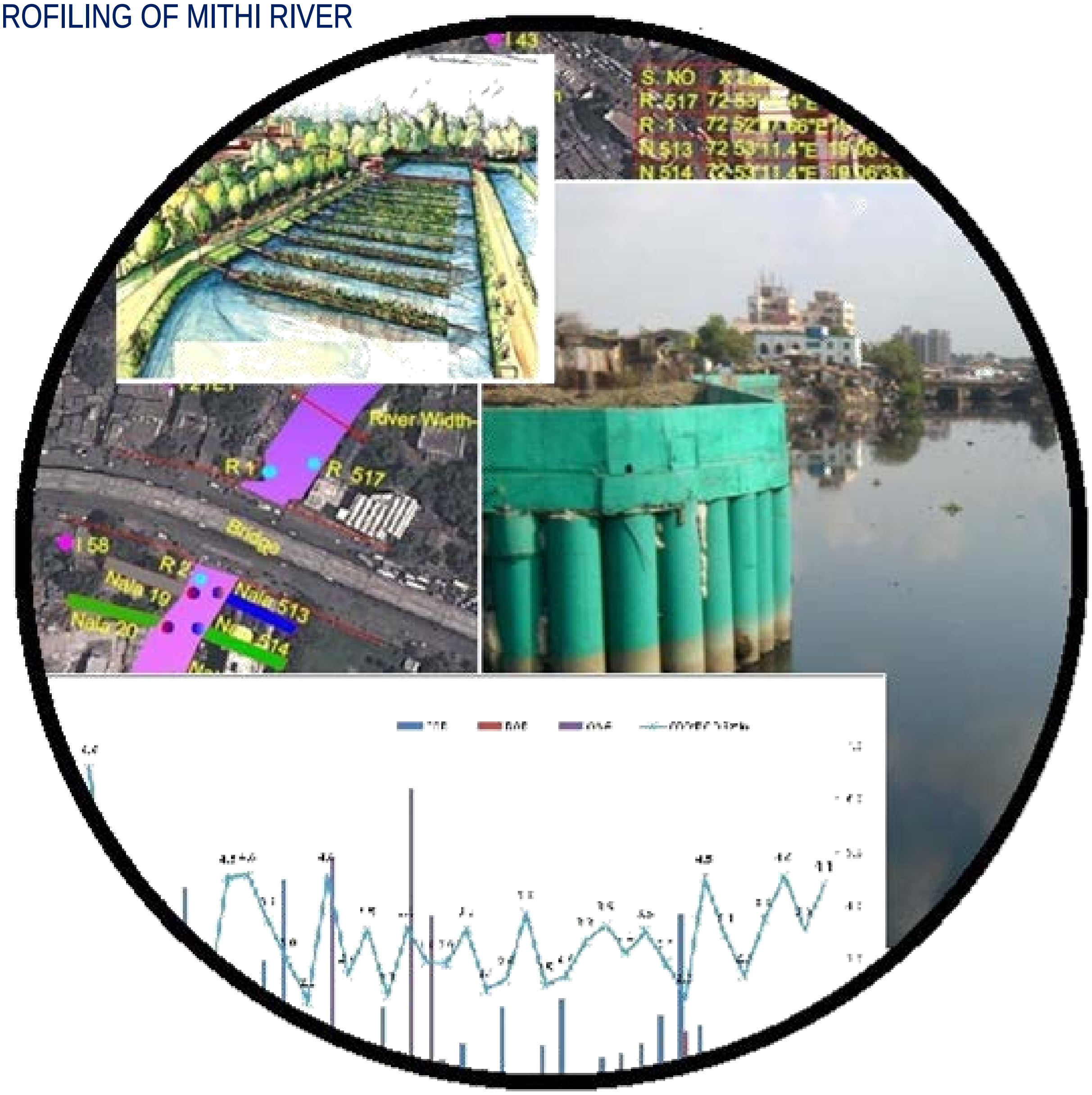
2014

COMPREHENSIVE STUDY/ PROFILING OF MITHI RIVER



Maharashtra Pollution Control Board, Mumbai

Foreword

After the deluge disaster of flood occurred in Mumbai in the year of 2005, Mithi River has got prime importance from its environmental degradation and pollution loading point of view. Government of Maharashtra has constituted Mithi River Development and Protection Authority (MRDPA) on 19th August, 2005. MRDPA awarded the work of environmental improvement and technical feasibility study to IIT, Powai which was published in June, 2006. Similar work on extended scope has been undertaken by Maharashtra Pollution Control Board in order to assess the pollution sources and to strategize the abatement measures oriented to fill gaps in research and strategy development found in earlier studies through a long period of time.

