, which corresponds to a unit sediment yield rate of 0.95 tonnes/ha. Assuming the bulk unit weight of the sediment as 1.80 tonnes/m^3, annual sediment volume is 319479 m^3. If the entire volume of sediments carried by the rivers is uniformly deposited in the water bodies covering a total area of 341.02 km^2, equivalent annual depth of sediment deposition will be mm. From the above discussions it is concluded that sediment deposition from the upper basins is not a significant threat to the Vembanad wetlands as reported earlier. Watershed management programmes implemented in the upper basin areas could be successful in reducing the sediment yield from the basins.

Table 6: Average Annual Sediment Load from the River Basins to the Wetlands

River	*Drainage Area (km^2)*	*Annual Sediment Load (tonnes)*	*Sediment Load per Unit Area (tonnes/ ha)*
Achencoil	1013.16	94892.11	0.94
Pamba	1705.34	159657.79	0.94
Manimala	793.79	80046.86	1.01
Meenachil	1030.94	50970.84	0.49
Muvattupuzha	1488.52	189495.50	1.27
Total	6031.75	575063.09	0.95

Water Level Variations

The seasonal pattern of the water levels in a wetland is called its *hydroperiod,* a hydrologic signature which define the rise and fall of the wetlands surface and sub-surface water (Mitsch and Gosselink, 1986). Pattern of water level variations is unique to each type of wetland, and its constancy from year to year ensures a reasonable stability for that wetland. The hydroperiod is an integration of all inflows and outflows of water, but it is also influenced by the physical features of terrain and proximity to other bodies of water. The Vembanad wetland is a low lying deltaic region where a part of the land is located below the Mean Sea Level (MSL). Water levels of the wetland is primarily governed by the river discharges from upper drainage basins, semidiurnal tides propagating from the downstream Cochin gut and the operation of the TP flood spillway and TM barrage. The mean daily water levels at stations, Alleppey (H2), Panavally (H3) and Cochin (Hd) for the period from 1 June 1998 to 31 May 1999 are shown in Figure 5.

Figure 5 shows that a number of flood events occur at stations H2 and H3 during the monsoon period from June to November. When the river flows to the wetland reduces, due to the increasing effect of tides from Cochin, salinity advances towards the south end of the lake. Presently, salinity intrusion to the polders of the region during the main crop period is cutoff by the operation of TM barrage. In water year 1998–1999, gates of TM barrage were closed on 7 January 1999 and reopened on 9 May 1999. During the closure period of barrage since the river flows to the wetland are very low, water levels on its upstream side gradually drops down, although the daily range of variations is practically negligible. Occasional rise in water levels observed during the above period is due to the water inputs from summer rainfall. It can be observed in Figure 5 that, due to higher summer rainfall received in the months of April and May, water level in the lake rise significantly from 22 April till the gates of TM barrage is opened on 9 May 1999. A summary of the range of daily water level variations at selected stations are given in Table 7. The maximum daily range of water level variations observed at Cochin estuary (Hd), and Alleppey (H2) are 1.01 m and 0.30 m respectively.

Table 7: Summary of Water Level Variations at Stations Hd, H2 and H3 in Water Year 1998–1999

	Cochin (Hd)	*Panavally (H3)*	*Alleppey (H2)*
Lowest low water level (m, MSL)	–0.54	–0.22	–0.09
Highest high water level (m, MSL)	0.56	0.76	0.69
Mean water level (m, MSL)	0.03	0.30	0.30
Max. range of daily water level (m)	1.01	0.66	0.38
Min. range of daily water level (m)	0.12	0.09	0.00

