Regression Models For Prediction Of Water Quality In Krishna River

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ABSTRACT
The River Krishna and its tributaries drain three important states of South India. The river water plays a very important role in the overall socioeconomic development of Andhra Pradesh. In large river basins monitoring non-point sources pollution is rather difficult and expensive and is subjected to analytical errors. Hence, modeling water quality using land use data of the basin is attempted in the present study. The contribution from non-point sources (runoff from the river basin) is quiet considerable as the river drains various type of land uses. In this context, it is necessary to make a detailed study of the water quality of the river, to estimate the level of pollution and also main sources of pollution. Correlation studies explain the relationships, between dissolved solids concentration and land use of the basins. The multiple regression models accounted for significant variation in concentrations for majority of dissolved solids. The predicted concentrations are in good agreement with the observed values. The proposed models can be useful for planning land use controls in integrated water quality management program. As water quality of flowing water is closely linked to the land use in the basin, it is essential to include land use management in future river basin planning. Carefully designed land use studies to identify characterized and quantity of non point sources is essential elements to be emphasized to plan water quality management programme. The results of study indicate relative importance of non point sources pollution in addition to point sources pollution.
Keywords: Dissolved solids, Land use planning , Regression models, Water quality.

1 Introduction

Study of water quality is fundamental to understanding a water resource, as it gives insight into the benefits derived from water management. Urbanization and industrialization are recognized to be main causes for water quality degradation for quite some time. Hence, assessment of non-point (diffuse) pollution, which arises from the river basin is overshadowed by the urgent need for treatment of domestic and industrial wastewater (point sources). At present, huge sums are being invested in treatment works in an attempt to revitalize streams/lakes and protect water resources, yet as investigators have pointed out, there is evidence that the clear water objectives will not be realized because of runoff wastes that reach the streams/lakes without being processed. It seams reasonable that the identification, evaluation and modelling of this type of pollution should be considered as an integral part of all watershed water quality management projects (Sekhar and Raj 1995). Hence, modelling of non-point source pollution, however complex, is very essential for any water quality management programme. The purpose of this paper is to develop models to study the influence of land use on stream water chemistry.

Two broad categories of methods are available for estimating non-point pollution sources to surface waters. The first is an indirect approach that utilizes measurements of water quality parameters in streams, rivers, or lakes to infer the importance of pollution sources. The alternative direct approach focuses on the non-point sources and attempts to mathematically describe the transport of pollutants to the water body (Haith and Dougherty, 1976). The indirect approach utilizes water quality data (immission data) from streams, rivers or lakes and infers the importance of non-point source pollution from these in stream observations. These provide general indications of the quality and quantity of non-point pollution. However, their focus is on the observed water quality of a water body than on sources or causes of pollution. Loading factors based on measured in stream water quality parameters have limited credibility, since the values of such parameters are affected by a variety of pollution sources as well as in stream physical and chemical processes. However, the influence depends on the nature of pollutant (conservative/non-conservative), time of travel, flow characteristics, etc.

Indirect approaches are generally based on comparisons of pollutant export in stream flow from watersheds. Watersheds are characterized according to land use and pollutant exports, e.g., urban agricultural and forested watersheds. The result is pollutant-loading factor, e.g., kg/km^2 of phosphorus for agricultural land and urban areas. The water quality planner can apply these reported values to his study region by taking an inventory of land uses and multiplying the areas of each use by the appropriate loading factor (Hartigan, et. al, 1983). Alternatively, when time and money permit, the planner may isolate small single land use watersheds within the study area, undertake a water quality sampling program, and determine these loading factors. The indirect inference approach can be extended beyond simple loading factors by the use of regression models, which have land use characteristics as independent variables and in stream water quality parameters as dependent variables (Haith, 1976).

2 Study Area

The Krishna river is the second largest eastward draining, perennial river in the peninsular India. The river basin stretches between $73^0\ 21^1$ and $81^0\ 09^1$ East longitudes and $13^0\ 07^1$ and $19^0\ 25^1$ North latitudes. There are about 13 major tributaries which join the along its length and draining an area of 258,000 km^2. The average annual rainfall in the river basin is about 780mm. The wet seasons sets in by the middle of June and withdraws by the middle of October. About 90% of the rainfall occurs during the wet/post-monsoon season (June-October) and during the rest of the year (dry/pre-monsoon season) there is very little rainfall with no regular pattern. The river basin has various land use patterns, of which agricultural land use (double crop – 35 %; single crop – 25 %), forests (15%), waste land (15%) and mixed land use (10%) are the important land use classifications. The predominant soils in the area are sandy loams and loams.

3 Materials and Methods

The Central Water Commission (CWC), Government of India collects hydrological (gauge and discharge observations) and water quality data from 57 monitoring stations on the River Krishna and it's tributaries. The Seba current meter is used to measure velocity and discharges are estimated by area velocity method. The discharge and water quality are monitored at an interval of 10 days. All the samples were collected from mid-stream at about 15 cm depth and stored in pre-cleaned polyethylene bottles (CWC Mannual, 1995). After measuring some of the parameters like conductivity, pH, temperature, etc., on the spot, appropriate reagents were added for preservation of samples before taking them to the laboratory for further analyses. The analyses for water quality parameters are carried out as per the "Standard Methods for Examination of Water and Wastewater" (APHA, 1985).

