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MASS BALANCE APPROACH FOR ASSESSMENT OF POLLUTION LOAD IN THE TAMIRAPARANI RIVER

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Abstract River Tamiraparani in the southern peninsula of India is a typical receiving water body of both point and non point discharges. Comparisons between upstream and downstream monitoring sites reveal changes in concentrations and load to the river. This information is used to discriminate between point and non point source contribution to pollution. The pre- monsoon and post monsoon water quality and flow data are used to assess river pollution loads. The resulting differential loads, if adjusted for uncharacterized non point source contribution may represent the total point loads to the river minus losses due to volatilization,sedimentation,adsorption and other physical,chemical and biological phenomena. The results of the mass balances indicate that non – point sources to be major contributors to the pollution loads. The non point sources in the study area predominantly include pollution due to agricultural practices and activities,soil erosion, dissolution of soil minerals or combination of these sources.

Introduction

To achieve goals of any water quality management programme must contain evalution of pollution loads from various sources. Catchment management plans require to recognize the total pollutant load to a water body consists of three components: 1. Direct/point waste water discharges; 2. Diffuse/ non – point contribution in seepage and run off water from the catchment manipulated/ managed by and 3. A background contribution from natural sources (possibly due to scoring/erosion from catchment surfaces and in stream secondary pollution). Maintenance or improvement of water quality and control water quality degradation may require control of both point and non point sources. An assessment of non –point source pollution has to certain extent been overshadowed by the urgent need for treatment of domestic and industrial waste waters. Consequently non –point source pollution has not been adequately studied and its role in water quality degradation is poorly understood. Now, it is becoming evident that to establish the goals of water quality management programme regulating and controlling only point sources is not sufficient . In fact in many cases, the pollutants emanating from non – point source comprised major contribution of pollutant load in the receiving water bodies. Mass balance approach is a commonly used indirect method to study source contributions of pollutant loads into the receiving water bodies. This approach is useful especially when there are distinct dry and wet seasons as existent in the tropical countries like India. The mass balance approach has been used extensively during recent years to study the instream reactions and pollution loading patterns.[1,2,3] The study on the river Hoje in Sweden has indicated that an essential pollution build up seems to take place in stream sediments,which receive rural urban run off [4]. The study also established water budgets and mass balances of some water quality and constituents for 5 Km long stretch of the river.

The river system under study is a very large basin, with a number of tributaries. Monitoring all sources of pollution to assess the loads contributed by these sources is rather difficult and /or impossible and expensive and subjected to analytical errors. [5] hence modeling which is relatively cheaper and less time consuming allows for stimation of loadings which otherwise could not be measured (ie rare events). However modeling is also subjected to analytical errors, methodological errors (if model is to reflect all processes and interactions) and calculations errors (if the procedure is wrong). In direct approach for modeling pollutant loadings using upstream and downstream flows and water quality data, can provide an alternative means and is the main focus of the work presented in this paper. Mass balance application is used in this work to assess the pollutant loads contributed by both point and non – point sources.

Description of the Study Area

The Tamiraparni River is one of the major perennial rivers, which drains the important states of south India. The river Tamiraparani drains an area of 5942 sq Km, which is nearly 8% of the total geographical area of the country. There are about 8 major tributaries, 9 reservoirs and 8 anicuts. The river and its tributaries flow through different terrain having varied and use activities, soil conditions, vegetation and agricultural practices. Here surface water potential is 1706 MCM and ground water potential is 827 MCM. The water potential of the river Tamiraparani and its tributaries are mainly used for drinking, industries, irrigation and power generations. The study area in particular is part of Tamiraparani river reach between two monitoring stations; Papanasam upstream and Srivaikuntam (downstream).