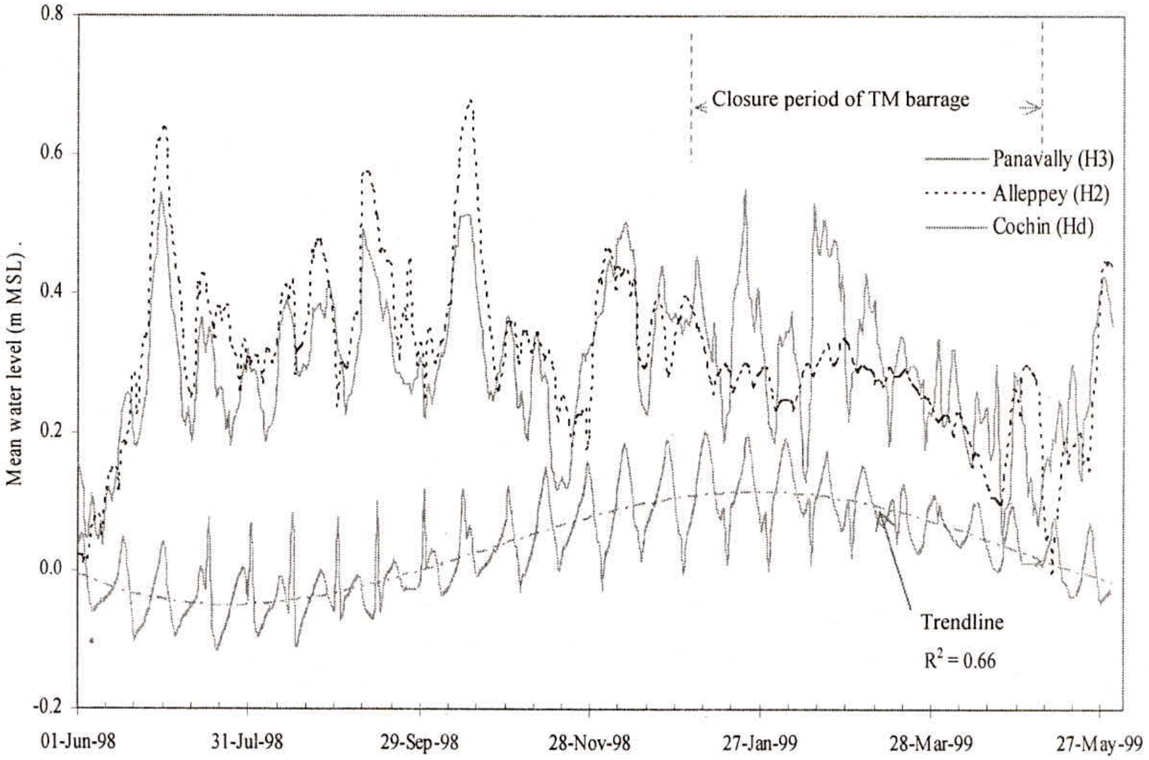


Fig. 5: Daily mean water levels in the Vembanad water system for the water year 1998–99

Overall Water Balance

One of the important factors that can be used to summarize the hydrologic state of a given wetland is the balance between the inflows and outflows of water. The general balance between water storage and inflows and out flows of a wetland (Mitsch and Gosselink, 1986) can be expressed as,

$$\Delta V = P + S_i + G_i - ET - S_o - G_o \pm T \qquad \text{... (2)}$$

Where,

V = volume of water storage in wetlands
ΔV = change in volume of water storage in wetland
P = precipitation
S_i = surface inflows
G_i = groundwater inflows
ET = evapotranspiration
S_o = surface outflows
G_o = groundwater outflows
T = tidal inflow (+) or outflow (–)

Although there may be temporary variations such as during floods or droughts, on an annual basis it can be assumed that the amount of water entering the Vembanad wetland and the amount of water leaving the system are equal. Water inputs consist of precipitation received directly on the lake and wetland area and the runoff from associated river basins. Water outputs consist of the evaporation from lake surface, evapotranspiration from the wetland and discharges to the Arabian sea. In the shallow ground water table conditions of wetland, ground water inflows and outflows are assumed to be equal. Similarly, the tidal inflows and outflows are also assumed to be equal. By assuming that there is no change in the water storage of wetland, Eqn. (2) is modified as,

$$S_o = S_i + P - ET \qquad \text{... (3)}$$

One of the methods for estimating the amount of water flowing into the Vembanad wetland and out of the system is by measuring the flow rates, but such measurements are available only for the inflows from five major rivers, and no measurements are available for the outflows through Vembanad lake. Therefore, the alternative method for computation of outflows is to subtract the estimates of evaporation from those of annual precipitation. The average annual flows from the total drainage area of the Vembanad wetland has been computed as 16609.47 Mm^3 (Table 4), which is equivalent to an average annual surface inflow rate (S_i) of 526.6 m^3/sec.

