MODELLING NUTRIENTS CONTRIBUTED BY OVERLAND FLOW FROM THE KRISHNA RIVER BASIN

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ABSTRACT

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. Hence, modeling which is relatively cheaper and less time consuming allows for estimation of loadings which otherwise could not be measured (i.e. rare events). Indirect approach for modeling pollutant loads 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. The results of mass balance application are presented in this paper. Comparisons between upstream and downstream monitoring sites reveal changes in the 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 were used to assess river pollution loads Mass balance approach indicates that non-point sources are major contributors to the pollutant loads. As the catchment is very large, the non-point sources predominantly include pollution due to agricultural practices and activities, soil erosion, dissolution of soil minerals or combination of these sources.

Keywords: Non-point pollution, Indirect approaches, water quality modeling, pollutant loads.

INTRODUCTION

Water quality management studies to achieve goals of any water quality management programme must contain evaluation of pollution loads from various sources. Catchment management plans require to recognize that total pollutant load to a water body consists of three components: 1. Direct/ point wastewater discharges; 2. Diffuse/ non-point contribution in seepage and runoff water from the catchment manipulated/ managed by man; and 3. A background contribution from natural sources (possibly due to scouring/ 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 wastewaters. 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 into the receiving water bodies.

Indirect methods to study source contributions of pollutant loads are essential to control water quality degradation in rivers. Especially in the case of rivers draining large basins, the application of direct methods/models becomes difficult as the availability/collection of data will be a major constraint (Sekhar, 2001). Regression models are useful especially when only limited data. i.e., receiving water quality and low data are available in the developing countries like India. Mass balance studies using water quality and flow data are extensively used during recent years to study the in-stream reactions and pollution loading patterns (Plummer and Back, 1980; Yuretich and Batchelder, 1988). The study on the river Hoje in Sweden has indicated that an essential pollution buildup seems to take place in stream sediments which receive rural and urban runoff (Berndtsson, 1990). Development of regression models for prediction of pollutant loads is the objective of the work presented in the present paper. The available data is used for development and testing the models.

DESCRIPTION OF THE STUDY AREA

Krishna River is one of the major perennial rivers, which drains three important States of South India. The river basin is the second largest river basin which is situated in the Deccan plateau. The river Krishna drains an area of 258,948 km^2, which is nearly 8% of the total geo-graphical area of the country. The total population in the basin as per 1991 causes has been estimated as 60.78 million. There are about 25 towns within the basin with the population more than hundred thousands. The river and its tributaries flow through different terrain having varied land use activities, soil conditions, vegetation and agricultural practices. The water potential of the River Krishna and its tributaries are mainly used for drinking, industries, irrigation and power generation. The study area in particular is part of the Krishna River reach between two monitoring stations: Pondugala (upstream) and Wadenapalle (downstream). The river reach between the monitoring stations is approximately 80 km long along the river. In addition to other districts, major parts of Nalgonda and Guntur districts drain into this part of the Krishna river reach in Andhra Pradesh. Typical tropical climate prevails in the basin for better part of the year. For practical considerations two seasons: dry (December – May) and wet (June – November) seasons exist in the area.

METHODOLOGY

The Central Water Commission (CWC) of Government of India is collecting hydrological data i.e., gauge and discharge observations and water quality data in River Krishna. Standard methods for examination of water and wastewater (APHA, 1992) are being adopted at all these 57 sites for collecting the discharge and water quality data throughout the stretch of the river. Data and preliminary information are obtained from Central Water Commission, National Remote Sensing Agency (NRSA), Andhra Pradesh State Remote Sensing Application Center (APSRAC), National Hydrological Project, etc.. Time series analysis is carried out for the discharge and loading of water quality parameters to understand the seasonal variations. Regression models are attempted for establishing load-discharge relationships for dissolved conservative pollutants namely, K^+, Na^+, Ca^{++}, Mg^{++}, $HCO3^-$, Cl^-, F^-, $SO4^{--}$, $NO3^-$ and $SiO3^{--}$.

RESULTS AND DISCUSSIONS

Stream Hydrology

The discharge in the river under study ranged from 100 m^3/sec to 4000 m^3/sec approximately at both upstream and downstream monitoring stations. The existing seasonal variation in rainfall during the dry (December-May) and wet (June-November) seasons suggests such a variation 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. The temperature variation pattern in the study area supports the variation in flows. The maximu m temperature 40^0-42^0 C in the study area is recorded during the month of May and the minimum 10^0-12^0 C during the month of December. Occasional summer storms/cyclones caused small peaks during dry seasons. In addition to the seasonal trends, the river hydrographs are characterized by rapid rises and falls in response to individual rainfall events (Sekhar, 2001). 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.