The river reach between the monitoring stations is approximately 120 sq km along the river and it is indicated in the basin map shown in fig -1

Typical tropical climate prevails in the basin for better part of the year. The climate in the catchment is generally dry except during the monsoon months. Hence for all practical considerations,two seasons dry (Dec,May) and wet(June, November) seasons exist in the area. The temperature fluctuates from 20 C (minimum in winter) to 45 C (maximum in peak summer). The average annual rainfall in the Tamiraparani basin is 1626 mm. About 90% of annual rainfall occurs during the monsoon of which more than 70% occurs during July, August and September. The basin is characterized by predominantly gentle slopes and moderately to poorly drained soils. Typically the basin consists of sandy, loam,clayey soils, black cotton soils, fine loam,rocky soils, mixed (calcareous) and sandy soils are observed in the exposed part of the river bed during summer indicating weathering/erosion action of the river. From the standpoint of this study, the geology of this area is important for the wide range of infiltration rates possible, for the dissolution capacity of soil minerals and for the rapid run off that depends on the slope of the basin. Land use in the basin ranges from typical rural areas such as agricultural, livestock raising to suburban, moderately dense residential and commercial uses and densely populated industrialized urban areas. Over the past decade, the basin has developed rapidly. The aerial photographs taken between 1989 and 1994, which are later transformed to land use maps. The largest part and most rapid pace of development are identified on the fringes of the existing urban and industrial centers in the basin.

Materials and Methods

Data Acquisition

The Public Works Department (Tamiraparani Division) is collecting hydrological data (ie) guage and discharge observations and water quality at 32 monitoring stations in the Tamiraparani river and its distributaries. The discharge and water quality are monitored at an interval of 30 days. All the samples are collected from mid – stream at about 15 cm depth approximately and stored in pre – cleaned polyethylene bottles. After measuring parameters like conductivity, pH, temperature etc., on the spot, appropriate reagents are added for preservation of the samples before taking them to the laboratory for further analyses. The analyses for water quality parameters are carried out as per the procedures given in " Standard Methods for the Examination of Water and Wastewater."[6] The data is processed and published by Central Water Commission. The work reported in this paper is based on the data extracted from the Published yearbook of Central Water Commission.

Methodology

The river system constantly receives pollution from both point and non –point sources. Mass balance approach, suggests the use of different loads between the upstream and downstream monitoring stations to obtain loads contributed by the area between the monitoring stations. Taking rainfall distribution into account, the water quality and flow data of upstream and downstream stations during the dry seasons are used to estimate the point loads. As little or no rainfall occurs during the dry season the differenrial loads between downstream and upstream monitoring stations should account for loads from point sources. The total pollution loads (point and non – point) of the river are assessed using the water quality and flow data of the wet season.

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Mathematically, the approach can be represented as

$$L_{wet} - L_{dry} = L_{non\ point\ load} \qquad (1)$$

This is possible, as the pollutants selected for the present study namely,sodium,calcium,magnesium,carbonates,chlorides, fluorides,sulphates,nitrates and slicates are conservative (concentrations do not change with respect to time) and the time of travel between the two monitoring stations is around 12 – 14 hours during the low flows during the summer. As such, not many losses can occur during the travel time. Also the base flow contributions are assumed to be uniform through out the river, as the river and tributaries are classified as influent streams. The river morphology suggests no storage stations and no sudden changes in the gradients between the monitoring stations. Hence the possibility of losses /additions due to sedimentation or resuspension are neglected.

Results and Discussion

The discharge in the Tamiraparani river reach under study ranged from 100m^3/sec (minimum during the dry season) to 3000m^3/sec (maximum during the wet season) approximately at both upstream and downstream monitoring stations. However

, during rare storm events discharge in the order of 10.000 m^3/sec is recorded. The existing seasonal variation in rainfall during the dry – May and wet (June – Nov) seasons suggests such a varaiation in the stream discharges. The stream hydrographs **is** characterized by high discharges from June to November followed by a decline until a low is reached in May, which is the end of the dry period. Though the rainfall in the basin begins in the first week of June due to the south west monsoon, a peak discharge of around 2000 – 3000 m^3/sec occurs during the months of September and October. This is due to the fact that river drains a very large area. Further , the onset of monsoon varies from year to year . during the later part of the wet season, the rainfall is considerably low and hence, smaller isolated peaks are observed. The temperature varaiation pattern in the study area supports such varaiation in flows.