As per the studies carried out by MPCB in July, 2004 covering monsoon and post monsoon pollution levels in Mithi River, short term and long term measures were recommended for control of pollution. Short term measures included immediate closure of unauthorized activities such as discharge of industrial effluents, oils, chemicals and chemical sludge in river along with proper system development of garbage collection system to avoid solid waste dumping in river. Long term measures comprised provision of Sewage Treatment Plants and interceptor sewer plan on both banks of the river. It also emphasized on dredging along entire length of Mithi River bed so as to improve its carrying capacity.

Extending the continuous efforts of MPCB rejuvenate Mithi River water close to desirable characteristics to the extent of at least achieving suitability of end use for contact purpose and wildlife propagation as a short term and long term vision, it gives me a great pleasure to present this report incorporating innovative and scientific methodology with advanced tools such as development of criticality indices represented as color code through simplicity of access of information to aid decision making process and source receptor modeling for understanding industrial vis a vis domestic source contributions to Mithi River. The report as it is includes enormous details of physico–chemical and part of biological characterization for more than 250 odd samples and almost equivalent surveys throughout an RoW of 200m across the length of 15kms of Mithi and 3.5kms of Vakola nallah supported by extensive QA/QC protocols. Finally, I believe that the comprehensive management plan described in the report that not only aims at direct discharge sources but touches upon allied sources such as open defecation, solid waste dumping and others that are equally quintessential to be addressed along with multiple hierarchy of permutation and combination of options for at source, in path and end of the pipe treatments.

Finally, the approach of prioritizing management options through planning for achieving designated end use based targets summarizing site specific, nallah specific and generic industrial sources shall come as a extremely handy tool for decision makers in the near future.

Rajeev Kumar Mital
Member Secretary, MPCB

Acknowledgements

Technogreen Environmental Solutions on the onset would like to extend its heartiest gratitude to Shri. Rajeev Kumar Mital, Member Secretary, MPCB for giving us this opportunity to be part of such an extremely important and socially relevant project and his keen involvement in form of continuous follow-ups, updates suggestions and comments helped us orient this study in a way which otherwise would have not happened and probably may have been never realized in the present form.

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Technogreen acknowledges hard work and sincere efforts of all its team members who have selflessly gone beyond personal miles to make this study achieve a form which we are sure would be appreciated by one and all.

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Chapter I

Introduction

1.0 Background

Mumbai, the economic capital of Maharashtra, stands at the 1st rank being highly populated city in the India. It is union of seven islands, which make up the Mumbai city. Urban development, modernization, public utilities, employment, infrastructure, education, technology; Mumbai is the most developed city in all sectors, offering tremendous scope of job opportunities and high living standards.

Along with the high rise infrastructure, slums are also the vital part of Mumbai. As per the 2001 census, about half of the population in Mumbai lives in slums (5.93 million out of total population of 11.91 million). It is believed that there are about 1,959 slum settlements. Out of those, around 47% slums are located on private lands, about 42% on public lands, 10% on other lands and about 1% on railway lands (www.mcgm.gov.in)

Industrial growth of Mumbai has attained tremendous pace in all of the industrial sectors including media, chemical factories, textile, pharmaceutical, automobile tanneries, oil refineries, engineering clusters, and so on.

MCGM is the agency which has control over the water supply in the city. The storm water drainage system in Mumbai comprises of a hierarchical network of roadside surface drains which are about 2000 km mainly in suburbs, underground drains and laterals(about 440km in the island city area, major and minor nallahs (200km and 87km respectively), and 186 outfalls, which discharge all the surface runoff into rivers and Arabian sea. The present storm water drainage system in Mumbai is about 70 years old, comprising of about 400km of underground drains and laterals built on the basis of population and weather conditions. This system is known to be capable of handling rain intensity of 25mm per hour at low tide per hour and when high tide occurs, there is always a possibility of water logging which disturbs all the traffic and day to day chores (www.mcgm.gov.in).

