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Development of Water Pollution Model: A Case Study of Mahi River Basin, Gujarat, India

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Abstract: *Water quality of River Mahi, Gujarat is evaluated by Water Pollution model. A Water Pollution Value (WPV) provides a single number that expresses overall water quality at a certain location and time based on several water quality parameters. The objective of the value is to turn complex water quality data into information that is understandable and useable by the public. The work is aimed to develop the Water Pollution model and apply it along a stretch of River Mahi. Six water quality indicator parameters, namely, pH, dissolved oxygen, biochemical oxygen demand, electrical conductivity, nitrate nitrogen and total coliform were selected for the calculation of WPV. The data for water quality quarterly concentration for the indicator parameters for four stations located on the Mahi river are collected for four year period from Gujarat Pollution Control board. The results show that the water quality of Mahi river is excellent. It is concluded that WPV can be used as a tool to assess the status of water quality of a river. The WPV can be used by decision makers, government bodies for framing policies for sustainable water quality management.*
Keywords: *water quality value, water pollution value, water pollution model*

I. Introduction

The surface water bodies are under a continuous threat due to growth of Urbanization and industrialization. Water quality is impaired by anthropogenic contaminants and thereby the surface water does not support a human use, such as drinking water, or undergoes a marked shift in its ability to support its constituent biotic communities, such as fish. Water quality indices are tools to determine conditions of water quality. The main focus of this study is to develop Water Pollution Value for four stations located on River Mahi, Gujarat.

Study Area
Mahi River basin

The Mahi basin extends over states of Madhya Pradesh, Rajasthan and Gujarat having total area of 34,842 Sq.km with a maximum length and width of about 330 km and 250 km. It lies between 72°21’ to 75°19’ east longitudes and 21°46’ to 24°30’ north latitudes. It is bounded by Aravalli hills on the north and the north-west, by Malwa Plateau on the east, by the Vindhyas on the south and by the Gulf of Khambhat on the west.
This study is aimed at examining the Mahi river water quality and developing the Water pollution value at four stations:

1. Station 1 (M_1) - Mahi river at d/s of Kadana dam located in Kadana taluka, Panchmahal district, Gujarat, latitude 23.2895° N, longitude 73.8382° E.
2. Station 2 (M_2) - Mahi river at Sevalia, located in Taluka Thasra, Kheda district, Gujarat, latitude 22.8250° N, longitude 73.3421° E.
3. Station 3 (M_3) - Mahi river at Umeta located in Taluka Anklav, Anand district, Gujarat, latitude 22.3912°N, longitude 72.9945° E.
4. Station 4 (M_4) - Mahi river at Mujpur located in Vadodara district, Taluka Padra, Gujarat, latitude 22.2374° N , longitude 73.0903° E.
5. The Map of Mahi River Basin with the location of the stations is shown in figure 1.

