A Spatial Model : Monitoring of Water Pollution of a Hydrogeomorphic Unit

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1. INTRODUCTION

The rate at which we deplete and degrade our fresh aquatic resources poses a great threat to our future life support system. The rise in human population exploits more of natural resources and this is met through the growth of industries specifically chemicals and petrochemicals, urbanization, deforestation and intensive agricultural practices. The industries and urban sprawl discharges the waste into the rivers. The deforestation process itself aggravates the sedimentation transport into the streams. The use of chemicalsin the crops for better production contaminates ground water through percolation, and rivers and lakes through surface run-off. All these sporadic degrading activities have lead to gradual deterioration in the quality of surface and subsurface water. The loss of quality is causing health hazards and death of human, livestock and aquatic lives, crop failure and loss of aesthetics.

Keeping in view the importance of good water quality, the Central Pollution Control Board (CPCB), in 1976, initiated a series of integrated river basin studies all over the country. CPCB in collaboration with the State Pollution Control Boards (SPCB) established the Water Quality Monitoring (WQM) network in the country. The CPCB has identified river stretches all over the country, which have been polluted to the maximum extent. The Krishna river, which is one such polluted rivers of the country, flows across the states of Maharashtra, Karnataka and Andhra Pradesh. The present study is taken up for the monitoring, identification and suggesting preliminary measures of water pollution control in the Satara-Sangli stretch (stretch-I) of the Krishna basin as an hydrogeomorphic unit in Maharashtra with the help of Geographic Information System (GIS). The stretch-I, also known as the country's sugar-belt, has been identified by CPCB and MPCB (Maharashtra Pollution Control Board) for the restoration of water quality under the National River Action Plan (NRAP).

2.Satara - Sangli Stretch : General Overview

The Satara-Sangli stretch of the Krishna River in Maharashtra is known as the sugar belt of the country. The Krishna River flows with a southeasterly trend in Maharashtra, traversing a distance of 280 kms from Mahabaleshwar through Satara to Sangli [latitudes 16 00'N-18 00'N, longitudes 73 30'E-75 00'E, altitude 150-600 m] on a rocky area. The river is met by river Koyna, abut 137 kms away from its source. The total geographical area of the Krishna basin in Satara is 10,816 km2 (4%) and that of Sangli is 8,572 km2 (3.2%).

2.1 Landuse / Landcover

The Krishna basin covers a non-arable land area of 53010 km2 out of which 22.4% fall in Maharashtra. In Satara 2.1% of the reporting area is non-arable land while the same is 3.3% in Sangli. Forestland accounts for 1583 km2 (15.1%) in Satara and 488 km2 (5.6%) in Sangli. The total cultivable land in these two districts of the Krishna basin is 13,844 km2 that is 65.3% in Satara and 81.5% in Sangli. The districts of Satara and Sangli exhibit substantially wooded tropical evergreen forest. About 75% of the total forest cover is dominated by teak species. Amongst all types of landuses, agriculture is dominant in Krishna basin with over 50% total land actually under cultivation. The intensity of cultivation is more clearly indicated by the average number of crops grown in a year given by gross sown area divided by the net sown area, which equals to 1.10. The extent of irrigation applied for crops in Satara and Sangli is 16.9% and 11.1% respectively. Irrigation is done mainly using stream diversions or canals (42%) and ground water source (58%). About 21% of gross sown area is irrigated.

2.2 Fertilizer and Pesticide consumption:

To get higher yields in the cultivated land, farmers apply more and more of chemical fertilizers. The total chemical fertilizer consumption in Satara and Sangli during 1995-96 were 50390 and 83153 tonnes. With the intensification of agriculture, particularly since introduction of higher yielding but low pest-resistant varieties of crops, the use of pesticides and biocides have been increasing steadily. The total pesticide consumption in Maharashtra is 711 MT/Year, of which 7% is consumed in Satara and 6.4% in Sangli. In these two basin districts organo-chlorine share is the highest. The application rate per hectare is about 0.09.

2.3 Water Consumption and Effluent Discharge

The state of Maharashtra is ranked first in terms of industrial investment in the country. Major industrial sectors are power, fertilizer, sugar and cement industries. In Satara and Sangli fifteen medium to large size sugar industries are located. There are many liquor factories located along the stretch-I. The quantity of water that is consumed for domestic, industrial and irrigation uses are respectively 66, 18 and 3366 MCM. Correspondingly, the amount of effluent that is being discharged from urban, industrial and irrigation sources are 29, 14 and 673 MCM. From the sugar factories and their surrounding domestic locations about 13400 and 1525 cubic meter of effluents Is being discharged everyday.