MCGM is formally responsible for the management of waste in the city. Around 5800 community garbage bins have been provided in the city where the collected garbage is dumped. In southern Mumbai, the garbage is transported to transfer station located at Mahalakshmi. In north part of Mumbai, dumping grounds are provided. Many schemes such as Slum Adoption Scheme, Advanced Locality Management, Parisar Vikas Scheme, has been adopted under the guidance of MCGM so as to manage and effective disposal of the collected solid waste.

1.1 Introduction

Maharashtra Pollution Control Board has undertaken the project of Comprehensive profiling of Mithi River. Mithi serves as one of the major rivers in Mumbai flowing from Vihar Lake to Arabian Sea. Mithi has been treated as an open nallah by the nearby residents as well as industries. Though the river water is seldom used as a source of drinking water, after the 26th July 2006 floods, major concern were given to Mithi River and its environmental degradation.

For this project, the methodology includes assessment of pollution sources and estimation of pollution load around the catchment area along with suitable conservation and management strategies. In past, several studies has been carried out and published data available across various reliable institutes are referred in order to give an insight to the approach of assessing the pollution potential across the pre-defined domain of Mithi River. **Figure 1.1** shows the stretch of Mithi from Origin at Vihar Lake to Mahim Bay.

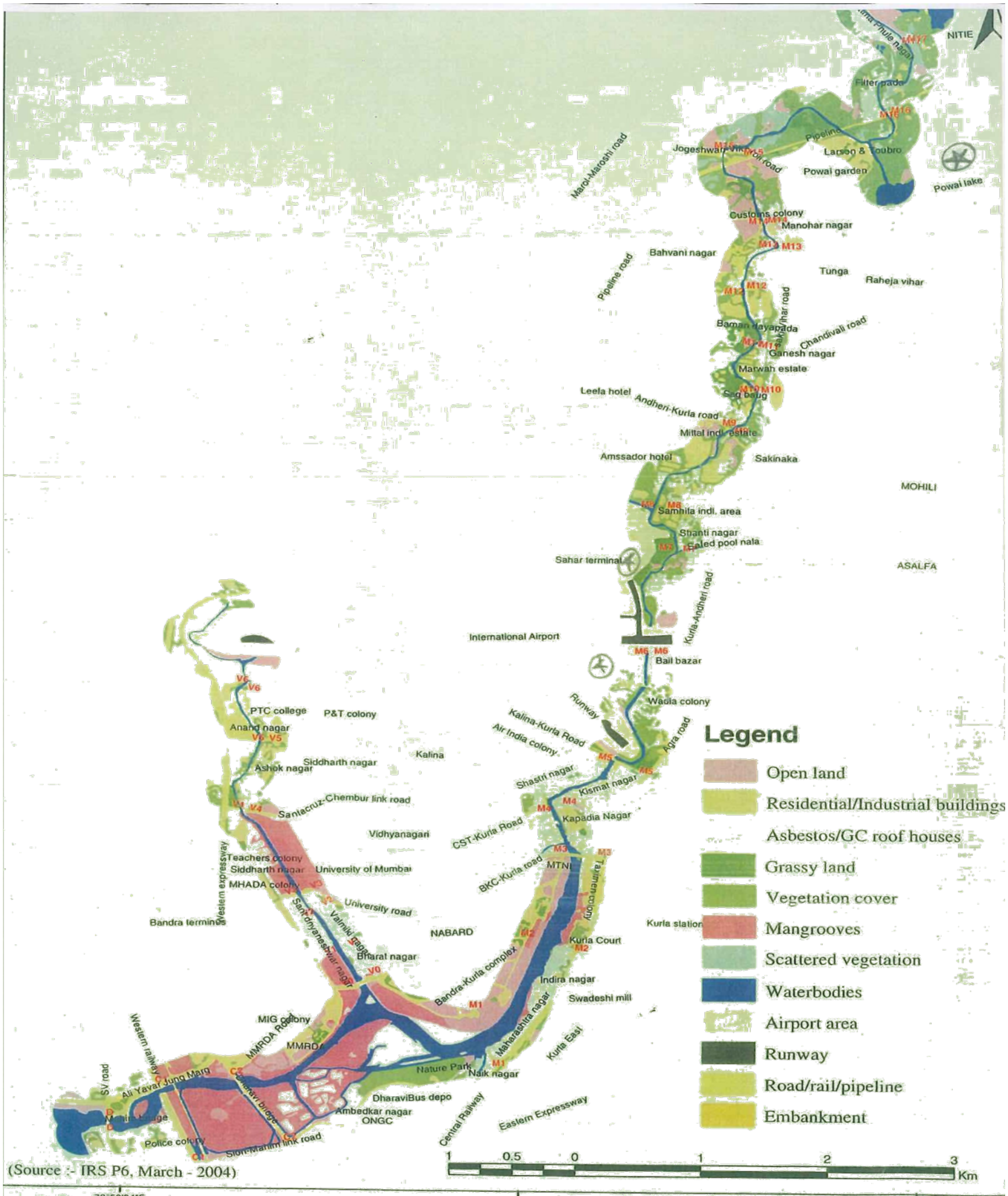
1.2 Probable Sources of Water Pollution in Mithi River

