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ORIGINAL RESEARCH PAPER

Water quality zoning of Vishwamitri River to access environmental flow requirements through aggregation of water quality index

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ABSTRACT: Environmental flow requirements, to maintain the functioning of freshwater-dependent ecosystems and restore rivers in ecologically acceptable conditions, depend upon the present water quality status of the river. Various stretches of Vishwamitri River vary in quality and quantity. Water quality index is a tool to converse information regarding water quality of various stretches of river and can be used for zoning them based on their present water quality status. Through such zoning, based on water quality index values as an integral component, Environmental flow requirements can be explored for Vishwamitri. In this paper, 'Weighted Arithmetic Index' method is used to find water quality index for both Vishwamitri and its tributaries using observed values of general physico-chemical parameters. The indices have been computed for pre-monsoon, monsoon and post-monsoon seasons at sixteen sampling stations, i.e. S-1 to S-16 along the Vishwamitri and eight sampling stations on its various tributaries. Based on the analysis, Vishwamitri is zoned in two various zones. Sampling stations, S-1 to S-7 represent Zone 1 which contains water quality index values from 50 to 75. Sampling stations S-8 to S-16 represent zone 2 which contain water quality index values more than 75. Zone 1 is rich with dissolved oxygen whereas zone 2 contains high biochemical oxygen demand and less dissolved oxygen . The water quality index value of Surya River, a major tributary of Vishwamitri, indicates that river water is suitable for irrigation purpose. The water quality index values of tributaries and drains, draining wastewater to stretch of Vishwamitri within Vadodara city, represents water quality as mostly unsuitable for drinking, irrigation or industrial purpose.

KEYWORDS: *Biochemical oxygen demand (BOD); Environmental flow requirements (EFR); Dissolved oxygen (DO); Physico-chemical parameters; Vishwamitri river; Water quality index (WQI);* Water quality status (WQS)

INTRODUCTION

Ecosystems and communities dependent on naturally flowing rivers have been threatened by pollution from various point and non-point sources, regulated and fragmented flows, over abstraction and human encroachment. The diminished flow velocity and truncated river flow, reduce the self-assimilation and self-cleaning capacity of the river (Bora and Goswami, 2015). The Vishwamitri River is a seasonal river. It flows east to west between the Mahi and Narmada rivers in Gujarat. It is a major tributary of Dhadhar River which confluence with the Arabian ocean near Khambhat.

The Vishwamitri originates from the Pavagadh hill at about 22°30' N latitude and 73°45' E longitude. Surya River and Jambuva River are two major tributaries of Vishwamitri. Vishwamitri watershed comprises of 9-mini-watersheds which cover a total area of about 1185 km^2 (Patel *et al.*, 2014). The historical Vishwamitri River is

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converted into the sewer, draining most of the pollutants from its own catchment area.

Various sources of pollution like sewage effluent disposal sites, industrial effluent disposal sites, landfill sites, slums, etc. were observed while monitoring the various stretches of Vishwamitri. The stretch of Vishwamitri on upstream of Vadodara city is surrounded with rural as well as mere industrial development. The development of urban infrastructure poses threats to water regime in terms of its quantity and quality (Giri and Singh, 2013). This stretch is affected mainly by the release of partially treated or untreated sewage from villages. The Vishwamitri flows west through the Vadodara city in the middle of its 21.80 km stretch with less carrying capacity and less velocity of water. This stretch of river is affected by stormwater drains flowing mainly sewage, industrial waste water and solid waste. River is also surrounded by solid waste dump sites, sewage treatment plants and recreational sites (Deshkar *et al.*, 2014).

The pollution resulting in Vishwamitri is largely due to less flow and discharge of the untreated sewage, which enters through various points across the stretch of the river in the city. Jambuva River, collecting sewage from Vadodara city, confluence at the downstream stretch of Vishwamitri. The villagers living on the bank of the river as downstream users are unable to use the river water. They need to go far away to find drinking water source. The downstream water is used for irrigation purpose by the adjoining farms, though it is found medium to very bad for irrigation purpose (Sharma, 2016). The flow in Vishwamitri is very low except in rainy season. River mainly flows in the month of July, August, and September (Vyas *et al.*, 2014). The river ceases flowing in the dry season as at its upstream river water is diverted to Ajwa reservoir during monsoon. Ajwa reservoir is a major source of drinking water for Vadodara city. Also the river being non-perennial, the water flowing in the river for the most part of the year is nothing but let out of sewage which has made the river odorous at some locations (Bhangaonkar and Patel, 2017).

