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PHYSICO-CHEMICAL AND BIOLOGICAL PARAMETERS INVESTIGATION OF MULA-MUTHA RIVER IN INDIA: FROM SOURCE TO SINK

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ABSTRACT

The Mula-Mutha, a river in India is a typical example of a river that got polluted due to urban proximity namely, Pune. Mula-Mutha river is used as a source of drinking water and for other domestic purposes. Indiscriminate sewage disposal, industrial wastes and various human activities which directly affect their physico-chemical and microbiological quality. Being a monsoon driven river, the quality of water changes significantly with season. Hence, the present study was designed to investigate physico-chemical and biological parameters at selected point locations from source (Mulshi dam) to sink (Ujjani dam) in both pre and post monsoon seasons. Our study demonstrated that due to the dilution of water during postmonsoon, the over all ionic strength was lower than the premonsoon water samples. But, the bacterial load is undesirably high in post monsoon, deteriorated the quality of water. It was observed that from Mulshi to Lavale, all tested parameters are within the desirable limit of water quality. Quality of water degraded progressively upon the urban entry due to illegal, untreated, uncontrolled dumping of industrial and domestic wastes. Among the selected locations, Daund is the location where untreated and uncontrolled dumping of wastes is significantly degrading the water quality. The high bacteriological load of Mula-Mutha river in this stretch (Wakad to Dalaj) signaling the civic authorities to take necessary action on the illegal dumping of effluents from Industries, Sewage disposal into river on the basis of environment protection.

KEY WORDS : Mula-Mutha river, Pune, Bacterial load, Effluents, Sewage disposal

INTRODUCTION

Water, the nature's gift for biological growth and survival. The rivers, our freshwater sources, have a capacity to distribute the flow of water at a long distance (Peel and McMahon, 2006) and to maintain natural cycle. Rivers in their journey, provide valuable water for drinking, irrigation as well as agricultural practices, domestic activities and industrial processes (Sehgal *et al.*, 2012). The water quality has alarmingly deteriorated due to in superfluous population growth and various anthropogenic activities like industrialization, domestic sewage mismanagement and agricultural practices, predominantly in South asian countries like Nepal, India and Bangladesh. In these countries, river pollution is a serious problem, especially near the urban stretches as large quantities of pollutants are released due to different urban activities (Joseph and Jacob, 2010).

The Mula-Mutha, a river in India, flowing across the Pune city is one such river that got polluted due to its urban proximity. This river meets the Bhima River and later meets the Krishna River and finally emptying into the Bay of Bengal. Pune Metropolitan region and downstream villagers are totally dependent on the waters of this stretch. But, they got polluted because of anthropogenic impact, urban impact, agricultural activities and industrialization (Ranpise *et al.*, 2018; Imandoust and Gadam, 2007; Jadhav and Jadhav, 2017; Kendre and Gawande, 2017). Usually, waste is discharged to receiving water bodies with little or without any consideration of their assimilative capacities (Halder and Islam, 2015). The natural self purification process of contaminated water is slow and it always travels a long distance without self purification process to be achieved (Halder and Islam, 2015). The polluted water not only affect the available potable water resource and also responsible for spreading of harmful water borne diseases (Jadhav *et al*., 2013).

According to Maharashtra Economic Survey report 2018-19, the dissolved oxygen (DO) content, coliform content, BOD and COD levels have exceeded the safety limits in Mula-Mutha river. It is therefore, necessary to understand the point as well as non-point sources that pollute the Mula-Mutha river stretch starting from Mulshi dam to Ujjani dam. Therefore, the water quality of this stretch of river is assessed by collecting water samples at different locations from source to sink. This may provide an idea about its sustainability, suitability to human needs or for any other use and for the assessment of probable point and non-point sources of pollution on site. Moreover, Mula-Mutha catchment area is monsoon driven region that are characterized by a pronounced seasonality of rainfall and quality fluexes (Wagner *et al*., 2011). Hence the present study was designed to investigate physico-chemical and biological parameters at selected point locations from source to sink in both pre and post monsoon seasons.

MATERIALS AND METHODS

(A) Study area

Source to sink stretch of a Mula river was selected for the study. It is a stretch between the Mulshi dam (built on Mula river, located in Mulshi Taluka of Pune district) to Ujjani dam (built on Bhima river, located in Madha Taluka of Solapur district) that partly covers Pune and Solapur district (Fig. 1). The total length of the selected stretch is approximately 194 km and it falls under Survey of India toposheet numbers 47 E, I, J, K, F+B, N and O. Nineteen