Taking rainfall distribution into account, the multiple regression models are developed for wet seasons as 90% of the rainfall occurs during that season. This is possible, as the pollutants selected for the present study namely are conservative (concentrations do not change with respect to time). One methodology which offers considerable promise is the use of statistical analysis of land use and water quality data. Correlation and regression analysis, are attempted for the study of land use and non-point source impacts on water quality. Emphasis is placed on dissolved solids representing the stream water chemistry, which are generally considered to be associated with non-point sources. Stepwise regression methods are applied to water quality parameters and land use data for eight watersheds draining to the River Krishna through the tributaries.

4 Results and Discussions

4.1 Land Use Classification: Land use classification of the river basin is of dynamic nature and it influences the hydrologic system and hence, the water quality of the river. As such land use classification is a first step in any water quality management study. In all the sub-basins of the Krishna river, land use is mainly classified into agriculture, forest and waste land. Agriculture is the most predominant activity and its percentage varies around 35 - 60%. Forests contribute 10 – 20 % area and waste land is about 10% for many sub-basins. However, for Ghataprabha basin forests contribute 56%. Urban areas and mixed land uses make up the remaining percentage. The existing land use (1981 - 91) are considered for the study, and the impact of changing land use pattern on water quality of the river is not attempted. As 90% of the rainfall occurs during the wet season, the influence of land use activities on water quality is restricted to the wet season between June and November. The other part of the year receives occasional insignificant rainfall.

4.2 Stream Hydrology: All the tributaries of the Krishna River considered for the study exhibit seasonality in flow conditions. The discharges are minimum during the dry season and maximum during the wet season. The variation in wet season ranges between 10-15 times of the dry flows. However, during rare storm events discharges in the order of 50-60 times the dry flows are recorded. This type of seasonal flow variation is one of the characteristics of watersheds with tropical climate. The temperature variation in the study area suggests such seasonal variations in flow. The maximum temperature is $40\text{-}42^0$ C is recorded in the month of May and minimum $10\text{-}12^0$ C during the month of December. The mechanism of overland flow is not considerable during the dry season even if there is a rare rainfall event, as water being absorbed by the soils to reach saturation conditions, before overland flow can take place. This is probable due to long dry spells as common to tropical regions, with little or no rainfall. However, during the monsoon period, overland flow contribution to the flow is considerable.

4.3 Water Quality: Large variations in flow conditions lead to variations in water quality of the tributaries of River Krishna. These large variations in flow and water quality explain the response of the stream to rainfall events on the sub-basins. Physical observations at the monitoring stations suggest high-suspended solids content during wet season, due to the influence of runoff from the basins. During the dry season, though flows are low, the water is clear with no considerable suspended sediment. These observations indicate considerable overland flow contribution to the stream flow monsoon season. The dissolved oxygen concentration in general varies around 10-8 mg/L, inspire of considerable pollution from both point and non-point (diffuse) sources. Though, dissolved oxygen is not directly considered for the purpose of the study, dissolved oxygen can influence NH_3, NO3, and SO_4 levels to certain extent. Further, maximum specific conductivity values are observed during the dry seasons due to contribution of dissolved solids by point sources and base flows. The reduced dilution effect during the dry season is another possible season for such observation. Decreases in electrical conductivity and pH, with increase in discharge prove the effect of dilution on water quality. Owing to lag effect, the concentrations, and electrical conductivity for a given discharge are usually lower on the falling limb of the hydrograph for some of the dissolved ions, which occur in combined form. These observations (though are qualitative in the present study) can be effectively used to study the impact of first flush, lag and dilution on the stream water quality.

4.6 Correlation Studies: The results of the correlation studies between concentrations dissolved solids and land use activities of the basin are presented in Table 1. Some of the parameters exhibited significantly good correlation, while the others indicated insignificant correlation. This is perhaps due to highly variable nature of chemical concentrations in precipitation and inputs from the basin. Further, most of the inputs and outputs occur during relatively short periods of heavy rainfall and high discharge. Sodium, calcium and magnesium seem to occur together in the basin, which is probably due to the geological characteristics of the soils in the basin. As sodium is reactive, it did not have any significant correlation with any other ions. Calcium is strongly correlated with sulphates, nitrates and phosphates, indicating that it occurs in combined forms, which later gets dissolved. Calcium is negatively correlated with silicates, which means that as silica increases calcium decreases. The soils contributing silica and calcium are quiet different, hence, negative correlation is obvious. Magnesium is strongly correlated with bicarbonates, suggesting its occurrence in the form of magnesium bicarbonates. Bicarbonates exhibit good correlation with silicates indicating that they occur together in the basin. Most of these observations are supported by the general classification of the soils found in the basin, which are reported to be predominantly loam, clay loam and laterite soils (Sekhar, 2001).