Though there have been several studies in the past regarding conservation and rehabilitation of Mithi River, efforts regarding understanding the sources and characteristics of inputs to Mithi River has been very limited. In fact the source profiling of all pollution points have been recently studied and elaborated by IIT, Mumbai which identifies about 9 major nallahs contributing to pollution of Mithi. However, it is prerogative of this study to go beyond the contributing nallahs up to the level of land and source surveys to understand the potential factors of contribution of pollution. Based on the baseline surveys, following are the prominent pollution sources observed by the surveyors which are generically elaborated as under.

1.2.1 Urban development

With the increasing scope of job opportunities and education in the city as well as its industrial growth especially in industrial sector causing in-migration and leading to exponential growth of population, demand for water supply has increased exponentially. About 70-80% of this water is disposed as wastewater (sewage). This sewage is partially treated and the untreated part of this

Figure 1.1 Location of Mithi River and Land Use base adopted from MCGM Report, 2006



(Source :- IRS P6, March - 2004)

Figure 2.6.2 Landuse/landcover across Mithi River/Vakola Nala course (200m buffer) - 2004

Wastewater is being disposed as it is in rivers harming the ecology and degradation of the river water quality. It was observed that there are about 5-6 lakh residential tenants around 200m RoW stretch of Mithi without any sewage treatment facilities that might contribute to direct discharges.

1.2.2 Industrial Wastewater

Mithi River stretch has been in discussion for habituating hitherto of industrial activities most of which are small scale enterprises and many of them are probably illegal and not listed in any of the departmental documents comprising from oil recycling / refining, dyes, tanning to barrel cleaning, etc. Most of the industries are known to consume the surface water in process and for domestic use and are not fully equipped with wastewater treatment facilities and thereby it cannot be ruled out that there may be several incidences that these wastewater forms one of the reasons for water pollution across the River though mostly mixed with domestic wastewater. To assess the ground reality of their existence and extent of water consumption and disposal, survey of industrial sectors along the stretch of Mithi was carried out. Out of the numerous industries located alongside the banks of Mithi, about 80 representative industries were identified &surveyed.

1.2.3 Resurfacing of Previously Deposited Pollutants

All the small scale unauthorized oil recycling units located in downstream of CST, MTNL &Kalina and leather tanning units that were once situated in Dharavi slums were known to be disposing raw wastewater generated from these activities in Mithi. Attempts have been made to control the pollution through shifting of certain activities, closure of several illegal establishments and regulation through policy and technology intervention since 2006. However, it is anticipated that the extent of accumulated pollution might have traversed through the banks to the waters and ultimately piled up in the sediments mainly via runoffs. The inherent property of these pollutants to resurface under the influence of phenomena of nature either physical or chemical may also be one of the sources of pollutant load in these sections of Mithi.

1.2.4 Solid Waste Dumping Scenario in Mithi River

In most of the stretches occupied by slum areas and few of the residential areas along the river stretches like those near Filterpada, Gautam Nagar, Dharavi slums, and others, people tend to dump the solid waste in the river practically treating it as an open dump. Situation is much worst during precipitation with the probability of leachate getting mixed with river water. Survey has revealed excessive dumping of solid waste in few stretches obstructing the river flow or bifurcating it into smaller streams within the wide width of the river bed also affecting overall aesthetics as presented in **Figure 1.2**.

1.3 Literature Review

Mithi River has been in the limelight of discussions and review since July 2005 cloud burst of Mumbai leading to massive disruption of life and property. Though MMRDA has been taking efforts every year through dredging and de-silting of river basin in certain stretches of known threat, rejuvenation of Mithi has not been upto desirable extent probably due to overcrowding and haphazard development / urbanization around the basin has been exponential. Numerous organizations have been working towards rejuvenation and several committees have been formed and requested to study the situation and suggest recommendations.