Fig. 1 Location Map of Mula-Mutha River

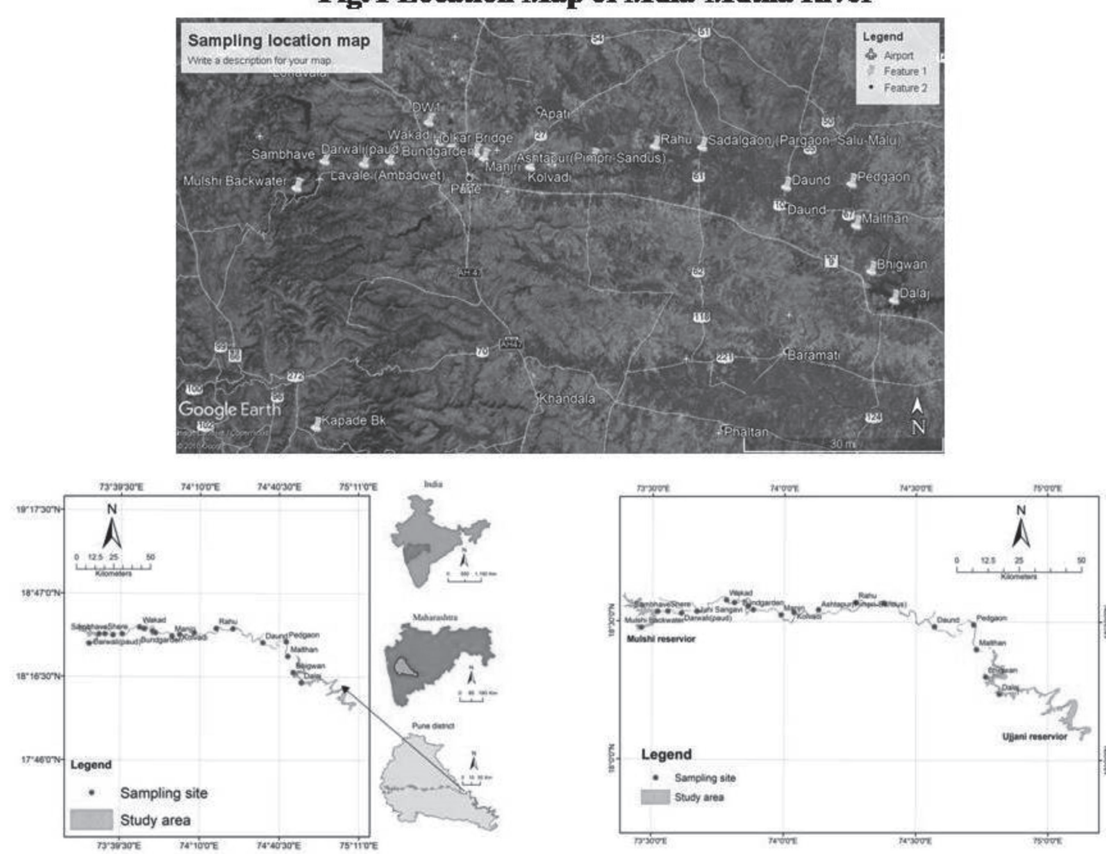

Fig. 1. Location Map of Mula-Mutha River

locations having minimum 10 km apart were selected for the study purpose viz. Mulshi, Sambhave, Shere, Darwali (paud), Lavale (Ambadwet), Wakad, Juni-Sangavi, Holkar Bridge, Bundgarden, Manjri, Kolvadi, Ashtapur(Pimpri-Sandus), Rahu, Sadalgaon (Pargaon, Salu-Malu), Daund, Pedgaon, Malthan, Bhigwan and Dalaj. The description of sampling location is provided in Table 1.

Sample Collection

The samples were collected from the selected locations during pre-monsoon (May 2018) and post –monsoon (January 2019) seasons (Fig. 2). Generally November month is considered for post monsoon data collection, but in the year 2018, intermittent showers due to reiterating monsoon were happened till the end of November. Hence the samples were collected at the start of the January month. Grab sampling Method was followed throughout the study as it is best known sampling method for studying the biological parameters (Trivedy and Goel, 1986). The samples were collected in cleaned and sterilized polypropylene-can having 1 liter Capacity with all necessary precautions as mentioned in APHA. In the present study 20 physico-chemical and biological parameters were evaluated for each sample.

Fig. 2. Sampling Locations amd Collection

Determination of physico-chemical and biological parameters

Field observations

Dynamic parameters like pH, Temperature, Total Dissolved Solids (TDS), Electrical Conductivity (EC) and Dissolved Oxygen (DO) are measured on the site. Temperature, pH, total dissolved solids and Electrical Conductivity were measured using HI 98130, Hanna instruments Ltd., Germany. Turbidity was measured using Nephelometer (Equip-Tronics: Digital Nephelometer EQ-815, Model No: EQ815, Sr.No: 033013). Winkler method of Azide Modification was followed for determination of dissolved oxygen. To fix the DO, the BOD (300 mL capacity) bottles were carefully filled without air bubbles. 2 mL of $MnSO_4$ and alkali iodide azide solution was added to form a precipitate.

Lab Testing

Determination of Physico-chemical parameters

Total Solids (TS) total hardness, total alkalinity and acidity were determined as per (Trivedy and Goel, 1986).

The methods used for determining ions (Calcium, Magnesium and Chloride) were followed as per the standard methods for the examination of water and wastewater by APHA-AWWA-WPCF (2012). ***Nitrate*** (NO_3^-) was calculated on HPIC in ppm range (High Performance Ion Chromatograph machine, ED 50 electrochemical Detector, Dionex 500). The preservation technique for High Performance Ion Chromatography study was done as per APHA, 2012. Similar to nitrate analysis, Sulphate (SO_4^{2-}) and Phosphate (PO_4^{3-}) were also analysed using HPIC.

Determination of Biological parameters

For Dissolved Oxygen (DO) the precipitate obtained on site using the Winkler method (Sawyer *et al*., 2000). For Biochemical Oxygen Demand determination, the unseeded BOD_5 method from APHA is used (BOD_5 (mg/L) = $(D_1-D_2)/P$). Chemical oxygen demand (COD) was determined using standard methods (Trivedy and Goel, 1986).

For Bacteriological Study: The method used for microbiology work is as per the procedure mentioned in APHA (2012) and Firozia and Sanalkumar (2012). The microbiological parameters such as Total Plate Count or Total Viable Count (TVC) and Total Coliform bacteria count were estimated through spread plate method. One Liter of water samples from all selected location was collected into pre-sterilized glass or plastic bottles. The samples were collected by taking precautions required for microbiological work analysis. The samples were held on ice in an icebox and transported to the base laboratory. The samples of water were subjected to 10^{-3} serial dilution. The

Table 1. Description of water sampling sites.