The area of land and water bodies in Vembanad wetlands are 341.02 km^2 and 1692 km^2 respectively (Table 2). The mean annual precipitation in the wetland is estimated as 2517 mm/year. The mean crop reference evapotranspiration for the wetland region has been estimated (Indo-Dutch Mission, 1989) as 1430 mm/year. Therefore, the amount of water (P-ET) entering the drainage system from the total land area of 1692 km^2 is 1087 mm; which is equivalent to an annual average flow of 58.32 m^3/sec. Evaporation from the water surface is estimated by multiplying reference evapotranspiration with the evaporation factor for water given in the FAO Irrigation and Drainage Paper No. 24 (1984). By taking an average evaporation factor of 1.125, evaporation from the water surface is estimated as 1609 mm/year. Assuming the mean annual precipitation received directly on the lake and other water bodies in the wetland to be same as 2517 mm/year, the net input of water directly through the water surface area is 908 mm; which is equivalent to average flow rate of 9.82 m^3/sec. The total average annual flow rate equivalent to (P-ET) for the land area and the water surface is 68.14 m^3/sec.

Under the given assumptions, the net average annual outflow (S_o) from the wetland to the Arabian sea is computed using the Eqn. (3) as 594.74 m^3/sec, which is equivalent to an annual volume of 18755.72 Mm^3. The overall water budget of the Vembanad wetland is schematically presented in Figure 6. Considering the major contribution of river flows (88.54%) in the total average annual outflow from the wetland, and the variability in monthly river flows discussed earlier, it can be concluded that ensuring optimal utilization of river flows by creating more storage in the river basins is essential for the future water resource development in the river basins, and also to sustain the different functions of wetlands.

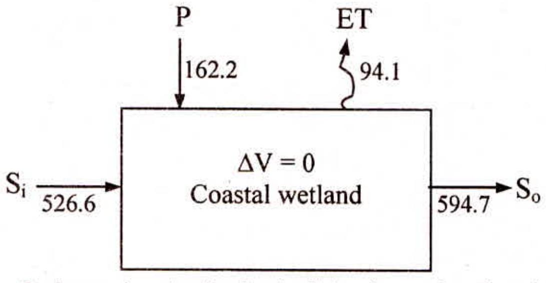


Fig. 6: Annual water budget of Vembanad wetlands (All values expressed as equivalent flow rate in m^3/sec)

CHARACTERIZATION OF FLOOD EVENTS

In the Vembanad wetlands, 398.14 km^2 area in the Kuttanad region lies below the mean sea level. The low level of relief makes the wetland susceptible to extensive flooding due to the high monsoon discharges from the five major rivers. Every year, floodwater entering from the upper basins spread out on the low lands, and high floods overtop the embankments and flood roads and homesteads and often cause loss of life. The total population of about two million in the wetland is widely spread, mainly on higher areas and in the raised lands between the polders. The combined discharge of Achencoil, Pamba and Manimala rivers entering into the southeast region of wetlands has to travel to about 30 km through the drainage channels of the relatively flat terrain, before joining the Vembanad lake. Therefore, during extreme events, flooding is severe in the southern region of Vembanad wetlands. Hydrographs at the five river gauging stations show that the duration of a typical high flood in the wetland region is several days (Figure 7). Based on the available discharge data, it is estimated that the monsoon flows to the Vembanad lake varies from 10000 Mm^3 to 18000 Mm^3.

Flood Frequency Analysis

Flood frequencies in the wetlands region is studied using the annual flood series data prepared from the available mean daily discharge data of the five river gauging stations (Figure1). Log-Pearson Type III probability distribution is used to estimate the peak flood discharges at gauging stations for different return periods up to 100 years. Since the combined flows of Achencoil, Pamba and Manimala rivers result in severe flooding in the southern region of Vembanad lake, frequencies for the combined flood discharge of stations Thumpamon (Q1), Malakkara (Q2) and Kallupara (Q3) are also analyzed. The annual maximum discharges estimated for various return periods at selected stations are given in Table 8. It can be observed that the sum of flood discharges estimated for the stations Q1, Q2, and Q3 for any selected return period closely matches with their combined flood discharge computed for the same return period; the difference in two estimates vary from 1.5% to 3.6%. Therefore, it is concluded that the annual flood series of river gauging stations located near the wetland has similar statistical properties in terms of the flood magnitudes for different frequencies, i.e. a 1:*T* year flood at station Q1corresponds to the situation of 1:*T* year flood at stations Q2 and Q3. Therefore, for the design of flood control schemes in the Kuttanad region, the one in *n* year floods can be assumed to occur simultaneously at the gauging stations Q1, Q2 and Q3. However, in the real condition of occurrence of extreme flood events in the wetlands, considerable variability is found in the frequencies of peak flood discharges at the five river gauging stations. The annual maximum discharges at the river gauging stations for various return periods given in Table 8 are found to be higher than the corresponding estimates made earlier (Indo-Dutch Mission, 1989) using the same probability distribution, but with a flood series data of limited length. More high flow events included in the added length of the annual flood series used for the present study is the cause for increase in the flood discharge estimates.