Seasonal variation

Seasonal variations in quantity and quality of river water are mainly due to the non-uniform distribution of rainfall. During the dry season, the river water is polluted due to discharge of treated/ untreated domestic and industrial wastewater, whereas during the wet season, the water quality of the river is degraded by both point and non-point sources. This pattern is not reflected when only concentrations of pollutants are taken into consideration due to the dilutional effects of large flows during the wet season. Though dilution also occurs during dry season, the river flow is so small to reflect the effect of dilution significantly. The upstream and downstream flows during the different seasons are presented in Table 1.

Table 1. River discharges during the various seasons

	Wet Season discharges (m^3/s)		**Wet Season discharges (m^3/s)**	
Year	**upstream**	**downstream**	**upstream**	**downstream**
1992-93	4834	5288	164	179
1993-94	10325	10418	113	175
1994-95	7955	8753	90	139

Time series analyses

Time series plots suggest that there is a strong seasonal dependence among the pollution load with higher loads during the wet season and lower loads during the dry season. Also, when pollutant concentrations are taken into account, the concentrations during the wet season are marginally higher than the concentrations during the dry season. Such an observation is possible only when the flow variations are very large (presented in Table1) as in the present case. In terms of concentrations, the dilutional effects of the river on point sources during the dry season are not significant due to lean flows. However, when total pollution loads are considered, it is obvious that during the wet season, the pollution loads are significant (though the concentrations are marginally higher) due to considerably greater flows in the river. Secondly, the pollution load among the wet season is contributed by both point and non-point sources of pollution. With the data analyzed during the present study, year-wise trends could not be established.

Indirect approach

Indirect estimation of loads from polluting sources using upstream and downstream river water quality is quite helpful for monitoring studies with limited data. If one is interested in information of constituents from individual sources, then indirect measurement of the sum the sources is possible in the receiving water using the following equation.
where Q_D and Q_U are downstream and upstream flows, C_D and C_U are the downstream and upstream concentrations in the river water and ΣL_i, is the sum of all individual point loadings to the rive, i.e.

$$Q_D C_D - Q_U C_U = \sum_{i=1}^{n} L_i \tag{1}$$

The equation represents the mass budget and can be used to determine a much more accurate estimate of than that likely to be obtained from summing the individual loadings. Here, the term ΣLi is not only the sum of loadings entering the receiving water body, but rather the net effect of the loading plus any loss/ generation within the water body. For pollutants that undergo significant volatilization/ degradation, this approach will not give accurate segments, unless the time of travel between upstream and downstream stations is small compared to the pollutant decay constants. The same is true for pollutants that settle from water column. This indirect approach is useful for measuring the changes in the differential concentration and/or load to the river from year to year (Dolan and El-Shaarawi, 1989). Such a study is very useful when the difference in the concentrations and/or loads are of interest. The approach has been utilized in this study to assess the contribution of point and non-point sources of pollution to the river and the results are presented in Table 2.

Table 2 Differential loadings during the wet season. (all loads in Metric tons/day)

1992 - 1993	K^+	Na^+	Ca^{++}	Mg^{--}	HCO_3^-	Cl^-	F^-	SO_4^{--}	NO_3^-	SiO_3^{--}
Upstream	624	8464	4328	2334	10251	7090	152	768	496	6087
Downstream	1872	24288	15230	7001	37100	22972	608	2305	1984	15825
Diff. Loading	1248	15824	10902	4667	26849	15882	456	1537	1488	9738
1993 – 1994										
Upstream	542	15652	22545	9454	64410	20679	564	18678	1722	13209
Downstream	1625	25555	36183	14856	94920	37419	1356	26683	4478	21662
Diff. Loading	1083	9903	13638	5402	30510	16740	792	8005	2756	8453
1994 – 1995										
Upstream	1393	9036	19324	10419	45765	22790	1000	13723	2214	5435
Downstream	4179	18893	59404	48620	202674	63304	2357	34307	6643	13586
Diff. Loading	2786	9857	40080	38201	156909	40514	1357	20584	4429	8151