Locations	Designation (N)	Latitudes (E)	Longitudes (m)	Altitude	Temporal Sampling	Selection
1. Mulshi Backwater	Rural	18^0 29' 682''N	$073^0$22' 224''E	690.20	Six monthly	Source location
2. Sambhave	Rural	18^0 31' 85''N	073^0 31'362''E	646.48	Six monthly	Source as inflow to city
3. Shere	Rural	18^0 32' 813''N	073^0 34'677''E	623.32	Six monthly	Source as inflow to city
4. Darawali (Paud)	Rural	18^0 30' 972''N	073^0 50'031''E	578.21	Six monthly	Source as inflow to city
5. Lavale (Ambadwet)	Rural	18^0 34' 287''N	073^0 41'318''E	633.37	Six monthly	Indicator of self purification, domestic waste and inflow to town
6. Wakad	Semi-urban	18^0 34' 636''N	073^0 46'877''E	585.22	Six monthly	Indicator of self purification, input of industrial waste, domestic waste and inflow to town
7. Juni Sanghavi	Urban	$18^0$19' 424''N	074^0 14' 116''E	664.16	Six monthly	Indicator of self purification, input of industrial waste, domestic waste and inflow to town
8. Holkar Bridge	Urban	18^0 33' 263''N	073^0 52'199''E	576.68	Six monthly	Indicator of self purification, input of industrial waste, domestic waste and inflow to town
9. Bund Garden	Urban	18^0 33' 298''N	073^0 53'401''E	583.08	Six monthly	Indicator of self purification, input of industrial waste, domestic waste and inflow to town
10. Manjiri	Semi-urban	18^0 31' 511''N	074^0 00'555''E	548.34	Six monthly	Indicator of self purification, input of industrial waste, domestic waste and inflow to town
11. Kolvadi	Rural	$18^0$32' 448''N	074^0 02'620''E	536.14	Six monthly	Indicator of self purification, input of industrial waste, domestic waste and inflow to town
12. Ashtapur (Pimpri-Sandus)	Rural+ Local fishing	$18^0$36' 601''N	074^0 07'890''E	542.54	Six monthly	Indicator of self purification, input of industrial waste, domestic waste and inflow to town
13. Rahu	Rural+ Local fishing	18^0 34' 080''N	074^0 16'310''E	519.68	Six monthly	Indicator of self purification, input of industrial waste, domestic waste and inflow to town
14. Sadalgaon (Pargaon, Salu-Malu)	Rural+ Local fishing	18^0 34' 094''N	$074^0$22' 697''E	513.59	Six monthly	Indicator of self purification, input of industrial waste, domestic waste and inflow to town
15. Daund	Rural+Industrial	18^0 28' 232''N	074^0 35'250''E	496.82	Six monthly	Input of industrial waste, domestic waste and inflow to town

Table 1. *Continued ...*

Locations	Designation (N)	Latitudes (E)	Longitudes (m)	Altitude	Temporal Sampling	Selection
16. Pedgaon	Rural+ Industrial	18^{0}26' 670''N	074^0 43'300''E	500.18	Six monthly	Input of industrial waste, domestic waste and inflow to town
17. Malthan	Rural+ Industrial	18^0 24' 001''N	074^0 43'783'E	509.93	Six monthly	Input of industrial waste, domestic waste and inflow to town
18. Bhigwan	Rural+ Industrial	18^{0}38' 344''N	073^0 45'461'E	597.41	Six monthly	Input of industrial waste, domestic waste and inflow to town
19. Dalaj	Rural+ Industrial	18^0 14' 226''N	074^0 49'142'E	506.58	Six monthly	Input of industrial waste, domestic waste and inflow to town

estimation of bacterial population of different water samples was carried through spread plate method. The spread plate technique applied for Total Plate Count (TPC) on Nutrient Agar and for Total Coliform Count (TC) on McConkey Agar. Once the spreading was completed on specific media, all the plates were subjected to incubation at 37 ^{o}C for at least period of 24 to 48 hours. After completion of incubation, the final colonies were counted and recorded as colony forming units (cfu) units.

(D) Statistical Analysis

The physico-chemical and microbiological parameters of water under study were presented in terms of Mean ± SD with probability of $p < 0.05$. All experiments were repeated twice in three replicates. Graphical representation was primed using Microsoft Excel Software.

RESULTS AND DISCUSSION

Determination of physico-chemical parameters of the Mula-Mutha river water

At the selected location, parameters like Temperature, pH, EC, TDS, Turbidity, Total Solids, Total Hardness, Total alkalinity and Total acidity were measured and tabulated in Table 2 for both pre-monsoon and post-monsoon seasons.

Temperature: Average temperature of collected pre-monsoon samples (31.6°C) was found to be more as compared to post-monsoon season (22.7 °C). The reason could be the sampling period because the pre-monsoon seasons samples were collected during summer (May) and post-monsoon season samples during the retreat of winter (January).

Aquatic chemical reactions and rate of reactions are totally dependent on the temperature and also affects the aquatic life (Kar *et al*., 2010). The temperature of water mostly depends on the depth of the water column, climatic and topographic changes (WQA, 1992). It has been reported (Lim and Song, 2010) that temperature fluctuations may also be due to direct and indirect input of waste water into the river.

In our study, we could demonstrate the impact of climatic changes in the form of monsoon with a significant difference in temperature between pre and post monsoon data. But the input of waste water has not significantly altered the temperature of the selected source to sink location [(31.6 °C ± 0.96 (pre-M) and 22.7 °C ± 1.7 (post-M)].

pH: The P^H of pre-monsoon and post-monsoon collected water samples was found to be more or less nearer to neutral or slightly alkaline (≈ 7.6) or basic in nature and the selected locations near-sink regions (≈ 8) were more alkaline than the locations near the source (≈ 7.8). Unlike temperature, the season had no significant impact on the pH of the river water. The significantly unaltered pH of Mula-Mutha river maintained due to the natural self purification process of river water and also ensures the equilibrium produced in between