Table 1.1 represents a précis of all earlier major studies and the relevant portions of actions & recommendations to give a better insight of the problems of Mithi River and the thoughtful approach by strategists in terms of interventions proposed. The status of those findings and recommendations are beyond scope of this report but may as well form an important part of study.

1.4 Organization of the report

Chapter II details the methodology adopted while carrying out assessment and measurement of pollution sources. It outlines steps involved in reconnaissance by MPCB during and Post – Monsoon in-house studies as well as those adopted during Pre-Monsoon survey which enabled to identify probable sampling locations in Mithi River as well as all the nallahs entering Mithi as well as detailed survey for source identification. During sampling along the entire stretch of Mithi, about 243 samples were collected out of which 77 samples represent those from Mithi River, 73 nallahs were identified and sampled, 79 samples were collected from the identified industries along with 14 Blanks to be used for QA/QC protocol.

It also describes the selection of parameters and their environmental significance in order to determine the pollution levels. A brief outline to evaluate the relative criticality of the stretches through developing the criticality indices for each stretch is also defined. The chapter also briefs about the Receptor Modeling that was carried out to understand the correlation in different parameters under consideration.

Chapter III describes detailed physical & environmental setting of Mithi River which has been classified into 16 virtual stretches of 1km each for ease of representation and prioritizing management needs. From the point of Origin as an overflow of Vihar Lake to Mahim Creek where it meets the Arabian Sea, the entire stretch of river has been surveyed within an RoW of about 200m on either sides. Various features observed such as land use, physical environment, aesthetics, nallahs discharging into Mithi along with the physical measurements such as average width, depth of the river, etc. are delineated in **chapter III**.

Figure 1.2 Solid Waste dumping at various locations along Mithi River

Chapter IV deals with the assessment of Flow of Mithi River and all the identified and physically approachable nallahs. Flow in river as well as sources of pollution contributing the river were determined using conventional process of manually measuring velocity of water flow and dimensions of nallah / river.

Table 1.1 Summary of Studies and Recommendations regarding Mithi River

Sr. No.	Case study Report	Objective of the report	Action Plan/ Recommendations
1.	Model Studies on the Effect of Proposed Reclamation in Mahim Creek Report (1978) by Central Water and Power Research Station (CPWRS), Pune	Report pertaining to Bandra-Kurla Complex area studied the effect of reclamation in Mahim Creek and changes in drain system for development of Bandra Kurla Complex (BKC)	• The report recommended widening and deepening of the Mithi, sluice gates at Mahim Causeway and pumping of floodwater into creeks.
2.	Report of NEERI , 1996, Supreme Court Case (PIL)	Report delineated the impact of mangrove removal and reclamation of land in BKC area	• Report concluded that the mangrove removal in BKC area (based on satellite maps) will lead to flooding in the region. • Further, it was suggested that an environmental assessment of the area development should be carried out.
3.	MPCB Report on Mithi River Water Pollution and Recommendations for its Control (2004)	Mithi river water quality was studied to assess the pollution load	**Short Term Measures include:** • Immediate closure of all the unauthorized activities, which discharge industrial effluents, sludge, oil and chemicals. • Provision of proper garbage collection system to prevent citizens from dumping the same into the river. **Long Term Measures include:** • Plan for interceptor sewers on both the banks and provide Sewage treatment plants at various locations. • Dredge the entire length of Mithi river bed to improve its carrying capacity. • Provide proper garbage collection stations for the benefit of hutment dwellers.
4.	Report of CWPRS, Pune: 1-D Mathematical Model and Desk Studies for mitigating floods of the Mithi River (2006)	report suggests that the first two segments, (origin to Jogeshwari) and (Vikhroli Link Road to Sir MV Road) have steep slopes, which provide a swift discharge of water eliminating the chances of flooding. The downstream segments, however, have flat slopes and hence may cause	Report recommends following measures: **Bandra Kurla Complex (BKC) Area** • Providing a dredged channel of 60 m width from -2 m (with respect to Mean Sea Level or MSL) contour in the sea to Mahim Causeway bed level (dredged to -1 m) and removing existing rock over-crops. • Widening of the waterway from Mahim Causeway to Dharavi Bridge to 100 m. • Widening of Vakola Nallah from the earlier designed width of 40 m to 60 m.