Vishwamitri has negligible socio-economic and ecological value. Vishwamitri is in moribund condition due to a various anthropogenic activities. It is the need of hour to avail maximum benefits of river water by ensuring required quantity and quality of water flow to sustain life. This can be initiated through exploring preliminary environmental flow requirements of Vishwamitri through its qualitative assessment. Various tributaries are confluencing with Vishwamitri at its upstream, middle and downstream stretches. Eventhough the river is highly polluted due to various anthropogenic activities, the overall water quality of the river at various stretches is governed by water quality of tributaries merging into it (Badr *et al.*, 2006).

The tributaries of Vishwamitri are getting affected by the release of discharges through various point and non-point sources of pollution throughout the year. Some of them remain dry during part of the year. The polluted water draining through tributaries is to be treated in prior (Ram and Joshi, 2012). The immediate maintenance and restoration of ‘wholesomeness’ of the water quality of Vishwamitri river must be considered as a mandate under the Water Act, 1974. Recently in India, there has been an increasing awareness of the need to reserve some water along a river to ensure the continued functioning of ecological processes that provide much needed goods and services for human use and maintenance of biodiversity. Environmental flow requirements are often defined as flow discharges of certain magnitude, timing, frequency and duration (Smakhtin and Anputhas, 2006). Partial un-utilized surface runoff of basin can adequately meet the Environmental Flow Requirement (EFR) of river and this can be one of the best options for sustainable water resource management (Khadse *et al.*, 2012). However, the ecological conditions (also referred as an environmental management class) depend upon water quality of river and its confluencing tributaries.

To explore the environmental flow requirements of Vishwamitri for its various stretches, it becomes essential to assess the water quality of the river and its various tributaries. In this paper efforts are made to assess the general pollution trend of the river and its tributaries. This paper focuses on determination of water quality status of Vishwamitri and its tributaries for zoning the river based on the WQS. For the same, WQI scores at various sampling stations along the Vishwamitri and on its various tributaries are analyzed. The assessment of release of excess runoff in terms of environmental flow may vary based on the water quality status of the respective zone. Present study has been carried out duirng 2015-2016.

MATERILAS AND METHODS

Water Quality Index (WQI)

The concept of Water Quality Index (WQI) is widely used to understand the general water quality status of both surface and sub-surface water quality assessment (Haritash *et al.*, 2016; Bora and Goswami 2017; Gor and Shah, 2014; Rajankar *et al.*, 2013; Balan *et al.*, 2012; Sharma and Kansal, 2011; Mophin-Kani and Murugesan, 2011; Samantray *et al.*, 2009; Fulazzaky *et al.*, 2010; Moscuzza *et al.*, 2007). WQI is evaluated based on analysis of various physical and chemical parameters. WQI is unique rating to express the overall water quality status in a single term by transforming a complex set of water quality data into extensive information to define specific environmental conditions of the water quality and its suitability for various purposes like drinking, irrigation, fishing and so on. (Abbasi, 2002). This information can help water resource managers and governmental decision makers in designing and evaluating the effectiveness of the regulatory program.WQI is helpful for the selection of appropriate treatment technique to meet the concerned issues (Tyagi *et al.*, 2013). In present study, WQI is calculated by the 'arithmetic weighted index method' as described by Brown *et al.* (1972). This method has been used by several water quality investigators (Bhutiani *et al.*, 2016; Shah and Joshi, 2017; Ramakrishniah *et al.*, 2009; Rao *et al.*, 2010, Cude, 2001). The WQI can be calculated by aggregating the quality rating with the unit weight linearly using the following Eq. (1);

$$WQI = \frac{\sum_{i=0}^{n} WiQi}{\sum_{i=0}^{n} Wi} \quad (1)$$

Where, W_i = Relative weight and Q_i = Quality rating. In general, WQI is defined for a specific and intended use of water. The quality rating scale (Q_i) of i_{th} parameter for a total of n general physico-chemical parameters is calculated using Eq. (2);

$$Qi = \frac{100[Vactual - Videal]}{[Vstandard - Videal]} \quad (2)$$

Where, V_{actual} is actual value of the water quality parameter obtained from laboratory analysis; V_{ideal} is ideal value of that water quality parameter [V_{ideal} = 0, except for pH (V_{ideal} =7) and DO (V_{ideal} =14.6 mg/l)] and $V_{standard}$ is permissible standard values of water quality parameters recommended by Bureau of Indian Standards (BIS), Central Pollution Control Board (CPCB) and World Health Organization (WHO).

The Relative (unit) weight (W_i) for physico-chemical parameters has been calculated by a value inversely proportional to the recommended standard (S_i) for the corresponding parameter using the Eq. (3);

$$Wi = \frac{1}{Si} \quad (3)$$

Where, W_i = Relative (unit) weight for n^{th} parameter; S_i = Standard permissible value for n^{th} parameter; 1 = Proportionality constant. The water quality status (WQS) according to WQI (Brown *et al.*, 1972) is shown in Table 1.