Table 2. Physical parameters of mula river from source to sink

Name of Location	Temperature (°C)		pH		EC (µS/cm)		TDS (mg/L)		Turbidity (NTU)		Total Hardness (mg/L)		Total solids (mg/L)		Total Alkalinity (mg/L)		Total Acidity	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Mulshi	34.1	23.4	7.78	7.01	70	60	40	30	2.47	2.9	13	11	60	136	30	30	2.5	2.5
Sambhave	30.5	21.3	7.9	7.33	70	70	40	40	1.0	1.9	14	13	36	104	35	30	2.5	2.5
Shere	30.7	20	7.81	7.04	70	70	30	40	3.13	5.9	13	15	36	68	30	35	2.5	2.5
Darwali	30.8	18	7.86	7.87	90	160	40	80	2.6	5.7	13	34	48	152	35	80	2.5	2.5
Lavale	32.5	23	7.47	8.3	80	250	40	130	2.2	6.6	17	59	48	208	40	125	2.5	2.5
Wakad	32.1	21.7	6.9	7.13	220	580	120	290	0.3	6.47	44	92	164	372	95	145	10	15
Juni Sangavi	31.8	24.9	6.97	6.94	570	700	290	350	4.0	8.3	74	86	300	264	120	125	32.5	25
Holkar Bridge	31.3	23.8	6.97	7.23	590	680	300	320	2.4	4.97	79	86	304	284	130	125	27.5	15
Bundgarden	31.1	22.8	7.07	6.94	440	520	230	260	1.23	4.2	63	73	264	228	110	110	2.5	15
Manjri	31.6	24.5	7.09	7.2	460	600	230	300	7.8	11.6	66	77	264	288	115	115	22.5	22.5
Kolvadi	32.1	23.8	7.47	7.2	520	660	270	330	4.5	9.2	68	85	276	296	125	130	25	20
Ashtapur	30.2	23	8.06	7.5	220	620	110	310	4.8	4.7	41	81	136	368	110	130	5	20
Rahu	31.4	22.3	7.81	7.18	590	700	310	350	0.2	2.0	78	89	396	420	190	170	0	10
Sadalgaon	31.5	20.7	7.92	7.58	550	820	280	410	0.53	2.6	71	105	332	504	185	220	0	7.5
Daund	32	24.4	7.54	8.37	1450	1490	760	750	6.9	5.8	174	165	1032	1068	390	290	10	5
Pedgaon	32.3	24.2	7.68	8.47	1430	1160	740	580	5.63	12.8	196	147	1060	792	340	215	2.5	5
Malthan	32.3	25	7.94	8.4	1110	410	580	820	0.7	3.4	156	120	792	628	300	195	2.5	2.5
Bhigwan	32.5	22	8.33	8.98	3050	420	1580	210	16.3	11.5	271	67	2300	292	340	140	0	5
Dalaj	30.1	24	8.08	8.4	650	440	340	220	0.3	7.2	97	72	460	280	205	145	0	5
Mean±sd	31.6 ± 0.96	22.7± 1.7	7.6± 0.4	7.63± 0.63	643± 702	547± 365	333± 375	306± 220	3.5± 3.8	6.2 ± 3.2	81±71	77±41	437± 548	355± 247	153± 114	134±66	8± 10	9.7±7.8
Permissible Limit (BIS for drinking water specification, IS10500:1991)	-	6.5 - 8.5	-	2000 mg L^{-1}	5 NTU	600 mg L^{-1}	-	600 mg L^{-1}	-									

carbonate-bicarbonate and Carbon dioxide (Halder and Islam, 2015).

Electrical Conductivity (EC): Electrical conductivity is as a quick measure of dissolved ionic or soluble salt concentration, fertilizer and chemical containing solutions. The near-source region (1-5) the ionic content was far lower than the downstream selected locations. The maximum EC measure (1450 (µS cm^{-1}) was noted at a downstream location, namely Daund where intense eutrophication was observed. Ranpise *et al.,* 2018 study got high results of EC and TDS in the downstream part of the pavana river which correlates with different discharge of sewage, agricultural runoffs or industrial sources (Gupta and Paul, 2013). Similar net increase in conductivity in downstream part Oum Er Rbia River (Morocco) was reported by Barakat *et al.*, 2016. The pre-monsoon and post-monsoon effect showed no significant change in EC of Mula-Mutha river water.

Total Dissolved Solids (TDS): Total Dissolved Solids (TDS) includes inorganic salts and small amounts of organic matters present in dissolved form (Odonkor and Addo, 2013). The TDS measurement of Bhigwan location was alarming (1580 mg L^{-1}) due to large input of waste matter created through human activities. Permissible Limit (Bureau of Indian standards for drinking water specification, BIS10500:1991) for TDS is 2000 mg L^{-1}. The water exceeding TDS level set by standard has an adverse impact on human health and other activities. Total solids measurements were also similar to TDS data.

Turbidity: Turbidity of water during pre-monsoon was found to be less as compared to post –monsoon. At locations like Manjiri, Daund, Pedgaon and Bhigwan, turbidity was more than the permissible limit (5 NTU) due to disturbance in the water current. In Post-monsoon, turbulence of water exceeded the permissible limit in most of the selected locations.

Total Hardness; Total Alkalinity (TA) and Total Acidity (TAc): Total hardness of pre and post-monsoon water samples were far below the permissible limit (600 mg L^{-1}). Total alkalinity of average pre-monsoon water samples showed higher than post-monsoon, but not significant. Conversely the total acidity of average post-monsoon water samples showed higher than pre-monsoon samples.

Ionic Parameters: At selected location, ions like Calcium, Magnesium, chloride, sulfate, nitrate and phosphate were estimated and listed in Table 3, for both pre-monsoon and post-monsoon seasons.

Calcium, Magnesium and Chloride content of the collected samples from both seasons is far below the permissible limit. Calcium and Magnesium in natural waters have no adverse effect noted on human health, but it can help increase the hardness (Eze and Madumere, 2012). Pre-monsoon water samples had significantly higher chloride content than post-monsoon samples. In rivers, chloride is understood as one of the complex anion (Ojutiku and Koloanda, 2011). High concentration of chloride in water causes toxic effects on flora and fauna of aquatic system and it also unsuitable for use in boilers because it supports corrosion process (Gaikwad *et al*., 2016). Increased level of chloride in water imparts salty taste and also produces laxative effects in organisms (Das and Achary, 2003). Excess of chloride concentration also mark as a pollution indicator (Gaikwad *et al.,* 2016).