The maximum temperature 40° – 42° C in the study area is recorded during the month of May and the minimum 15°C – 20° C during the month of Dec. Occasional summer storms /cyclones caused high peaks during dry seasons. Further due to large variations in the rainfall distribution in the Tamiraparani basin. Occasionally the discharge at the upstream monitoring stations is marginally higher than the downstream discharge. In addition to the overall seasonal trends the river hydrograph is characterized by rapid rises and falls in response to individual rainfall events. This rapid response is probably related to the ease with which water can travel through the porous, shallow and loamy soils of the study area.

Stream velocity has two – fold effect on the water quality models. Increases in velocity to a certain level aid complete mixing and reduction in time of travel for the pollutant to reach downstream monitoring station from upstream monitoring station. The flood hydrograph studies on the Tairaparani River suggest that the stream velocity to be around 1 m/s during lean flows, which remains a time of travel about 12 – 16 hours to cover the stretch under observation. The changes in the concentration of the conservative pollutants considered for the study during this short time are negligible and hence neglected. However during the monsoon flows, the time of travel is considerably reduced which fulfills the changes in concentration of the pollutants during travel time.

Seasonal Variation Pollutant Loads

The correlation matrix presented in Tables 1 and 2 indicates strong correlations between discharge and pollutant loads in the Tamiraparani River for majority of dissolved ions under study. Significant correlations for sodium, calcium and magnesium with discharge indicate the increase in loads with increase in discharge. Further , these dissolved solids have good correlation with chloride , bicarbonates and sulphates suggesting that they occur together in the combined form before dissolution. After rainfall they reach the river in the dissolved form. Bicarbonates, chlorides and sulphates have good correlation with discharge indicating their possible entry into the river reach after rainfall. Nitrates have significant correlation at downstream monitoring station due to considerable inputs from agricultural inputs. Considerable correlations for phosphates and silicates with discharge did not exist possibly due to slow release of phosphates after being adsorbed by the soils. Further , Dissolution of silicates is a lengthy process, which occurs during continuous storm events[7]**.** Except for phosphates and silicates , which did not represent significant correlation with discharge, the total load plots closely followed the stream hydrograph[8]**.** however silicates , sulphates and phosphates did not indicate significant correlations with the discharge. The varaible relationship observed for these loads may be due to considerable dilution effect of precipitation on the stream water and lag effect.

Majority of the dissolved solids in the river Tamiraparani follow a general seasonal pattern of variation. For obvious reasons, strong seasonal dependence is observed in the pollutant loads with maximum loads during the wet season and relatively less loads during the dry season. As most of the water quality parameters under study are contributed through runoff from the basin (diffuse origin, such trend is always predicted. From the time series plots, it is evident that the water quality parameters, which have significant correlation with discharge, follow the discharge time very closely and the others deviate from the discharge line. Phosphates and silicates deviate from the discharge line at both upstream and downstream stations on the river reach. The correlation matrices presented in Tables 1 and 2 support such observations. Nitrates follow the discharge line at downstream stations and deviate from at the upstream, possibly due to higher agricultural inputs to the downstream stations.

Not only the amount of sulphates accumulated in the basin very seasonally, the concentration and loads of sulphates in river Tamiraparani water demonstrate seasonal and short-term variations. However in terms of load, considerable correlation exists with discharge. Phosphates and nitrates are generally used as indicators of nutrient levels and as guide for the possibility of algal blooms and hence eutrophication[9,10]. In terms of concentrations, nitrates and phosphates in the Tamiraparani river vary between 0.13 mg/l to 3.1 mg/l and 0.02 mg/l to 1.6 mg/l respectively (based on records available for sixxxx. Though in terms of concentrations the levels are not very high, the nutrient loads are considerable from bth point and non point sources. However eutrophication in or development of algal blooms is not yet observed due to considerable flushing during the wet weather(peak flows are about 10 times the lean flows). The possible accumulation of the nutrients in the bed sediments may lead to such a phenomena in the long run. The existing domestic and industrial waste water treatment plants in the Tamiraparani river basin do not aim in removal of nitrates and phosphates hence there is a need to improve the treatment facilities inorder to control nutrient inputs into the river.