Table 1: WQI ranges and corresponding water quality status and possible usage (Brown *et al.*, 1972)

Assigned Water Class	WQI	Water quality status (WQS)	Possible usage
1	0 to 25	Excellent	Drinking, irrigation and industrial
2	26 to 50	Good	Drinking, irrigation and industrial
3	51 to 75	Poor	Irrigation and industrial
4	76 to 100	Very por	Irrigation
5	Above 100	Unsuitable for drinking and fish cultura	Proper treatment required before usage

In the present work, sixteen sampling stations along the Vishwamitri and eight sampling stations on various tributaries are observed for water quality. In the first phase of water quality monitoring programme, water samples were collected from seven sampling stations along the Vishwamitri (i.e. S-2, S-7, S-11, S-13, S-14, S-15 and S-16) and eight (i.e. S-1 L, S-2 R, S-3 L, S-4 L, S-5 R, S-6 R, S-7 L and S-8 R) on various tributaries during pre-monsoon (April-2015 and June -2015), monsoon (September-2015 and October-2015) and post-monsoon (December-2015 and March-2016) seasons. In the second phase of water quality monitoring programme, in addition to previously observed sampling stations during the first phase, water samples were collected from nine additional sampling stations (i.e. S-1, S-3, S-4, S-5, S-6, S-8, S-9, S-10, S-12) along the river. In this second phase, water samples were collected from the stations during pre-monsoon (May-2017 and August-2017 due to delayed monsoon), monsoon (September-2017 and October-2017) and post-monsoon (Novermber-2017 and December-2017) seasons.

The present work deals with the analysis of general physico-chemical parameters like Dissolved Oxygen (DO), pH (Hydrogen Ion Potential), Total Hardness (TH), Chlorides (Cl), Dissolved Solids (DS), Calcium (Ca), Magnesium (Mg), Sulphate (SO_4), Nitrates (NO_3), Total Alkalinity (TA) and indicative parameters like Total Suspended Solids (TSS) and Biological Oxygen Demand (BOD) for collected water samples. Concentration of indicative parameters is observed once during each season (i.e. during April-2015, October-2015, December-2015 and August-2016, October-2016, December-2016) for both the years. The grab samples were collected in 2L clean polyethylene plastic containers labeled for respective station number, placed and transported in ice box to laboratories. Parameters were analyzed as per Bureau of Indian Standards (BIS) and American Public Health Association guidelines (APHA, 2005). Dissolved Oxygen (DO) was measured in situ by hand held portable dissolved oxygen meter. Geographical locations of sampling stations are ascertained using hand held Garmin GPSMAP 78s Global Positioning System device. Table 2 represents the locations of sampling stations selected within Vishwamitri watershed. Fig. 1 represents the study area with all sampling stations in Vishwamitri watershed. The values of various general physico-chemical parameters, observed at various sampling stations during pre-monsoon, monsoon and post-monsoon, are analyzed with univariate descriptive analysis. The result obtained in terms of mean and Standard Deviation (SD) for sampling stations along Vishwamitri and on tributaries are shown in Tables 3 and 4 respectively.