The pre-monsoon water samples collected from the downstream locations from Daund onwards showed a very high content of Sulfates beyond permissible limit (400 mg L^{-1}), making the water unsuitable for drinking purposes. Sulfates bestow a foul smell to drinking water and causes diarrhea in infants (Jadhav *et al.,* 2013). Source of sulfur in water is from sulfur containing minerals found in different types of rocks and domestic waste and addition through agricultural runoff. Post monsoon samples showed reduced sulfate content compared to pre-monsoon samples at all selected locations.

The high nitrate level is responsible for algal growth and eutrophication (Fried, 1991) and have negative impacts on growth of fauna and flora (Barakat *et al*., 2016). Addition of sewage, agricultural waste and activity of nitrifying bacteria (Mallika *et al*., 2017) also leads to eutrophication. Water with more than 45 mg L^{-1} of nitrate concentration is considered to be unsuitable for drinking purpose (Mallika *et al*., 2017). According to many reports the Mula-Mutha River is reported as ecologically most polluted rivers (Joshi, 2003; 2004; Joshi and Joshi, 2005; Joshi and Jog, 2005). Ministry of Environment and Forests reported that the water from Pune to Ujjani was unsuitable for human consumption (Joshi and Joshi, 2005). In accordance with earlier reports, the nitrate content was far higher than the permissible limit, especially urban locations like Holkar Bridge, Bund garden that has intense human activities.

Pattern of estimated Phosphates showed similar to nitrates in selected locations. In pre-monsoon samples collected from locations starting from Juni-Sangavi upto showed the presence of phosphate content in the samples. The locations down to Sadalgaon showed absence of phosphates. Phosphate in natural water has no direct deleterious effect on human health (EPA, 1995; Eze and Madumere, 2012). But both phosphates and nitrates content in water expedite the eutrophication process.

Biological Parameters: At the selected location, parameters like dissolved oxygen, chemical oxygen demand and biological oxygen demand were determined for both pre-monsoon and post-monsoon seasons.

Dissolved Oxygen (DO): Dissolved oxygen measurement is a direct indicator of water resource ability to support aquatic life. Each and every organism has its own tolerance range for DO, generally 3 mg/L and above promotes aquatic life and level below 1 mg L^{-1} considered as an Hypoxic condition that is usually devoid of life (USEPA, 2000). BIS – IS: 10500 – 2012 categorized in to Class A – 6 mg L^{-1} Class B – 5 mg L^{-1} Class C – 4 mg L^{-1} and No relaxation (permissible)on the DO levels. According to WHO report, 7 mg L^{-1} dissolved oxygen is desirable to coin the status of water as drinking water (1993).

The water quality of Mula-Mutha river at source region, namely Mulshi is potable as reflected by the DO measurement as close to 7 (6.73 mg L^{-1}). Down the line, the water become hypoxic (0.3 mg L^{-1}) due to huge input of domestic waste materials and pollutants especially in city centric locations (Table 2). According to Gaikwad *et al.*, (2016) Low dissolved oxygen level reflects high load of organic waste. Anaerobic decomposition of organic waste imparts foul smell to water and also responsible for reducing dissolved oxygen level in water. The oxygen content gets replenished in water as the river flew in periurban locations (Fig. 3). Towards the sink region starting from Daund the DO measurement again observed a down fall. This is the resultant impact of sugar Industry hub in this region. The average DO content is slightly more in

Table 3. Ionic parameters of Mula Riaver from Source to Sink

Name of Location	Ca+ ions		Mg+		Cl-		SO4 $^{2-}$		NO_3-		PO_4 $^{3-}$	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Mulshi	6	6	1.7	1.22	0	5	5.53	5.398	0.56	0.08	0	BDL
Sambhave	7	8	1.7	1.22	0	5	5.72	7.73	0	0.0135	0	BDL
Shere	6	9	1.7	1.46	0	5	6.01	4.53	0	0.05	0	BDL
Darwali	7	21	1.46	3.16	0	10	6.52	7.64	1.3	0.08	0	BDL
Lavale	9	34	1.94	6.08	0	10	7.24	14	1.3	0.35	0	BDL
Wakad	26	54	4.37	9.23	5	54.98	10.27	30.72	16.79	60.59	0	BDL
Juni Sangavi	45	51	7.05	8.5	44.99	54.98	53.23	38.62	127.37	58.68	15.07	BDL
Holkar Bridge	51	51	6.8	8.5	44.99	49.98	57.11	42.05	126.63	103.67	15.64	BDL
Bundgarden	41	40	5.35	8.01	29.99	39.99	42.09	30.68	96.44	86.51	9.16	BDL
Manjri	36	39	7.29	9.23	39.99	49.98	36.31	33.89	117.06	112.48	16.28	BDL
Kolvadi	40	48	6.8	8.99	39.99	49.98	40.45	39.98	131.35	103.61	14.53	BDL
Ashtapur	25	44	3.89	8.99	0	49.98	21.29	37.3	7.41	89.68	10.23	BDL
Rahu	43	42	8.51	11.42	44.99	59.98	90.81	59.86	87.27	81.79	8.98	BDL
Sadalgaon	33	49	9.23	13.61	34.99	64.98	162.89	138.94	23.91	52.91	3.57	BDL
Daund	72	83	24.79	19.93	129.96	134.96	604.5	361.84	22.86	5.89	0	BDL
Pedgaon	62	57	32.56	21.87	154.95	114.96	599.97	303.99	5.23	5.01	0	BDL
Malthan	47	57	26.49	15.31	119.96	79.98	482.46	235.12	4.11	2.45	0	BDL
Bhigwan	49	32	53.95	8.51	524.84	29.99	941.27	71	11.7	1.85	0	BDL
Dalaj	47	37	12.15	8.51	69.98	34.99	321.17	78.274	6.65	2.33	0	BDL
mean±sd	34±20	40±19	11±13	9±5.6	67±120	47±35	183±273	81±104	41±52	40±44		
Permissible Limit (BIS for drinking water specification, IS10500:1991)	200 mg L^{-1}	30 mg L^{-1}	1000 mg L^{-1}	400 mg L^{-1}	100 mg L^{-1}	-						

Note: BDL: Below Detection Limit

post-monsoon ensuring the existence and blooming of aquatic life.