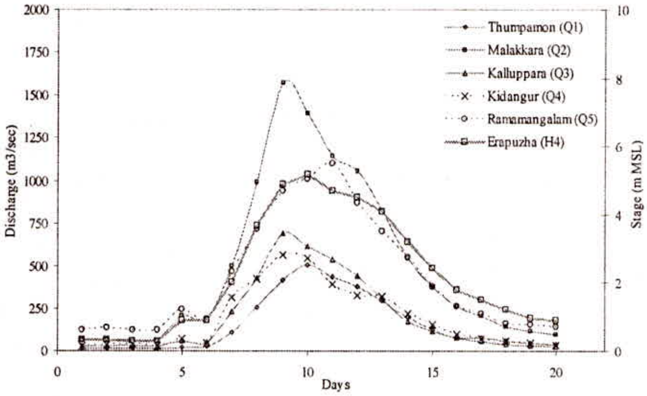


Fig. 7: Hydrographs at the river gauging stations and stage at Erapuzha for the 1986-flood

Table 8: Annual Maximum Discharges at the River Gauging Stations for Various Return Periods

Basin	*Station*	*Discharge (m^3/s) for Return Periods in Years*				
		2	*10*	*25*	*50*	*100*
Achencoil	Thumpamon	374	676	839	965	1094
Pamba	Malakkara	1066	1636	1929	2150	2375
Manimala	Kallupara	562	761	834	880	921
Meenachil	Kidangur	680	847	957	1062	1169
Muvatupuzha	Ramamangalam	988	1350	1481	1563	1634
Achencoil+Pamba+Manimala		1973	3018	3518	3882	4237

Hydrographs of the 1986-Flood Event

The flood occurred from 1 to 20 August 1986 is the oldest extreme event in the wetland region for which flood discharge data are available. Hydrographs of the gauging stations (Figure 7) show that the flood event is caused by extensive storms covering all the five river basins. Stage hydrograph at Erapuzha (station H4) located in the main channel of Pamba river within the wetlands is also shown in Figure 7. Hydrographs show that for the first six days, increase in the mean daily discharge is insignificant for the stations in Achencoil, Manimala and Meenachil rivers whereas a gradual increase noticed at the gauging stations in Pamba and Muvattupuzha. During the 6-day period, a total of 53 mm of rainfall is received in the wetland region. Stage hydrograph at station H4 shows a gradual increase in the water level.

From 7 August, flows increased in all the rivers and the flood peak is reached at Malakkara (Q2), Kalluppara (Q3) and Kidangoor (Q4) on 9 August. The flood peak at Thumpamon (Q1) occurred with a lag of one day compared to the stations Q2, Q3 and Q4; whereas the lag is two days at Ramamangalam (Q5). Elongated shape of the Achencoil basin and larger extent of flat area in Muvattupuzha basin are the probable reasons for the delayed flood peak in these basins. Water level at station H4 also increased significantly from 7 August and a peak level of 5.17 m is reached on 10 August, one day later compared to the occurrence of peak discharge at upstream station Q2 on the same river. Shape and daily rate of rise and recession of hydrographs at stations Q2 and H4 show that the flood in Pamba river is attenuated within the wetlands.

Table 9: Peak Discharges and Their Dates of Occurrence during the Flood in 1986

River Basin	*Station*	*Discharge, m^3/sec*	*Date of Occurrence*
Achencoil	Thumpamon	504.60	August 10, 1986
Pamba	Malakkara	1570.20	August 9, 1986
Manimala	Kallupara	692.80	August 9, 1986
Meenachil	Kidangur	565.00	August 9, 1986
Muvattupuzha	Ramamangalam	1101.70	August 11, 1986

Peak flood discharges and their dates of occurrence at the river gauging stations are given in Table 9. The combined peak flood discharge of stations Q1, Q2 and Q3 for the extreme event is 2854 m^3/s. The 1986 flood is rated as a 1:4 year flood at station Q1 in Achencoil, a 1:9 year flood at Q2 in Pamba, 1:6 year flood at Q3 in Manimala, a 1 year event at Q4 in Meenachil and a 1:3 year flood at Q5 in Muvattupuzha river. The combined flood discharge of stations Q1, Q2 and Q3 has a return period of 7 years. Above discussion on the flood hydrographs at the gauging stations located in and around the wetlands for an extreme event indicates that, due to the storage availability in floodplains and wetlands, river floods in the region are slow rising and attain peak in a duration of a few days. The wetlands helps to attenuate the flood peaks, but the very high volume of river flows received for extended period results in severe inundation in the region depending on the storage conditions and discharge capacity of the lake drainage system.