3. A framework for monitoring water quality in GIS

River water quality monitoring is the process of regular study of parameters related to river water. It helps determining the quality trend and hence the threshold values for the restoration of water quality to its normal. The factors that affect the water quality are physical, chemical and socio-economic parameters of the river basin. A detailed monitoring framework is shown in figure 1. The present case study is followed up as per this framework. Using GIS, the database on pollution load, the relationship between pollution load and population, fertilizer consumption and factory location, and the river zonation have been assessed and graphically presented. The techniques of river zonation has been reviewed and modified. The prime objectives of using GIS over traditional methods are:

Effective storage and analysis system for spatial and temporal databases such as maps on geology, geomorphology, soils, landuses and attributes on meteorology, population, water quality etc., Spatial analysis on depicting the source-pollutant relationship, Graphical presentations, visual impacts and spatial distribution of graphical outputs on water quality changes, pollution load and relationship with sources and Management of river basins by generating buffers zones on the basis of water quality criteria.

4. Water Quality and Pollution Load at Stretch-I

The stretch-I is about 180 kms. This stretch, covering a total area of 13065.22 km2, is subdivided into three sub-watersheds SW1 (1705.17), SW2(3545.4) and SW3 (7814.65) km2. A WQM station accompanies each one of these sub-watersheds. The WQMs 1194, 36 and 37 respectively fall within the sub-watersheds SW1, SW2 and SW3. The coverage of Krishna channel within these subwatersheds are respectively 40.92, 300.84 and 531.10 km2. About 19 water quality parameters, the physical parameters temperature, run-off and turbidity and the chemical parameters pH, hardness, conductivity, alkalinity, DO, BOD, COD, Fcoli, Total Coliform, Nitrogen, Chlorine, Sulphur, Sodium, Calcium, Magnesium and TKN, were studied from their monsoon and non-monsoon readings.

While computing the pollution load, it was assumed that the river flows in the stretch 365 days a year (a perennial river). The exposure of total population to pollution load in each subwatershed is correlated to their growth trend. Generally along the stretch-I, turbidity and the chemical parameters BOD, COD, Na, Mg, Ca, Cl, TKN and Sulphate show slightly increasingly trend over the years (1984-1997) in the downstream direction of river flow. Parameters like pH, N and DO don't show much of variation from the mean. However, the water quality readings of Fcoli and Tcoli are slightly decreasing along the downstream direction.

In the individual WQM station the trend in BOD and COD loads, the indicators of organic pollution, show positive and the COD values are quite higher than BOD. The minimum and maximum BOD values during 1997 were 227 and 13241 tonnes/year whereas the COD values were 655 and 33453 tonnes/year respectively. The BOD and COD loads of the stretch, are showing sharp positive trend from 1990 onwards (Figure 2 a,b,c,d). These indicated that the inflow of pollutants to river have been increasing after 1990.

Amongst all the chemical parameters, the load of magnesium was the maximum. The highest Mg-load obtained was 224416 tonnes year in 1988 for SW3. If the load of each pollutant is listed in terms of their total contribution in an year, the sequence in descending order for these pollutants will be Mg, Ca, Na, Sulphate, Cl, N, COD and BOD. The first five major pollutants in the sequence is generally from the agricultural sources and the last two are from both domestic and industrial sources.

5. Source Identification

GIS was used to organize both spatially and temporally and presenting graphically the pollution load data for each subwatershed over the period 1984 to 1997. For each pollutant, the load data for four years was presented which included years of minimum and maximum pollution loads and the pollution loads of starting and ending years. One such case for `Mg' is shown in Figure 3. The spatial variation of all the pollutants showed a steady increase in the load towards the downstream direction. This is due to two reasons - (i) the flow rate (cumecs) of river increased in the downstream direction and (ii) the increase in concentration of water quality parameters, though inconsistent, downstream due to addition of wastes from upstream and additional streams.

One of the facts for additional increase of concentration downstream is due to increasing number of sugar factories. In 1997, the number of major sugar factories in SW1, SW2 and SW3 were zero, three and five respectively. The effluents which comes out of these factories and surrounding urban setup are added to the stream as a fresh input. The waste discharge of these large and medium sugar factories and the surrounding urban setup are in the order of 13400 and 1524 cubic meter per day respectively. The growth or density of population has increased highly along the downstream which has produced such a large quantity of domestic wastes.

Between 1951 and 1991, the population growth per sq.km in Satara and Sangli were 121 and 141 respectively. The growth of population synchronized with the growth in factories and the consumption rate of fertilizers. The consumption quantities of fertilizers in the agricultural land have increased by more than 3-fold in Satara and 4-fold in Sangli. This explains why the pollution loads from agricultural sources such as Mg, Ca, Na, Sulphate, Cl and N is continuously increasing along the downstream direction.