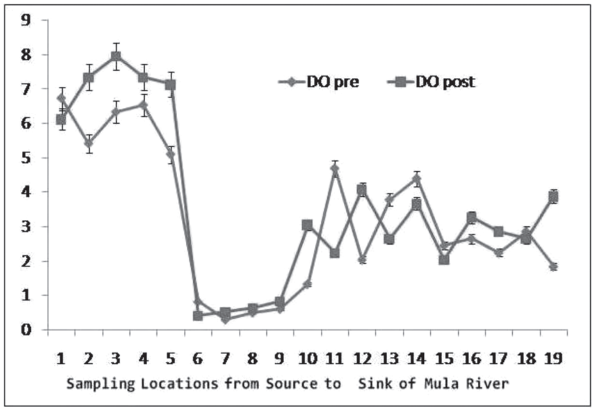

Fig. 3. Level of dissolved oxygen in the Sampling Locations of Mula River

Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD)

BOD and COD are two parameters used to quantify the organic contamination load (Galal-Gorchev *et al.,* 1993). The COD and BOD levels determined in our study in the selected locations clearly reflects on human interference. Low COD and BOD levels were in the scarcely populated source region. As Mula-Mutha river moves to the densely populated urban region, organic contamination in the form of domestic sewage wastes, shoots up the COD and BOD levels. Further down the line in periurban region, though both COD and BOD levels temporarily drop and shoots up again due to industrial impact (Fig. 4 and 5). The industrial areas like Daund, Pedgaon, where industrial effluents are also added to domestic contaminants, there by increasing the organic contamination load in this region and thus escalating the BOD shoots up far higher than COD in these regions.

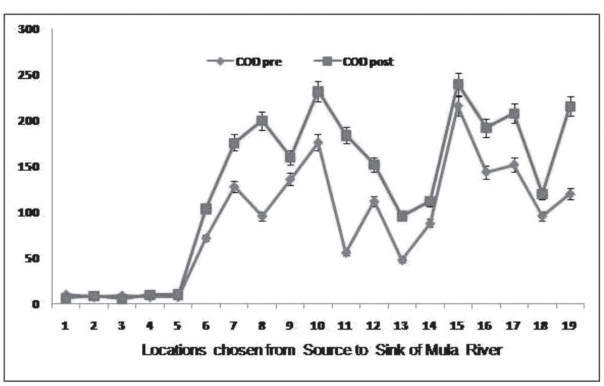

Fig. 4. Level of COD in the Sampling Locations of Mula River

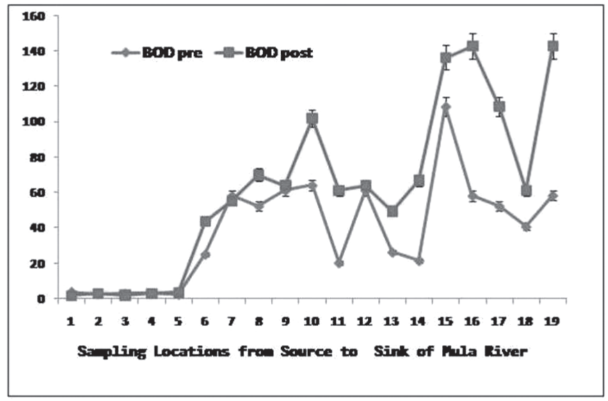

Fig. 5. Level of BOD in the Sampling Locations of Mula River

The Mula-Mutha river showed a range between 5.6 to 240 mg L^{-1} COD in our study with the average of 88mg L^{-1} in premonsoon and 128 mg L^{-1} in post monsoon. Similar results were reported by Ranpise *et al*. (2018) where many sampling sites were exceeded the permissible limit (30 mg L^{-1}) which indicating the heavy load of organic waste. Jadhav *et al.* (2013) reported that all water samples Indrayani River were found to have COD in the range of 114 to 246 mg L^{-1}.

In our study, BOD levels ranged between 2.6 to 142 mg L^{-1} with average of 38 mg L^{-1} for premonsoon and 62 mg L^{-1} for postmonsoon. High level of BOD of river water could be attributed to discharge of organic waste in the form of refuse, human and animal excreta, detergents and other thing into the river (Odonkor and Addo, 2013). Mallika *et al.*, 2017, reported that the BOD concentration average results were ranged between 4.5 to 22.6 mg L^{-1} of Vaigai River in Madurai District of Tamilnadu state.

Overall, the values of BOD and COD obtained in our study exceeded the limits prescribed by WHO (1983) and BIS (2012).

Bacterial Parameters

Total viable count (TVC) generally reflects the bacteriological quality of water. High level of TVC in water can possibly impart a stale/stagnant taste and or odour to the water. No statutory limit is provided by MPCB. According to UK water supply regulations, 2000, the guide limits for TVC count were set at 10 cfu mL^{-1} at 37 °C and 100 cfu mL^{-1} at 22 °C (UKAS, 2000). Our study demonstrated a high level of TVC count both in pre and post monsoon samples at all selected locations. In fact, the post monsoon TVC data were several folds higher than the premonsoon samples indicating poor quality of water. For example mulshi sample showed $1.2 \pm 0.1 \times 10^4$ cfu mL^{-1} in premonsoon got doubled in post monsoon period ($2.37 \pm 0.59 \times 10^4$). Whereas, industrial centric region like Daund, TVC increased to several folds ($2.76 \pm 0.18 \times 10^4$ to $23.7 \pm 1.5 \times 10^4$) (Fig. 6). In the premonsoon, TVC counts doubled (Table 4) when the river entered the Pune city mainly due to human causes. TVC count showed a increasing pattern from source to sink region.