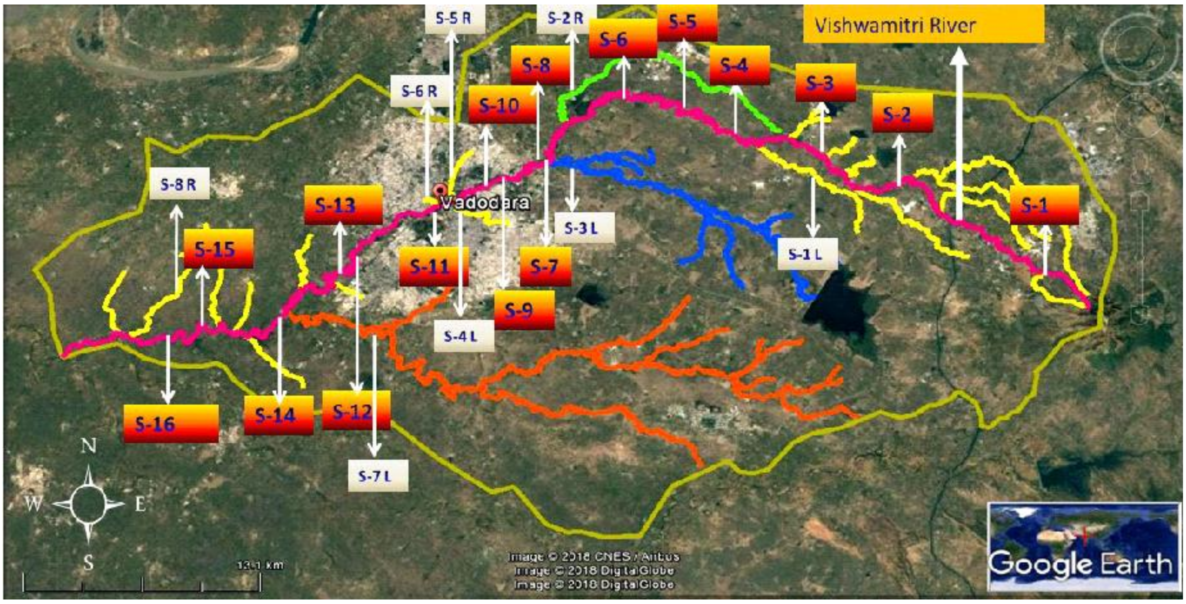

Fig.1 :Study area representing sampling stations in Vishwamitri Watershed

Table 2: Locations of Sampling Stations along Vishwamitri and its tributaries

Stations along Vishwamitri River			Stations on various tributaries		
Station No.	Distance from origin (km)	Geographical Location	Station No.	Lateral Distance from river (km)	Geographical Location
S-1*	6.66	43Q 0340684, UTM 2485490	S-1 L	5.90	43Q 0328475, UTM 2482589
S-2	14.30	43Q 0335564, UTM 2485196	S-2 R	0.90	43Q 0314954, UTM 2476474
S-3*	22.3	43Q 0330939, UTM 2483305	S-3 L	1.00	43Q 0316570, UTM 2473856
S-4*	26.7	43Q 0327397, UTM 2483690	S-4 L	0.41	43Q 0313869, UTM 2467960
S-5*	32.8	43Q 0324318, UTM 241580	S-5 R	0.24	43Q 0313330, UTM 2468224
S-6*	45.5	43Q 0317351, UTM 2479763	S-6 R	0.43	43Q 0311536, UTM 2464414
S-7	59.70	43Q 0316049, UTM 2473459	S-7 L	5.60	43Q 0313180, UTM 2458361
S-8*	63.4	43Q 0315079, UTM 2471353	S-8 R	3.60	43Q 0304366, UTM 2452325
S-9*	65.2	43Q 0314096, UTM 2469917	---	---	---
S-10*	66.5	43Q 0313594, UTM 2469144	---	---	---
S-11	68.50	43Q 0313430, UTM 2468083	---	---	---
S-12*	69.7	43Q 0312778, UTM 2467037	---	---	---
S-13	72.90	43Q 0311536, UTM 2464414	---	---	---
S-14	88.10	43Q 0310288, UTM 2456884	---	---	---
S-15	93.30	43Q 0308731, UTM 2453914	---	---	---
S-16	100	43Q 0305700, UTM 2450951	---	---	---

*Additional sampling stations observed during second phase of water quality monitoring programme

Water quality index model

The Water Quality Index model developed in the present study consists of 5 steps:

1. Selection of parameters for measurement of water quality and development of quality rating (Q_i) for i^{th} parameter using Eq. 2
2. Estimating the unit weight of each parameter (W_i) by considering the weightage of each parameter using Eq. 3
3. Aggregating the unit weight of all parameters i.e. $\sum_{i=1}^{i=n} Wi$
4. Determining the subindex value (W_iQ_i) for each parameter.
5. Aggregating the subindices. i.e. $\sum_{i=1}^{i=n} Wi\ Qi$
6. Calculating WQI using Eq. 1

Table 5 shows the drinking water quality standards and the unit weights assigned to each parameter used for calculating the WQI. Maximum unit weight is assigned to dissolved oxygen. However, BOD and pH are also observed influencing parameters. Analysis of WQI is involving the essential impact and considerable significance of all parameters in overall water quality assessment. Tables 6 and 7 represent the sample calculations for WQI from the observed average values of the selected physico-chemical parameters at sampling station S-1 along the Vishwamitri and at S-1 L on the tributary. Similar calculations for WQI are been carried for all other sampling stations.

Table 3: Statistical Assessment of Physico-Chemical characteristics of water along Vishwamitri