The spatial relationship between the pollutants (BOD & COD) and the population growth was correlated using three estimators contingency coefficient, Tschuprow's T and Cramer's V. The estimators showed well relationships (V=0.67, T=0.56, Contingency Coefficient=0.56) between BOD and population growth and COD and population growth. Therefore, using the overlay techniques the composites BOD - population growth and COD-population growth were produced. The results in composite were classified into good, bad, very bad and worst (see figures 4 & 5). For example, good regions have low population growth and low BOD. Similarly, the relationships between the rate of fertilizer consumption with BOD and COD were estimated. The estimators showed again good relationship. These analyses supported the fact that population rise is a dominant factor to increasing pollution load due to domestic and agricultural sources in the downstream direction.

6. Pollutant Balance

Industrial and domestic wastes contribute to the major rise in BOD and COD concentrations. The waste disposals from sugar and distillery factories are the prime sources of BOD and COD loads. In Table 1 the balance of pollutants is estimated for three subwatersheds. Since the total pollution load for the stretch is coming from SW1 to SW3 through SW2, the share of each subwatersheds to pollution load has been computed. In each subwatershed the total addition (fresh input) is estimated. By subtracting the total waste assimilation capacity (WAC) of river from the total addition, the result becomes the net addition of load that will go into the subsequent subwatersheds in the downstream.

7. Suggestion on River Water Quality Restoration through Zonation

Buffer zones are used in proximity analysis where the distance from either side of riverbank is an important criterion in determining suitability or risk. Buffer zones provide storage for floods and pollution control. Buffer strips made of uneven vegetation (grasses, shrubs, trees) attenuate runoff pollutants that would otherwise reach the body of water. The methods of creating buffer zones on both sides of a river bank, also known as corridors, are called as river zonation. The present study suggests over an existing river zonation method. The Satara-Sangli stretch is classified into zone A-II by MPCB but the present study found three clearly demarcated zones A-I, A-II and A-III contained in SW1, SW2 and SW3 respectively.

Each of these subwatersheds was used for buffer zones demarcating the red, orange and green zones. The buffering distance for each zone was considered as per MPCB's distance criteria (MPCB, 1997).

The characteristics of watersheds influence the pollution load at substretches due to the water quality properties of streamlets which are induced artificially and naturally. For better understanding of pollution loads in a stretch (watershed), it is essential to know the addition of pollutants at substretches, or it might be said that the pollution load is better dependent on the subwater shed (substretch) characteristics than the flow channel. It is suggested that the river zonation at stretch-I should be done in the subwatersheds rather than along the flow channel. The comparison of these two types of river zonation are shown in Figures 6 and 7. The total Arial coverage as per flow channel zonation are 2849 km2 (within 1 km) and 1845 km2 (within 1-2 kms) and the same from the present suggestion of subwatershed zonation are 1653 km2 (within 3, 1, 0.5 kms) and 1897 km2 (within 8, 2, 1 kms).

8. Conclusions

GIS has been utilized in the storage and retrieval of attribute data such water quality parameters (pollution loads), population density and fertilizer consumption over the spatial database (map) of the Satara-Sangli stretch in the Krishna basin. This database was useful in monitoring the trend of pollution load and population load and population growth in the entire watershed between 1984 and 1997. With the aid of map comparison utility in GIS, pollution map could be compared with the population, fertilizer and industry location maps. The Satara-Sangli stretch of the Krishna river is polluted grossly by the human-induced activities in the subwatersheds. The factors for acute pollution of water is: the intensive use of fertilizers and pesticides in the agricultural land, growth of medium to big size sugar and distillery factories and very high growth of population leading to high domestic load from urban setup. Amongst the physical parameters, turbidity values increased and the same results were witnessed after 1990 for chemical parameters such as BOD, COD, Na, Mg, Ca, Cl, TKN and Sulphate. For all the pollutants, load values increased abruptly for the subwatersheds along the downstream direction.

There has been a good relationship between the pollution parameters and the population density. About 32 lakh people got exposed to the pollution in 1991. The growth of people synchronized with that of the growth in industries. About 8 major sugar factories were responsible for most of the industrial effluents. Of all sources, the share of agriculture to water consumption and water pollution was the highest. Agricultural sources contributed to 91% of the total waste discharge while the same for domestic and industrial sources were 4.5% each.

It is very much indispensable that some standard economically feasible technologies are adopted to mitigate and reciprocate the process of water quality degradation, and restore the quality back to normal. The river zonation suggested in this paper on the basis of subwatershed approach is fairly better in terms of Arial coverage and pollution control.

Table 1 : Pollutant Balance (tonnes/year)

Source	Nature of Pollutants	Subwatersheds SW1	SW2	SW3	Total for the Stretch
Agriculture	N, P, K & Pesticides	579447860	1204791570	2655560570	4439800000
Domestic	BOD	3893	8063	19321	31277
Sugar	BOD, COD	6561	11664	21276	39501
Others	BOD, COD	3294	13175	17128	33597
	Total Addition	579461607	1204824473	2655618295	4439904375
	Total Assimilation	115892321	240964895	531123659	887980875
	Net Addition	463569286	963859578	2124494636	3551923500
	Addition from Upper Subwatershed	0	463569286	963859578	