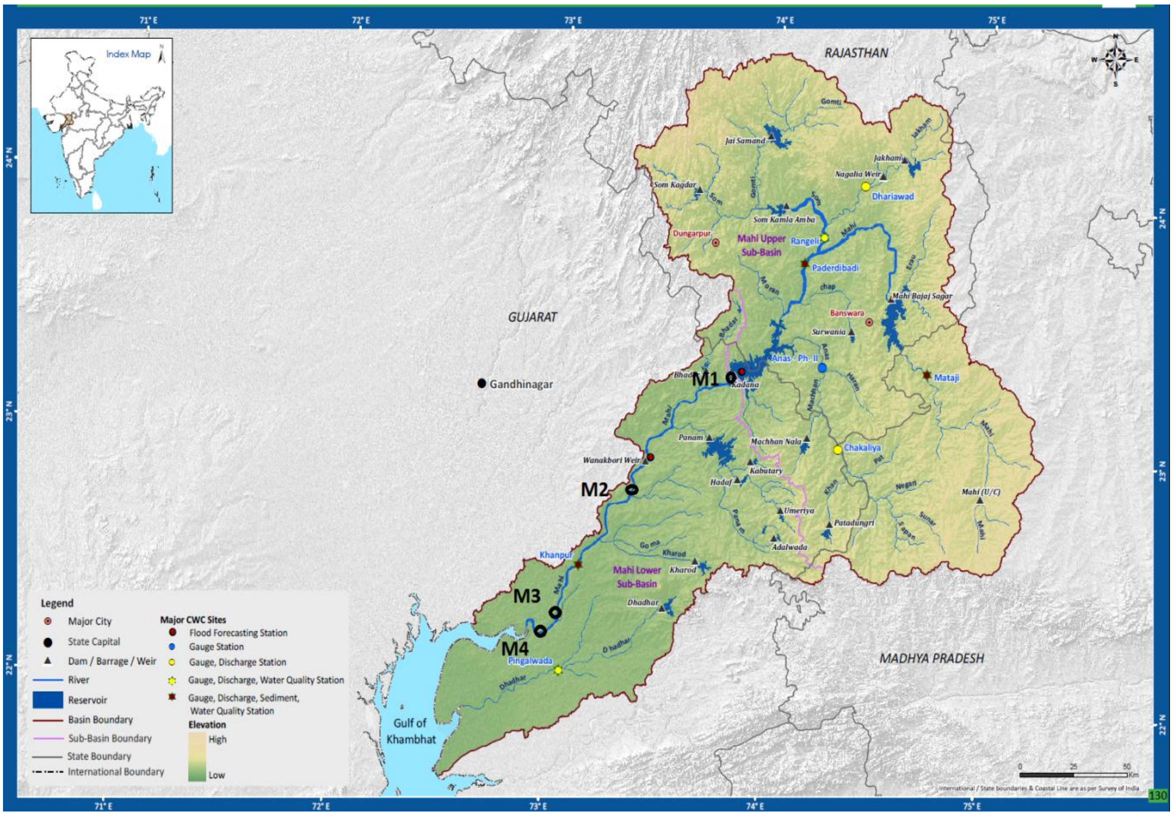

Figure 1 Map of Mahi River Basin with stations under study

II. Methodology

2.1 Selection of Indicator parameters for water quality

Water quality parameters pH, DO, BOD, Electrical Conductivity, Nitrate Nitrogen, Total Coliform are selected as significant indicator parameters of surface water quality in the present study.

2.2 Development of a rating scale to obtain the rating (Vr)

Rating scale (Table 1) was prepared for range of values of each class. The rating varies from 0 to 100 and is divided into five classes. The subindex rating (Vr) = 0 implies that the concentration of the parameter in water remained exceeded by the standard maximum permissible limits and water is highly polluted. The rating (Vr) = 100 denotes the excellent water quality since the parameter remained within the prescribed permissible limit for drinking water and water is clean. The other ratings fall between these two extremities and are Vr = 40, Vr = 60, and Vr = 80 standing for excessively polluted, moderately polluted and slightly polluted, respectively. Accordingly, 5 classes are proposed, (class 1–5). This scale is modified version of rating scale given by Tiwari and Mishra (1985). The concentrations ranges of these parameters in the given classes are defined with due consideration of Central Pollution Control Board (CPCB) of India standards/criteria and Indian Standards (IS) 10500. For parameters and classes not included in the CPCB standards, reference was made to the standards defined by other agencies. The proposed classification along with ranges of concentrations of these parameters is given in Table 3.1. The effects of each of the parameters under consideration in the above classes are detailed below.

Effect of pH

The pH is a measure of the acidic or alkaline conditions of the water. When the water is used for drinking purpose, the pH level of the water has an important effect on all body chemistry, health and disease because human body consists of 50–60 % water. The pH level of our body fluid should be in the range 7–7.2. If pH is less than 5.3, assimilation of vitamins or minerals is not possible; hence, it should be above 6.4. If pH is greater than 8.5, causes the water taste bitter or soda-like taste. If the pH is greater than 11, causes eye irritation and exacerbation of skin disorder. pH in the range of 10–12.5 cause hair fibers to swell. pH in the range 3.5–4.5 affects the fish reproduction. (Avvanavar and Shrihari 2008; Leo and Dekkar 2000).

Effect of dissolved oxygen

The amount of DO present in surface waters depends on water temperature, turbulence, salinity, and altitude Natural waters in equilibrium with the atmosphere will contain DO concentrations ranging from about 5 to 14.5 mg O2 per liter. The DO concentration present in water reflects atmospheric dissolution, as well as autotrophic and heterotrophic processes that, respectively, produce and consume oxygen. DO is the factor that determines whether biological changes are brought by aerobic or anaerobic organisms. Thus, dissolved–oxygen measurement is vital for maintaining aerobic treatment processes intended to purify domestic and industrial wastewaters. A rapid fall in the DO indicates a high organic pollution in the river. The optimum value for good water quality is 4 to 6 mg/l of DO, which ensures healthy aquatic life in a water body (Sawyer et al. 1994; Leo and Dekkar 2000; Burden et al. 2002; De 2003).

Effect of biological oxygen demand

Biochemical oxygen demand (BOD) determines the strength in terms of oxygen required to stabilize domestic and industrial wastes. For the degradation of oxidizable organic matter to take place minimum of 2–7 mg/l of DO level is to be maintained at laboratory experimentation or should be available in the natural waters (De 2003).