Parameters	Pre-Monsoon			Monsoon			Post-Monsoon		
	Min.	Maxi.	Mean + SD	Min.	Maxi.	Mean + SD	Min.	Maxi.	Mean + SD
DO	0.30	11.90	4.00 ± 2.41	0.50	9.70	3.45 ± 3.10	0.60	11.50	4.65 ± 3.44
BOD	1.20	68.00	11.22 ± 13.31	2.80	20.00	7.06 ± 4.92	2.00	36.00	10.23 ± 9.56
pH	6.61	7.98	7.28 ± 0.31	5.87	8.22	7.19 ± 0.43	6.35	8.08	7.27 ± 0.41
NO_3	4.84	41.17	15.16 ± 6.08	2.42	48.44	16.95 ± 6.42	4.84	46.01	16.46 ± 4.86
Mg	8.16	71.52	30.26 ± 16.23	12.48	201.60	35.36 ± 24.23	8.10	58.56	25.53 ± 10.97
Ca	20.80	84.00	43.71 ± 12.32	24.00	58.40	38.39 ± 6.77	19.20	84.80	41.89 ± 8.17
TA	22.30	487.60	241.97 ± 105.47	61.60	534.00	229.44±53.00	62.80	386.80	218.54 ±50.00
SO_4	5.72	105.60	21.57 ± 15.08	5.72	99.00	24.32 ± 16.33	5.72	34.32	11.44 ± 4.45
TH	108.00	508.00	235.28 ± 95.63	128.00	392.00	218.78 ± 54.19	128.00	358.00	208.59 ± 64.19
TSS	8.00	68.00	33.78 ± 14.52	11.00	121.00	31.38 ± 20.01	11.00	154.00	39.83 ± 32.19
Cl	28.00	260.00	107.22 ± 61.72	40.00	252.00	99.13 ± 44.23	24.00	220.00	84.88 ± 45.30
DS	181.00	970.00	474.45 ± 227.24	239.00	710.00	426.70±133.17	180.00	755.00	392.89 ±135.90

Table 4: Statistical Assessment of Physico-Chemical characteristics of water in tributaries of Vishwamitri

Parameters	Pre-Monsoon			Monsoon			Post-Monsoon		
	Min.	Maxi.	Mean + SD	Min.	Maxi.	Mean + SD	Min.	Maxi.	Mean + SD
DO	0.50	11.20	3.55 + 2.67	0.40	11.80	3.39 + 3.80	0.50	10.50	4.18 + 2.87
BOD	3.20	78.00	25.92 + 17.84	2.00	58.00	13.20 + 14.09	4.00	60.00	22.13 + 18.87
Ph	6.10	7.93	7.24 + 0.39	6.22	8.06	7.14 + 0.38	6.27	7.95	7.14 + 0.35
NO_3	2.42	39.72	18.45 + 4.65	1.21	58.12	24.28 + 12.67	7.27	41.17	21.95 + 6.65
Mg	9.12	106.08	43.34 + 19.96	6.72	56.18	31.67 + 12.83	9.12	70.56	30.65 + 13.62
Ca	27.20	136.00	46.69 + 11.79	28.80	57.60	40.20 + 6.64	31.20	73.80	42.64 + 5.39
TA	34.00	776.80	333.00 + 164.56	56.40	534.00	251.99 + 124.92	60.80	481.50	243.51 + 90.74
SO_4	8.58	396.00	51.26 + 41.17	5.72	115.50	25.33 + 13.96	5.72	99.00	20.91 + 15.45
TH	136.00	782.00	298.98 + 108.45	104.00	358.00	233.38 + 64.20	116.00	376.00	235.06 + 68.05
TSS	10.00	5580.00	396.63 + 974.402	9.00	151.00	58.75 + 23.48	14.00	296.00	84.75 + 296.00
Cl	40.00	784.00	231.42 + 168.59	20.00	316.00	144.00 + 81.06	24.00	280.00	120.75 + 63.08
DS	184.00	1870.00	728.28 + 382.92	24.00	940.00	513.84 + 229.65	180.00	1180.00	500.34 + 219.94

Table 5: Unit Weight of each parameter (Wi) used for Calculation of WQI

Sr. No.	Parameters	Desirable limit ($V_{standard}$)	Recommended Agency	Unit weight (W_i)
1	DO	4.00	CPCB	0.3746
2	BOD	3.00	CPCB	0.3122
3	pH	6.50-8.50	BIS, 2012	0.2204
4	NO_3	45.00	BIS, 1998	0.0416
5	Mg	30.00	BIS, 2012	0.0187
6	Ca	75.00	BIS, 2012	0.0094
7	TA	200.00	BIS, 2012	0.0094
8	SO_4	200.00	BIS, 2012	0.0047
9	TH	300.00	BIS, 1998	0.0031
10	TSS	300.00	WHO	0.0031
11	Cl	250.00	BIS, 2012	0.0019
12	DS	500.00	BIS, 2012	0.0009
				$\sum_{i=1}^{i=12} WiQi = 1$