Mass Balance Studies

Mass balance equation for a reach of river can be described using the differential load between upstream and downstream monitoring stations. To understand the source contributions (point and non point source) such differentiation in loads during dry and wet weather, mass balance for conservative and dissolved constituents in river water is of great utility, where monitoring individual sources is difficult and expensive. This approach is based on immision data (flow and water quality for the river reach under considerations[11,12]. As very little or no rainfall occurs during the dry season, the pollutant loads are from point sources. The main point load contributions in the study area are domestic waste water discharges and scattered industrial contributions of all such sources are not attempted in the present study as the present study aims at an indirect approach, which is useful in separation of source contributions with help of limited data. The pollutant loads during the wet season are contributed by point and non point sources. Hence the estimated differential loads between downstream and upstream monitoring stations during the dry season give an estimation of point load contribution to the river reach. The estimated differential loads of the wet season represent the total loads entering the river between the two monitoring stations . The difference in loadings (wet and dry seasons) in the Tamiraparani river reach need to be due to the contribution from non point source pollution resulting from mainly agricultural activities, road run off, waste water from unsewered areas and other surface activities.[12]. The results of the mass balance studies presented in Table 3 indicate the contributions due to point, non point source contribution to the river stretch under study.

The study on the Tamiraparani river indicates the contributions from point and non point sources but further classification of individual point and non point sources is not possible due to lack of classified data. The information pertaining to non – point sources of pollution due to agricultural remobilization from or entrainment of contaminated bed sediments, groundwater intrusion or a combination of these sources is required if classification of individual sources is to be attempted. Knowledge of specific point sources of pollution , which could be identified only through a detailed survey of the river basin is also essential for such classification. Also, the contribution of loads through base flow, which is also a diffuse category, is not reported in this paper. Hence the influence of base flow contributions to both point and non point sources can be attempted after separating the base flow.

In developing countries including India, the conventional wastewater treatment plants do not aim at removal of nitrogen and its compounds, hence the inputs contributed by point and non point sources to surface water are quite large. At the same time, the indiscriminate application of fertilizers in the agricultural sector is a major contributor of nitrogen for the river water. The increase in contribution of nutrients from agricultural sector is established by considering the growth of fertilizer shops and the turn over of such agencies. as there is considerable contribution of nutrients from non point sources

(especially when agriculture is the dominant land use, as in the present case, suitable best management practices (BMP) are to be adopted in the Tamiraparani basin for control of nutrients from non – point sources. Considering the existing agricultural practices in the basin, the study indicates that the agricultural sector is comparatively biggest player in regard to nitrogen in the environment, and thus also to the Tamiraparani river.

The results of the study on the river Tamiraparani in terms of load prove such an observation. From the year wise trends, it can be established that the non point source contribution is much higher than the point source contribution to the Tamiraparani river in terms of load. Further, the results of the study with respect to nitrate loads emphasise the need to decrease the share of nitrogen from agricultural sector in addition to aiming for denitrification in waste water treatment plants.

Conclusion

The stream hydrograph is characterized by peaks and lows depending on the rainfall events in the Tamiraparani river basin . There appears one significant peak in the discharge every year during the month of August or October in addition to smaller peaks in response to the other rainfall events. However the stream hydrograph depends on the rainfall and the onset of the monsoon in the region. The loads of all the dissolved solids except for nitrates, phosphates and silicates are very strongly correlated with discharge. Strong seasonal dependence in loads of dissolved solids in the river is evident from the results of the study.

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