Effect of total dissolved solids/electrical conductivity

Total dissolved solids (TDS) is the amount of dissolved solids (i.e., salts) in the water. TDS can be measured indirectly by measuring the EC. The more dissolved salts in the water, the more electricity the water will conduct. EC is the ability of the water to conduct an electrical current. Conductivity is important because it directly affects the quality of the water used for drinking and irrigation. Waters with higher solids content have laxative and sometimes the reverse effect upon people whose bodies are not adjusted to them and cause the water to have an unpleasant mineral taste. TDS consists of oxygen-demanding wastes, disease-causing agents, which can cause immense harm to public health. The presence of synthetic organic chemicals (fuels, detergents, paints, solvents, etc) imparts objectionable and offensive tastes, odors and colors to fish and aquatic plants even when they are present in low concentrations (Sawyer et al. 1994; Leo and Dekkar 2000). Dissolved ions affect the pH of water, which in turn may influence the health of aquatic species.

Effect of nitrate nitrogen

Excess nitrate nitrogen can cause eutrophication of surface waters due to overstimulation of growth of aquatic plants and algae. It causes anaerobic conditions in the water bodies leading to fish kills, and can even ‘‘kill’’ a lake by depriving it of oxygen. High levels of Nitrate nitrogen can cause the respiration efficiency of fish and aquatic invertebrates to lower down, leading to a decrease in animal and plant diversity, and affects use of the water for fishing, swimming, and boating. High levels of Nitrate nitrogen in water can cause serious health hazards. The acute health hazard associated with drinking water with elevated levels of nitrate occurs when bacteria in the digestive system transform nitrate to nitrite. The nitrite reacts with iron in the hemoglobin of red blood cells to form methemoglobin, which lacks the oxygen carrying ability of hemoglobin. This creates the condition known as methemoglobinemia (sometimes referred to as ‘‘blue baby syndrome’’), in which blood lacks the ability to carry sufficient oxygen to the individual body cells. Infants under 1 year of age have the highest risk of developing methemoglobinemia from consuming water with elevated levels of nitrate.

Table 1 Rating Scale

Parameters	**Range**				
pH	7-8.5	8.5-8.6	8.6-8.8	8.8-9.0	>9.0
		6.8-7.0	6.7-6.8	6.5-6.7	<6.5
DO (mg/l)	>6	5.0-6	4.0-5	3.0-4	<3
BOD (mg/l)	0-3	3.0-6	6.0-80	80.0-125	>125
Electrical conductivity (micromhos/cm)	0-75	75-150	150-225	225-300	>300
Nitrate Nitrogen (mg/l)	0-20	20.0-50	50.0-100	100-200	>200
Total Coliform MPN/100 ml	0-5	5.0-50	50-500	500-10000	>10000
Vr	100	80	60	40	0
Class	1	2	3	4	5
Extent of pollution	Clean	Slight	Moderate	Excess	Severe

2.3 Estimating the Weighing factor of each indicator parameter (W_i)

Weightage of each parameter

Weighing means the relative importance of each water quality parameter that play some significant role in overall water quality and it depends on the permissible limit in drinking water set by National and International agencies viz.,WHO,IS-10500, etc. Those parameters, which have low permissible limits and can influence the water quality to a large extent even fluctuate a little, allocate high weighing while parameter having high permissible limit and are less harmful to the water quality allocate low weighing. The intended use of water is considered for this study is as per class B & C i.e, outdoor bathing Organized (B), drinking water source with conventional treatment followed by disinfections (C). Hence the weightage is assigned with respect to class 1&2 of table-3.1. Weightage of parameter is inversely proportional to its permissible limits, i.e, Weightage of parameter I = 1/Si, where Si = maximum permissible limits of the parameter.

Weighing factor of each parameter

The Weighing factor (Wi) of each parameter is proportional to the weightage of each parameter. i.e, W_i ά $1/S_i$ or $W_i = K/S_i$

$$\text{where, } K = 1/\sum_{i=1}^{n} 1/Si \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

1/ (Σ 1/Si) = 1/ [Σ 1/Si (pH)] + 1/ [Σ 1/Si (DO)] + 1/ [Σ 1/Si (BOD)] + 1/ [Σ 1/Si (Total Coliform)] + 1/ Σ [1/Si (Nitrate- Nitrogen)] + 1/**[** Σ 1/Si (EC)]

Where, K = constant of proportionality ,Wi = Weighing factor of the parameter & n = number of water quality parameters

The Weighing factor of each parameter calculated are shown in Table 2.