Table 6: Sample Calculation of WQI at S-1

Parameters	Pre-Monsoon			Monsoon			Post-Monsoon		
	V_{actual}	Q_i	W_iQ_i	V_{actual}	Q_i	W_iQ_i	V_{actual}	Q_i	W_iQ_i
DO	6.10	88.54	33.17	7.30	76.04	28.67	8.20	8.20	66.67
BOD	4.50	90.00	28.10	3.00	60.00	18.85	4.00	4.00	80.00
Ph	7.54	36.00	7.93	7.57	38.00	8.43	7.47	7.47	31.33
NO_3	19.37	43.04	1.79	10.90	24.22	1.01	14.53	14.53	32.29
Mg	62.64	208.80	3.91	57.36	191.20	3.60	47.52	47.52	158.40
Ca	67.70	90.27	0.85	45.60	60.80	0.57	59.20	59.20	78.93
TA	338.00	169.00	1.58	288.80	144.40	0.45	245.40	245.40	122.70
SO_4	20.02	10.01	0.05	12.87	6.44	0.03	8.58	8.58	4.29
TH	430.00	143.33	0.45	353.00	117.67	0.37	346.00	346.00	115.33
TSS	20.00	6.67	0.02	11.00	3.67	0.01	17.00	17.00	5.67
Cl	124.00	49.60	0.09	64.00	25.60	0.05	60.00	60.00	24.00
DS	575.00	115.00	0.11	401.00	80.20	0.08	440.00	440.00	88.00
	$\sum_{i=1}^{i=n}$ Wi Qi= 78.05			$\sum_{i=1}^{i=n}$ Wi Qi= 62.12			$\sum_{i=1}^{i=n}$ Wi Qi= 63.21		
	WQI	= 78.05		WQI	= 62.12		WQI	= 63.21	
	WQS	= Very Poor		WQS	= Poor		WQS	= Poor	

Table 7: Sample Calculation of WQI at S-1 L

Parameters	Pre-Monsoon			Monsoon			Post-Monsoon		
	V_{actual}	Q_i	W_iQ_i	V_{actual}	Q_i	W_iQ_i	V_{actual}	Q_i	W_iQ_i
DO	3.40	116.67	43.98	2.80	122.92	46.34	4.80	102.08	38.48
BOD	25.00	500.00	157.07	6.00	120.00	37.70	4.00	80.00	25.13
pH	7.27	18.00	3.99	7.43	28.67	6.36	7.46	30.67	6.80
NO_3	19.70	43.78	1.83	12.41	27.58	1.16	18.17	40.38	1.69
Mg	44.28	147.60	2.78	27.00	90.00	1.70	17.88	59.60	1.12
Ca	49.00	65.33	0.62	41.40	55.20	0.52	34.00	45.33	0.43
TA	415.70	207.85	0.65	206.45	103.23	0.32	145.70	72.85	0.23
SO_4	45.71	22.86	0.11	12.16	6.08	0.03	9.30	4.65	0.02
TH	307.00	102.33	0.32	216.00	72.00	0.23	159.50	53.17	0.17
TSS	28.50	9.50	0.03	56.50	18.83	0.06	40.00	13.33	0.04
Cl	204.00	81.60	0.15	148.00	59.20	0.11	49.00	19.60	0.04
	767.25	153.45	0.14	347.50	69.50	0.07	263.00	52.60	0.05
DS	$\sum_{i=1}^{i=n} W_i Q_i$	= 211.69		$\sum_{i=1}^{i=n} W_i Q_i$	= 94.58		$\sum_{i=1}^{i=n} W_i Q_i$	= 74.20	
	WQI	= 211.69		WQI	= 94.58		WQI	= 74.20	
	WQS	= Unsuitable		WQS	= Very Poor		WQS	= Poor	

RESULTS AND DISCUSSION

The summary of WQI values and representative water classes for water samples collected from all sixteen sampling stations along Vishwamitri river and eight sampling stations on various tributaries during each season are represented in Table 8.

Fig. 2 represents the spatial and temporal variations in WQI values along Vishwamitri. Fig. 3 represents the temporal variation in WQI values on various tributaries. WQI values at most of the sampling stations along the river and on tributaries were observed less during monsoon. Reason of more WQI in monsoon season at few sampling stations in the upstream stretch of river (i.e. at S-5, S-6 and S-7) can be decreased DO values due to increased surface run-off containing more organic waste water from adjust agricultural fields and flushing of untreated sewage from nearby villages. WQI values at most of the sampling stations along the river and on various tributaries were recorded maximum during both pre-monsoon and post-monsoon seasons which can be mainly due to increase in BOD with reduction in flow.The WQI value of only S-3 L i.e. on Surya River, a major tributary of Vishwamitri, indicates that river water is suitable for irrigation purpose. WQI values of sampling stations, i.e. S-4 L, S-5 R and S-6 R on tributaries draining wastewater to stretch of Vishwamitri within Vadodara city urge prior treatment.