High TVC count reflects on human's undesirable activities like disposal of faecal material into the mula-mutha river once the river enters the Pune city. Due to its public health impact, the microbiological quality of river has gained more attention worldwide. It is imperative to have regular assessment of the microbiological quality of the river. Human fecal material generally contaminated with enteric pathogens that include a coliform group of bacteria, Salmonellae, Vibrio and dysentery causing agents. Coliform bacteria are the most reliable indicators of fecal contamination, in which Streptococci plays a strong evidence. Hence total coliform counts were determined for water samples collected from the selected locations (Fig. 7).

Total Coliform counts (TCC) of both pre and post monsoon seasons from near source regions viz. Mulshi, Sambhave, Shere, Darwali (Paud) and Lavale (Ambadwet) were found to be zero, due to less human interventions in these rural areas and found no drain of any sewage material directly into the river water. Similar observation was reported in Yamuna river upstream parts were free from sewage or any kind of organic or industrial waste and devoid from getting coli form count, hence water quality found to be somewhat undisturbed (Khaiwal *et al.*, 2003)

A notable detection of TCC at the entry into the periurban area namely wakad and got stretched in all samples collected downstream upto Dalaj. The premonsoon TCC were less than 1×10^4 cfu mL^{-1} in all locations (Table 4). But the post monsoon samples from wakad and other downstream sampling locations showed elevated TCC load even upto 18×10^4 cfu mL^{-1} indicating alarming contamination that urges immediate attention. In the culture plates on MacConkey agar, small pink colonies is of *E. coli* and large pink mucoid colonies are of *Klebisella* sp. were observed (Fig. 7).

It is desirable to have drinking water with no microbial counts. As the Mula River starts entering

Table 4. Bacterial Parameters of Mula River from Source to Sink

Name of Location	Total Viable Count		Total Coliform Count	
	TVC pre-monsoon Mean ± SD	TVC post-monsoon Mean ± SD	TCC of pre-monsoon Mean ± SD	TCC of post-monsoon Mean ± SD
Mulshi	$1.2 \times 10^4 \pm 0.1$	$2.37 \times 10^4 \pm 0.59$	0	0
Sambhave	$0.9 \times 10^4 \pm 0.1$	$1.47 \times 10^4 \pm 0.90$	0	0
Shere	$1.08 \times 10^4 \pm 0.15$	$1.83 \times 10^4 \pm 0.84$	0	0
Darwali	$1.18 \times 10^4 \pm 0.16$	$1.78 \times 10^4 \pm 1.11$	0	0
Lavale	$1.52 \times 10^4 \pm 0.35$	$2.00 \times 10^4 \pm 0.36$	0	0
Wakad	$2.13 \times 10^4 \pm 0.32$	$20.0 \times 10^4 \pm 1.00$	$0.67 \times 10^4 \pm 0.13$	$8.7 \times 10^4 \pm 2.5$
Juni Sangavi	$2.72 \times 10^4 \pm 0.13$	$23.3 \times 10^4 \pm 3.5$	$1.2 \times 10^4 \pm 0.1$	$7.67 \times 10^4 \pm 4.51$
Holkar Bridge	$2.4 \times 10^4 \pm 0.46$	$24.0 \times 10^4 \pm 4.6$	$1.03 \times 10^4 \pm 0.15$	$16.3 \times 10^4 \pm 7.6$
Bundgarden	$1.62 \times 10^4 \pm 0.10$	$16.7 \times 10^4 \pm 2.1$	$0.58 \times 10^4 \pm 0.19$	$5.17 \times 10^4 \pm 0.76$
Manjri	$2.62 \times 10^4 \pm 0.18$	$28.0 \times 10^4 \pm 1.0$	$0.77 \times 10^4 \pm 0.25$	$17.3 \times 10^4 \pm 1.5$
Kolvadi	$2.1 \times 10^4 \pm 0.15$	$24.0 \times 10^4 \pm 2.0$	$0.53 \times 10^4 \pm 0.10$	$17 \times 10^4 \pm 1$
Ashtapur	$2.33 \times 10^4 \pm 0.25$	$27.0 \times 10^4 \pm 1.0$	$0.8 \times 10^4 \pm 0.15$	$17.8 \times 10^4 \pm 1.6$
Rahu	$2.17 \times 10^4 \pm 0.31$	$13.1 \times 10^4 \pm 1.9$	$0.7 \times 10^4 \pm 0.22$	$5.33 \times 10^4 \pm 0.25$
Sadalgaon	$2.48 \times 10^4 \pm 0.30$	$4.20 \times 10^4 \pm 3.86$	$0.79 \times 10^4 \pm 0.12$	$2.73 \times 10^4 \pm 2.37$
Daund	$2.76 \times 10^4 \pm 0.18$	$23.7 \times 10^4 \pm 1.5$	$0.81 \times 10^4 \pm 0.14$	$18.8 \times 10^4 \pm 1.3$
Pedgaon	$2.70 \times 10^4 \pm 0.13$	$15.33 \times 10^4 \pm 3.79$	$0.6 \times 10^4 \pm 0.18$	$3.03 \times 10^4 \pm 0.06$
Malthan	$2.68 \times 10^4 \pm 0.37$	$27.67 \times 10^4 \pm 1.53$	$0.82 \times 10^4 \pm 0.26$	$14.0 \times 10^4 \pm 7.0$
Bhigwan	$2.82 \times 10^4 \pm 0.10$	$6.33 \times 10^4 \pm 1.53$	$0.82 \times 10^4 \pm 0.15$	$3.5 \times 10^4 \pm 1.32$
Dalaj	$2.75 \times 10^4 \pm 0.26$	$6.30 \times 10^4 \pm 1.25$	$0.80 \times 10^4 \pm 0.16$	$3.77 \times 10^4 \pm 0.25$