Table 1 Correlation Matrix

Parameter	Na	Ca	Mg	NH_3	HCO_3	Cl_2	SO_4	NO_3	PO_4	SiO_2	Waste land	Agl. Land	Forest land
Sodium	1.00												
Calcium	0.67	1.00											
Magnesium	0.93	0.35	1.00										
Ammonia	-0.22	-0.10	-0.25	1.00									
Bicarbonates	0.43	-0.31	0.73	-0.36	1.00								
Chlorides	0.17	0.08	0.27	-0.24	0.44	1.00							
Sulphates	0.14	0.67	-0.12	-0.09	-0.44	0.37	1.00						
Nitrates	0.27	0.72	-0.01	-0.25	-0.42	0.25	0.89	1.00					
Phosphates	0.38	0.69	0.13	-0.53	-0.31	0.03	0.49	0.73	1.00				
Silicates	-0.08	-0.76	0.28	0.02	0.78	0.11	-0.64	-0.70	-0.73	1.00			
Waste land	0.04	0.50	-0.20	-0.10	-0.61	-0.33	0.14	0.27	0.71	-0.81	1.00		
Agl.s Land	0.38	0.74	0.17	0.13	-0.30	0.41	0.49	0.48	0.48	-0.71	0.53	1.00	
Forest land	-0.39	-0.87	-0.09	-0.07	0.49	-0.16	-0.59	-0.63	-0.65	0.88	-0.68	-0.94	1.00

Waste land has significant positive correlation with calcium and phosphates, indicating the absence of plant uptake or soil leaching. Agriculture land has significant positive correlation with calcium and negative correlation with silica. This is perhaps due to low calcium uptake by plants and the negative correlation may be due to land cover controlling silica erosion from the basin. Forest land is positively correlated with silicates, due to significant deforestation activities. Nitrates and phosphate uptake is quiet good in the forest land and hence, negative correlation. Forest area is negatively correlated with waste land and agriculture land indicating the influence of forest land on them.

4.7 Regression Models: The multiple regression models developed during the study are presented in Table 2. The final equations are given in the table and stepwise equations are not indicated in the table. The coefficient of determination (r^2) gives an indication about the suitability of the model. The models explain 87% variation of calcium, 52% variation of bicarbonates, 69% variation of chlorides, 56% variation of sulphates, 67% variation of nitrates, 62% variation of phosphates and 92% variation of silicates. For sodium, magnesium and ammonia, the models could not explain significant variations. This is possibly due to the reactions of these ions with soils and other ions. The models are verified and found to provide reasonable estimates of dissolved solids concentrations generated from the river basin. The predications of the dissolved solids using the developed models are in good agreement with observed values. However, it is observed that nitrates, phosphates and silicates are over predicted by the models.

5 Conclusions

The River Krishna is a very large basin, with number of tributaries. Considering the above fact, it is rather difficult or impossible and expensive to monitor all individual sources of pollution. The study reported in the paper illustrates the impact of land use on the water quality and attempts to model stream water chemistry with the available land use and water quality data. Land use in the basin is dominated by agriculture. However, forests are diminishing due to increased urbanization and industrialisation. The influence of land use activities on water quality is mainly restricted to post monsoon season, as 90% of the rainfall occurs during the season. The tributaries of the river exhibit seasonality in flow conditions with minimum flows during dry season and maximum flows during the wet season. The available water quality information indicates high concentration of suspended solids during the wet flows and high concentration of dissolved solids during the dry season which are due to flushing and dilution effects. The models developed form a basic tool to support water quality and land use management in future. The proposed models are based on the use of available data at the river scale and would therefore be directly applicable to the study area. It could be further useful for policy makers to impose land use controls, so as to minimize water quality degradation.

Table 2 Multiple Regression Models

Parameter	**Model**	**R^2**
Sodium	Na = -725.42 FL – 556.70 Ag. L – 1800.79 WL + 675	0.255
Calcium	Ca = -86.13 FL – 97.09 Ag. L – 84.19 WL + 109.44	0.869
Magnesium	Mg = -200.31 + 64.83Ag. L – 5.82 FL+ 5.1	0.148
Ammonia	NH_3 = 5.74 Ag. L - 0.058 WL + 1.288FL – 3.1	0.062
Bicarbonates	HCO_3 = -335.25 WL + 349.88 FL + 654.41 Ag. L – 283.98	0.520
Chlorides	Cl^- = 688.88 AgL – 420.72 WL + 208.76 FL – 305.87	0.690
Sulphates	SO_4 =-564.93 FL – 682.90 AgL – 1002.45 WL + 650	0.564
Nitrates	NO_3 = -15.76 FL – 22.05 AgL – 20.94 WL + 20.00	0.672
Phosphates	PO_4 = 8.64 WL – 5.59 FL – 8.66 AgL + 6.00	0.618
Silicates	SiO_2 = 34.78 FL – 23.52 WL + 43.47 AgL – 22.35	0.925

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