Table 2 Water quality parameters and their assigned Weighing factors

Parameter	Weighing factor (Wi)
pH	0.165
DO (mg/l)	0.281
BOD (mg/l)	0.234
Electrical Conductivity (micro mhos/cm)	0.009
Nitrate Nitrogen (mg/l)	0.028
Total Coliform (MPN/100 ml)	0.281

2.4 Determining the sub-index value .(W_i x V_r)

The sub-index value is determined by multiplying its weighing factor with its rating obtained from Table.1

2.5 Aggregating the sub- indices to obtain the overall Water Quality Value (WQV)

Water Quality Value is the sum of product of rating (V_r) and Weighing factor (Wi) of all the parameters.

$$WQV = \sum_{i=1}^{n} (W_i \times V_r) \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

2.6 Computation of Water Pollution Value

Water Pollution Value (WPV) is calculated by the formula (3)

WPV = 100 - WQV ………………………………………(3)

3. Data base for Water Quality

Water quality quarterly concentration for the parameters, pH, Dissolved oxygen, BOD, Electrical Conductivity, Nitrate nitrogen and Total Coliform for the stations M_1, M_2, M_3 & M_4 has been collected for the present study for a four year period from Gujarat Pollution Control Board, Gandhinagar . Descriptive statistics of water quality parameter concentration at stations M_1 ,M_2, M_3 & M_4 is shown in table 3. Based on the value of WQV obtained, the river water quality can be judged (Table 4).

Table 3. Descriptive statistics of water quality parameter concentration at stations M_1

Station M_1				
Parameter	**Min**	**Max**	**Mean**	**Std Deviation**
pH	7.2	8.6	8.14	0.33
DO (mg/l)	6.2	10.4	8.01	1.22
BOD (mg/l)	0.2	6	1.88	1.38
EC (micromhos/cm)	224	404	333.44	46.38
Nitrate Nitrogen (mg/l)	0.1	0.35	0.17	0.09
Total Coliform (MPN/100 ml)	3	15	9.31	3.65
Station M_2				
pH	7.9	8.8	8.41	0.27
DO (mg/l)	6	11.5	9.11	1.35
BOD (mg/l)	0.6	4.1	2.43	1.06
EC (micromhos/cm)	228	430	349.87	3836.31
Nitrate Nitrogen (mg/l)	0.1	0.3	0.17	0.08
Total Coliform (MPN/100 ml)	4	20	9.77	5.25
Station M_3				

pH	7.4	8.9	8.29	0.44
DO (mg/l)	6.9	11	8.52	1.31
BOD (mg/l)	1	4.7	2.77	1.07
EC (micromhos/cm)	186	621	425.8	109.92
Nitrate Nitrogen (mg/l)	0.1	0.4	0.21	0.09
Total Coliform (MPN/100 ml)	3	21	10.33	5.74
Station M_4				
pH	7.6	8.9	8.32	0.42
DO (mg/l)	6.6	10.9	8.98	1.13
BOD (mg/l)	1.6	5.9	3.33	1.44
EC (micromhos/cm)	199	7080	1557.36	2315.26
Nitrate Nitrogen (mg/l)	0.1	0.4	0.23	0.11
Total Coliform (MPN/100 ml)	3	28	13.07	7.65

Table 4 Scale of Water Quality based on WPV

Value of WPV	Quality of Water
0 - 10	Excellent
10-20	Good
20-30	Medium
30-40	Bad
40-50	Very Bad

III. Results

Water Pollution Value of Stations on Mahi River

The equation (3) is used to compute the Water Pollution Value of the stations, M_1, M_2, M_3, & M_4 for four years and is shown in Table 5.

Table 5 Water Pollution Value for the stations on Mahi river

Station	Year	Water Quality Value	Average Water Quality Value	Water Pollution Value
M_1	**2005**	93.44	95.17	4.83
	2006	93.44		
	2010	94.75		
	2011	99.06		
M_2	**2005**	86.82	93.19	6.81
	2006	93.44		
	2007	93.44		
	2008	99.06		
M_3	**2005**	90.13	89.78	10.22
	2006	93.44		
	2007	93.44		
	2008	82.13		
M_4	**2005**	85.44	86.28	13.72
	2006	93.44		
	2007	88.75		
	2008	77.5		

IV. Conclusions

The average water pollution value obtained for the stations, M_1 and M_2 are 4.83 and 6.81 respectively. From the table 4, it can be concluded that the water quality at these stations is excellent. Whereas the average water pollution value obtained for the stations, M_3 and M_4 are 10.22 and 13.72 respectively which indicates good water quality from table 4. The catchments of stations M_1 and M_2 are comparatively less urbanized than the catchments of stations M_3 and M_4. This may be attributed to the fact that as an area develops, there are various water pollution issues created due to the urban development, namely, Population Growth impacts, Erosion and Sedimentation, urban runoff impacts and sewage overflows (USGS, 1996). The present paper presents methodology to compute water pollution value, which is a tool to assesss the conditions of a water body in a concised and uncomplicated approach. The water quality parameters vary with respect to their concentrations in the surface water bodies. Therefore, in this study, first the weightage of each parameter is estimated and then the water pollution value is developed and applied to the Mahi river basin. The methodology presented can be useful to water quality management agencies for decision making and policy framing for water quality issues.

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