Sr. No.	Case study Report	Objective of the report	Action Plan/ Recommendations
		flood.	• Deepening of bed level at Mahim Causeway to -1 m & at CST Bridge to +0.67 m. All the suggested cross sections of Mithi River up to chainage 10.5 km need to be provided with slopes of 1:1.5. Further upstream up to Moraraji Nagar, the required slope is 1:2. **<u>Additional Recommendations</u>** • Moderating the river course by replacing existing sharp bends with longer gentler bends. • Providing Non-return valves for cross drains. • Removal of temporary bridges with small waterways across the Mithi River and Vakola Nallah.
5.	Chitale Committee's Fact Finding Report for July 2005 flood of Mithi river (2006)	The report studied the causes of 2005 floods and also suggests control measures for future.	Report recommended following measures: • Stream gauging –measurement of flow (1 for 200000 population) should be based on catchment area, • Implement automatic rain gauges • Removal of obstructions/ constrictions –water pipes, drain pipes, cables • Study of the environmental impacts of MUIP / MUTP's reclamation and building projects in Mumbai including all the developmental projects undertaken by MMRDA and BMC.
6.	Development of Action Plan for Environmental Improvement of Mithi River and along its banks (2006) by Indian Institute of Technology (IIT), Bombay	Report includes assessment of all environmental aspects for 200 m stretch on either side of Mithi river and development of action plan for improvement of Mithi river along its bank.	Report recommended following measures: • Area should be immediately declared as Eco-zone • Hydrological continuity between east and west should be restored by providing structure for adequate passage of water. • Alternate storage system to make up for loss in Powai and Vihar reservoir capacity should be provided to take care of the run off. • To enhance the flow along river course, bridges/crossings should maintain the width of river either by reconstruction or repositioning of ducts and removal of debris from riverbed.

Sr. No.	Case study Report	Objective of the report	Action Plan/ Recommendations
			• Immediate stoppage of wastewater entering into river from all sources and diversion of wastewater to STP and then to river. • Industries to set up CETP. • De-silting of entire stretch of riverbed from D/S of Vihar and Powai lake up to BKC. • Provide properly engineered storm water drains. • Immediate stoppage of wastewater entering into river from all sources and diversion of wastewater to STP and then to river.

Chapter V elaborates the variations in the organic loads in Mithi River and that in nallahs. The survey carried out revealed various pollutant bearing inputs into river, hence it was essential to analyze the organic load in river and the identified nallahs. Major emphasis is given on the COD to BOD ratio which helps in predicting the pollution source; either sewage or industrial.

Chapter VI explains the trends observed in the physico-chemical parameters considered for the analysis of samples. These include Chlorides, sulfates, phosphates, nitrates along with the heavy metals such as Lead, Cadmium, Zinc, Iron, Manganese, etc. Along with these parameters, chapter briefs the variation in the concentrations of Phenols and MPN values analyzed for the samples.

Chapter VII outlines the criticality indices developed for each river stretch as well as for all of the identified nallahs. Color code is developed to represent the relative criticality of the stretches & nallahs; Red is indicative of highly / critically polluted and Green being the cleanest stretch in terms of parameter vis a vis prescribed Standards wherever applicable. Color map is developed on the basis of obtained results which is self-explanatory and elaborates the prioritized need of mitigation.

Chapter VIII briefs the adopted methodology and the consequent outputs of the Source Receptor Modeling carried out for various categories of analysis data i.e. river, nallah for organics and metals aimed at identifying components that are responsible for particular traits of independent or dependent variables that ultimately represent sources thereby achieving the main overlooked objective of previous studies i.e. understanding industrial v/s domestic wastewater contribution to Mithi River.

Chapter IX of the report deals with the conservation management strategies proposed based on the analytical data and criticality indices. In developing the management strategies, various aspects such as flow to be treated, land availability, extent of treatment required are taken into account. The principles of mitigation / management conservation are centered in 3 verticals i.e. At Source, In the path & End of Pipe either singly or in combination of each other. Citing of successful technologies that could be tailored and adopted for Mithi along with details of designs for industrial source effluent treatment is also outlined.