MASS BALANCE STUDIES

The estimated differential loadings for the various water quality constituents compare favorably with point source loadings of the corresponding constituent, considering that the later does take into account uncharacterized non-point sources of pollution. Therefore it can be argued that the difference in loadings may be mainly due to the contribution of non-point sources of pollution resulting from agricultural activities, groundwater intrusion and/or sediment water interactions. Similar conclusions were drawn by Latimer, et.al (1988). for the increase in metal ion concentration in the d/s sections of the river Pawtuxet. Berndtsson(1990) also established water budgets and chemical mass balance of some constituents for small reach of the river Hoje and reported that half of the transported zinc is retained in the stream sediments. The loadings contributed by point sources between the upstream and downstream stations are presented in Table 3. Further classification of point loadings is not possible in the present study due to lack of classified data.

The percentage contribution of point and non-point sources of pollution are presented in Table 4. However, analysis of suspended and bed sediment samples (not attempted in the present investigation) could have provided valuable information regarding the observed differences in concentrations and/or loads to the river (Berndtsson, 1990). The analyses of sediments permits us to detect pollution that could escape water analysis and also provides information about that the critical sites of the water system under consideration. Additional inputs regarding the changes/losses of pollutants during the travel time are essential to explain source contributions within the river system. As the present investigation is the first of its kind on assessment of pollution loads from different sources in the river system, such limitations regarding source classification, data limitations, changes/losses during the time of travel, etc., could not be overcome.

Table 3 Differential point source loadings *(all loads in Metric tons/day)*

1992-1993	K^+	Na^+	Ca^{++}	Mg^{--}	HCO_3^-	Cl^-	F^-	SO_4^{--}	NO_3^-	SiO_3^{--}
Upstream	126	2013	1704	587	4322	2009	158	1281	50	380
Downstream	230	2511	2138	1256	5288	2954	633	1441	153	507
Diff. Loading	104	498	434	669	966	945	475	160	103	127
1993 -1994										
Upstream	124	2038	2095	747	4438	2820	239	2565	156	994
Downstream	177	2770	2824	912	6657	3867	669	3493	269	1210
Diff. Loading	53	732	729	165	2219	1047	430	928	113	216
1994 –1995										
Upstream	149	1265	1478	411	3908	1861	266	2282	200	475
Downstream	295	2300	2605	912	8543	3501	976	4563	448	1141
Diff. Loading	146	1035	1127	501	4653	1640	710	2281	248	666

Table 4 Percentage estimation of point and non-point source pollution *(All loads in percentages)*

1992 –1993	K^+	Na^+	Ca^{++}	Mg^{--}	HCO_3^-	Cl^-	F^-	SO_4^{--}	NO_{3-}	SiO_3^{--}
Point Source	8.33	3.15	3.90	14.33	3.60	5.96	9.42	9.41	6.93	1.31
Non-Point Source	91.67	96.85	96.10	85.67	96.40	94.04	89.58	89.59	93.07	98.69
1993 -1994										
Point Source	4.89	7.40	5.35	3.06	7.28	6.26	5.5	4.11	4.11	2.56
Non-Point Source	95.11	92.60	94.65	96.94	92.72	93.74	94.5	95.89	95.89	97.44
1994-1995										
Point Source	5.25	9.541	2.72	1.32	2.97	4.05	5.24	11.09	5.6	8.18
Non-Point Source	94.75	89.49	97.18	98.68	97.03	95.95	94.76	88.91	94.4	91.82

CONCLUSIONS

The quality of the river water deteriorates considerably as a result of pollutants discharged into the river from both point and non-point sources. The pollutant loadings obviously reduce the self purification capacity of the receiving water body. The present investigation provides an account of the advantages of using u/s and d/s river water quality data to estimate pollutant loads. This approach is also useful to detect changes in water quality constituents within the system. Indirect modeling of point and non-point sources carried out in the present work provides a better alternative for a systematic study over the conventional techniques. However, the limitations such as short time of travel, changes/losses with respect to time and distance, source classification, data limitations, etc., have to be considered carefully. As the study indicates major contributions of pollution from non-point sources, it is essential to emphasize the importance of control of non-point sources to achieve goals of water quality management programs. The control of non-point source pollution through Best Management Practices (BMP's) is beyond the scope of the work presented in the paper. However, Water quality management planning must, in future, include provisions for the control of water pollution associated with land use and non-point sources.

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