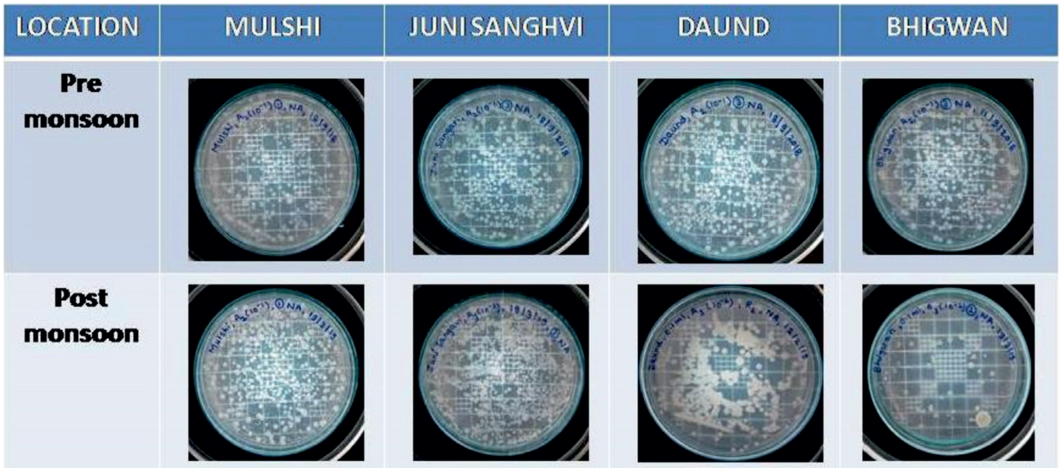

Fig. 6. Total Viable Count of samples collected from selected locations

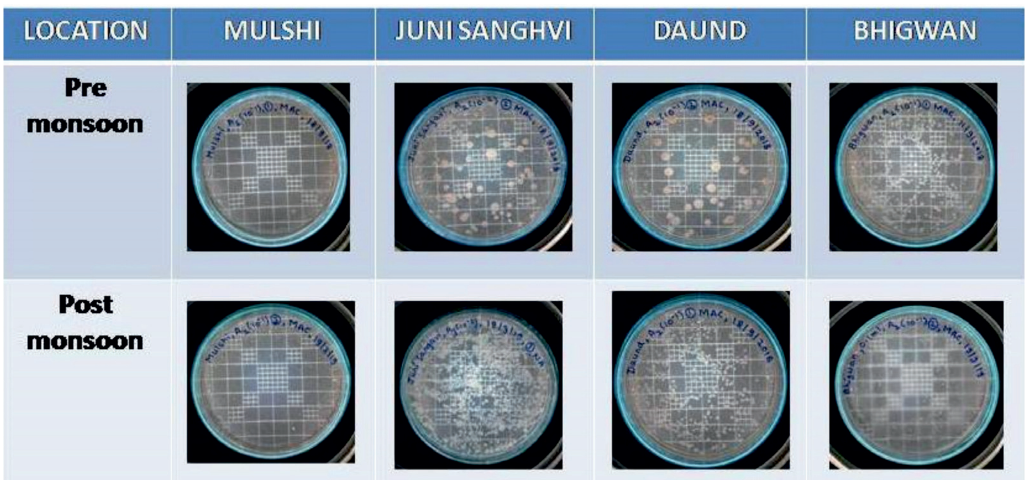

Fig. 7. Total Coliform Count of samples collected from selected locations

in city limits there is mark increase in TVC and TCC with little bit fluctuations and this is true for whole pre and post monsoon samples. In case of results of TVC and TCC from Wakad to Dalaj, it is clear that the poor city management in terms of sanitation system, lack of proper drainage line, stagnant wastewater and it is released without any treatment to nearby natural water body and encroachment in the flow of natural water bodies are responsible for entering these pathogens into the main river.

Venkatesharaju *et al*., 2010, upon assessment of river Cauvery of Kollegal stretch in Karnataka documented that the improper release of municipal wastes and septic tank discharges directly into the Cauvery river are responsible for generating high concentration of *E. coli* but water containing pathogenic bacteria makes it unsuitable for any kind of further use.

CONCLUSION

The present study investigated physico-chemical and biological parameters of Mula-Mutha river at selected point locations from Mulshi (source) to Dalaj (sink) in both pre and post monsoon seasons. In our study, we could demonstrate that the water samples in premonsoon showed reduced ionic contents compared to post monsoon samples. In constrast to other ions, sulfate and nitrate content got reduced in post monsoon samples at all selected locations.phosphates were not in detectable limits in post monsoon samples. The DO measurement as close to 7 (6.73 mgL^{-1}) at source region, namely Mulshi reflects on the potable nature of water. Down the line, the water become hypoxic (0.3 mgL^{-1}) due to huge input of domestic waste materials and pollutants especially in city centric locations.

The values of BOD and COD obtained in our study downstream to Lavale, exceeded the limits prescribed by WHO (2004) and BIS (2012). At source region up to Lavale, TCC and TVC of both pre and post monsoon seasons were found to be nearly zero, due to less human interventions in these rural areas. The biological load was pronounced in postmonsoon season degrading the quality of water, indicating an alarming contamination that urges immediate attention.

Locations near the source region right from Mulshi to Lavale, the quality parameters tested that include physiochemical, ionic and biological parameters are very well within the desirable limit of drinking water quality and are potable. However, locations starting from waked (downstream to Lavale) to Dalaj faced an alarming situation due to aforesaid reasons of human interference. High bacteriological load of Mula-Mutha river in this stretch observed in the present study signals the civic authorities to take necessary action on the illegal dumping of effluents from Industries, Sewage disposal into river on the basis of environment protection in and around pune region.

To avoid further deterioration of river water, it should be necessary to monitor it regularly and dire need of good management practices to be followed while discharging sewage or industrial waste or any kind of waste to nearby water body at all point and nonpoint sources especially in the urban and industrial centric locations like Daund. The point locations enlisted by this study may lay a platform for immediate protective measures and policy creation by the Government of Maharashtra.

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