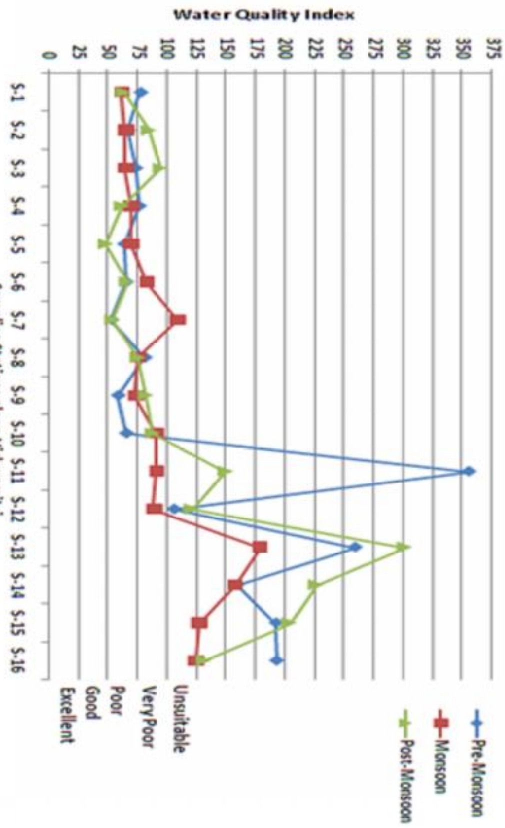

Fig. 2: Spatial and Temporal variations in WQI values along Vishwamitri

Table 8: Summary of WQI of the Vishwamitri river and its tributaries

Sampling Stations	Pre-Monsoon		Monsoon		Post-Monsoon	
	WQI	WQS	WQI	WQS	WQI	WQS
S-1	78.05	Very Poor	62.12	Poor	63.21	Poor
S-2	67.29	Poor	65.27	Poor	84.52	Very Poor
S-3	73.93	Poor	65.57	Poor	94.42	Very Poor
S-4	76.73	Very Poor	69.90	Poor	61.85	Poor
S-5	64.24	Poor	69.82	Poor	48.22	Good
S-6	65.81	Poor	83.47	Very Poor	65.88	Poor
S-7	53.54	Poor	109.19	Unsuitable	53.86	Poor
S-8	81.58	Very Poor	75.45	Very Poor	75.15	Very Poor
S-9	58.93	Poor	73.71	Poor	81.90	Very Poor
S-10	65.84	Poor	91.48	Very Poor	87.82	Very Poor
S-11	356.71	Unsuitable	91.81	Very Poor	149.82	Unsuitable
S-12	106.43	Unsuitable	89.29	Very Poor	120.96	Unsuitable
S-13	260.20	Unsuitable	179.24	Unsuitable	301.59	Unsuitable
S-14	159.65	Unsuitable	158.31	Unsuitable	226.37	Unsuitable
S-15	193.07	Unsuitable	127.81	Unsuitable	203.99	Unsuitable
S-16	193.54	Unsuitable	124.85	Unsuitable	131.39	Unsuitable
S 1-L	211.69	Unsuitable	94.58	Very Poor	74.20	Poor
S-2 R	96.57	Very Poor	102.19	Unsuitable	106.42	Unsuitable
S-3 L	75.84	Very Poor	60.95	Poor	80.02	Very Poor
S-4 L	272.66	Unsuitable	321.99	Unsuitable	395.94	Unsuitable
S-5 R	78.76	Very Poor	75.74	Very Poor	306.79	Unsuitable
S-6 R	305.57	Unsuitable	227.79	Unsuitable	280.67	Unsuitable
S-7 L	344.20	Unsuitable	132.63	Unsuitable	175.92	Unsuitable
S-8 R	346.43	Unsuitable	61.88	Poor	80.69	Very Poor