CONCLUSIONS

1. Out of a total average annual river flow of 16609 Mm^3 contributed to the Vembanad wetlands, 89.6% of the flows are received during the monsoon season and the remaining 10.4% occurs as base flow during the period from December to May. Among the five major rivers, Achencoil and Muvattupuzha contribute the lowest and highest discharge respectively per unit area of the basins, both during the monsoon and non-monsoon periods. The non-monsoon flows from the Achencoil, Manimala and Meenachil rivers are only 5% of the annual discharges, whereas the corresponding flows from the Pamba and Muvattupuzha rivers are 8.6% and 17.6% respectively.
2. High flow regimes in all the five major rivers are very similar with higher flows occurring only for a very short period of the year. Low-flow regions of the flow-duration curves indicate poor ability of Achencoil, Manimala and Meenachil river basins to sustain low flows during the non-monsoon season. Operation of reservoirs existing in the upper area of Pamba and tailrace discharge of Idukki hydroelectric project received by the Muvattupuzha in the adjacent Periyar basin are the primary reasons for the slightly better low flow regime in these rivers. Therefore, increasing of reservoir storages in the river basins would be the only sustainable solution to bridge the wide seasonal flow variations and thus ensure optimal utilization of the river flows draining to the wetlands.
3. Contrary to the earlier reports on excessive sedimentation, the average annual sediment load

entering to the wetland from unit area of the upper basins is found to be 0.95 tonnes/ha. Even if the entire volume of the sediments from the rivers are deposited in water bodies of wetlands, annual rate of sediment deposition would be 16.8 tonnes/ha, with an equivalent depth of 0.937 mm. Therefore, sediment deposition from the upper basins is not a significant issue in the wetlands; possibly a positive impact resulted from the watershed management programmes implemented in upper basins.

4. In the Vembanad lake, maximum daily range of the water level variations in a year vary from 1.01 m at Cochin estuary to 0.30 m at Alleppey on the southern end. After the closure of TM barrage, although the daily range of water level variation is practically negligible on its upstream side, the water level gradually drop down until the barrage is opened again except for the occasional rise in level due the to the water inputs from summer rainfall.
5. With the assumption that the amount of water entering the wetlands is equal to the amount of water leaving the system, net average annual outflow to the Arabian sea is computed as 594.74 m^3/sec. Considering the major contribution (88.54%) of river flows in the net annual outflow from the wetland, and the large seasonal variations in river flows, it is concluded that ensuring optimal utilization of the river flows by creating more storage in the basins is essential not only for the future water resources development in the river basins, but also to sustain the different functions of wetlands.
6. For the gauging stations in the five major rivers draining to Vembanad wetlands, annual maximum discharges estimated for the various return periods are higher than the estimates made earlier during the KWB Study (1989) with annual flood series of limited length. The flood series of gauging stations in Achencoil, Pamba and Manimala rivers are found to have similar statistical properties in terms of their flood magnitudes for different frequencies, thus indicating that the one in *n* year floods can be assumed to occur simultaneously at the gauging stations of these rivers for the design of flood control schemes in the upper and lower Kuttanad region. However, for real extreme events, considerable variability is observed in the frequencies of the peak flood discharges at the river gauging stations.
7. Hydrographs at the river gauging stations show that this extreme flood event in August 1986 is caused by extensive storms covering all the five river basins. Elongated shape of Achencoil basin and large extent of flat area in Muvattupuzha basin are the probable reasons for the delayed flood peak in these basins compared to the Pamba, Manimala and Meenachil basins. Due to storage availability in the floodplains and wetlands, river floods in the region are slow rising, and thus allow sufficient time for flood warning and emergency management. The wetlands help to attenuate the floods, but, severity of inundation during extreme events is decided primarily by the storage availability in the wetland and conveyance capacity of drainage system.

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