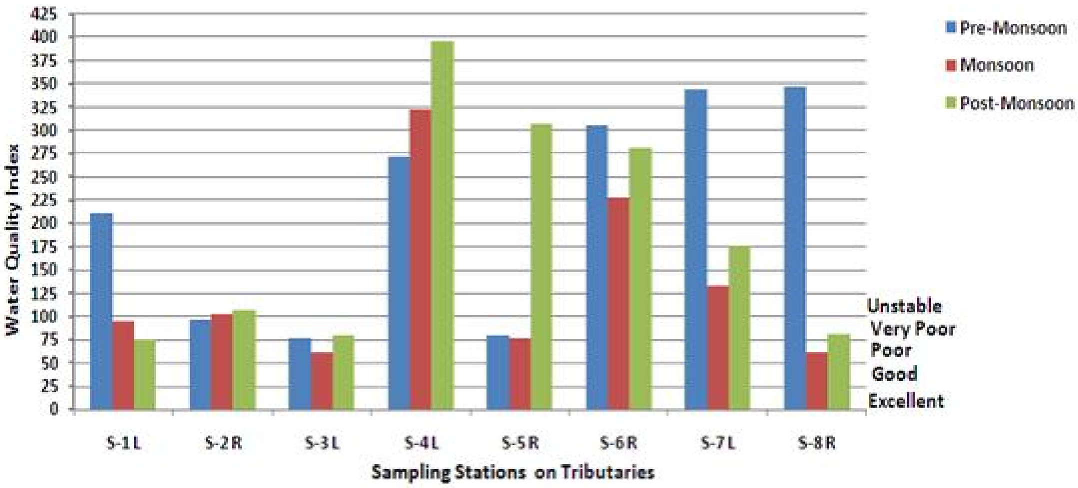

Fig. 3: Temporal variation in WQI values of sampling stations on tributaries

CONCLUSION

The water quality index is found very useful to define Water Quality Status (WQS) of various stretches of Vishwamitri river and its tributaries. Through this study, Vishwamitri can be classified into two major zones as follows:

Zone 1: This is a stretch of Vishwamitri from sampling station S-1 to S-7. Water quality of most of sampling stations along this stretch of Vishwamitri have represented WQI values from 50 to 75, reflecting class "3". Zone 1 is rich with DO. It can support a good ecological environment if made perennial. WQI values of water samples collected through sampling stations (i.e. S-1 L, S-2 R and S-3 L) on tributaries confluencing in this zone are reflecting mostly class "3" and class "4".

Zone 2: This is a stretch of Vishwamitri from S-8 to S-16. Water quality of majority of the sampling stations along this stretch have replecated WQI values more than 75, reflecting class "4" and "5". Zone 2 is more polluted than zone 1. Zone 2 contains high BOD and less DO.This downstream water of Vishwamitri is also used for irrigation purpose by the adjoining farms (Sharma , 2016). Thus, zone 2 requires more attention in qualitative and restoration aspects. WQI values of water samples collected through sampling stations on tributaries confluencing in this zone are reflecting mostly class "4" and class "5". However, WQI values of water samples collected through sampling stations (i.e. S-4 L, S-5 R, S-6 R and S-7 L) on Urban stormwater drains (minor tributaries) flowing partially treated or untreated sewage through Vadodara city and confluencing in this zone describe mostly class "5".

The river water quality is deteriorated due to excessive abstraction of water from the river with meager flow in non-monsoon periods followed by increasing waste water. Assessment of both Point and Non-point sources of pollution is essential. Zone 2 of the river contains a higher concentration of hardness, chloride, sulphate and alkalinity.

Recommendation

Environmental flow requirements of the river in its various zones can be assessed based on their present Water Quality Status (WQS) as an integral component. Environmental flow, which will neither cause overflow nor trickling flow conditions in the river can be the best solution. More the WQS value, more will be required fresh water flow.

Zonewise recommendations for establishing freshwater flow in terms of environmental flow for Vishwamitri river are mentioned herewith:

• For Zone 1: Vishwamitri in this zone is surrounded mainly by mere industrialization, agricultural fields and villages. Untreated sewage and polluted water released through the tributaries confluence into the river in zone 1 are to be controlled. Check dams can be constructed along the river and on the tributaries at suitable locations to control bed erosion and to reduce dissolved solids in monsoon and post-monsoon season. Storage capacity of reservoirs like Pratappura Sarovar, Dhanora Talav, Haripura Talav and Vadadla Talav and Ajwa Sarovar located nearby upstream stretch of Vishwamitri can be increased to store excess runoff. Supplementing consistent release of fresh water flow through the tributaries of these reservoirs with a certain magnitude throughout the year can efficiently restore can Zone-1 into higher WQS.

• For Zone 2: Solid waste dumped on bank of Vishwamitri, release of polluted water through various point-sources and untreated sewage disposal due to inadequate treatment capacities of Sewage Treatment Plants (STPs) are to be managed scientifically in this zone. Release of untreated or partially treated waste water is to be immediately controlled. Reduce; recycle and reuse of water at source can minimize the pollution load on Vishwamitri. Encroachment of banks of the river by urbanization can reduce the flow carrying capacity of the river. The storage capacity of existing ponds like Harani pond, Chaani Pond, etc. located in the vicinity of Vishwamitri river are to be increased and consistent release of treated amended freshwater flow through these ponds with certain magnitude and frequency throughout the year can restore Zone-2 of river into higher WQS, causing neither trickling flow nor flooding conditions.

The use downstream water of this zone of Vishwamitri for irrigation is to be adopted after proper treatment. River Jambuva, the major tributary of Vishwamitri, is merging in this stretch. WQI of S-7 L representing, Jambuva river, replicates "unsuitable" WQS. Untreated or partially treated waste water from industries and adjoining tributaries is to be controlled. Sampling station S-8 R is on a tributary, collecting wastewater from various villages at downstream. Feasibility of construction of check dams on such tributaries confluencing with Viswamitri in this zone is again to be assessed.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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