References

Adopted from website of MCGM citing Urban basic services in slums

Adopted from website of MCGM citing Strom Water Drainage

Adopted from website of MCGM citing Solid Waste Management

Chapter II

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Chapter II

Methodology

2.0 Background

This report is a compilation of the overall action plan for conservation of river Mithi. Some of the data represented have been previously studied by MPCB through baseline information gathering exercise regarding river pollution status during monsoon & post monsoon season. It has to be borne in mind that this report only forms a guideline for the methodology to be adopted in such cases and shall never be interpreted as standalone method for river conservation.

Ideally for a detailed cross-sectional study of the entire river stretch, the 15kms of river is to be virtually divided into 15 stretches, each of about 1 km length in order to effectively represent the cross-sectional data considering land-use patterns in RoW of about 200m on either sides of river, ease of interpretation and with the view of micro-level conservation planning which has also been attempted in the pre-monsoon studies carried out recently under the supervision and guidance of MPCB.

2.1 Baseline Survey of the Mithi Basin and RoW

In order to make the sampling convenient, two distinct and individual teams each for survey and sampling were deployed with sufficient manpower. Survey team carried out detailed information collection, sketching of sources, inventory, etc in each of the stretch and the nearby catchment areas, land-use, industries, etc. along with questionnaire administration whereas sampling team collected samples as well as prepared sketches of each sections to be used later for understanding specific issues of particular location and parallel transporting samples to laboratory.

Firstly, a survey team investigated and recorded data from catchment area (RoW), the land use (residential/commercial/industrial), pollution sources, their types, contribution and extent of potential impact on the river in that particular stretch finally leading to the sources. A questionnaire circulated to the survey team for the preliminary data collection is presented in **Annexure II -1**. This questionnaire will be used to obtain data from all the residing industries, residential areas as well as commercial areas. The survey also rendered identification of probable, accessible sampling points. Additionally, these sampling locations were compared with those identified by using Google Imaging for a more effective and complete strategy of deciding monitoring network.

2.2 Baseline Monitoring

MPCB has carried out monitoring of stretch of river at 12 different locations during the period of June 5 to 7 i.e. Monsoon of 2013 in order to assess the preliminary pollution potential of Mithi River using Grab sampling technique. Same has been repeated in January 2014 in order to compile seasonal variations during post Monsoon season. These sampling locations were approximately 2.5kms apart throughout the stretch of Mithi from origin to its convergence into Arabian Sea. Results of the same are discussed in subsequent Chapters.

Though these monitoring data helps understand the overall status of river pollution to some extent, a more rigorous sampling network needed to be established for cross-sectional studies that would help elaborate not only pollution in the river but also the source profiling, contribution of industrial vis-a-vis domestic wastes, dilution/flushing impacts in terms of tidal influence and thereby ultimately help prioritize stretches that need immediate interventions. The details of these studies are discussed in the following sections.

2.2.1 Sampling

Grab samples were collected using manual sampling method. Although the sample is from varied sources, it was envisaged that the composition of the samples would not vary over space and time due to monotonous & consistent source. Samples were collected for understanding diurnal variations wherever possible and also to accommodate working and non-working days of especially around industries in critical areas.

Several of the river stretches had bifurcated / split flows that do not cover the entire width of river and thereby it was essential to understand the flow dynamics in each of the stretches for desired measurements and sampling. Thereby a capped approach to sample both banks of river including bifurcated / split streams upstream as well as downstream was adopted essentially attempting representativeness of river in each stretch.

Though there were input nallahs in several stretches which were underground, piped, inaccessible or carrying miniscule wastewater, attempt has been made to overlook the characters of such nallahs and all those that were possibly within the reach of sampling were considered in this study. Several of those where flow measurements were impossible, samples were still collected for analysis purposes.

With regards to industrial samples in critical stretches, attempts were made to identify polluting industries with the help of MPCB officials on ground and selecting representative industries in each of these areas. Most of the samples were collected from outlets of ETP/STP wherever available in industries whereas raw samples for nallahs emanating near individual or cluster of industries especially those in unorganized industrial sectors such as those in Dharavi area were also collected.

2.2.1.1 Sampling Frequency and Duration

Further to already existing monitored data, a more thorough and detailed sampling was carried out for a fortnight during May,2014 in order to include pre- Monsoon seasonal variability thereby accommodating all the seasons during 2013 to 2014. During each of the season, sampling was carried out minimum twice or more at each location of river. Some locations which were not included as part of earlier sampling was also added in the latest one following exactly similar protocol of frequency.

2.2.1.2 Sample Containers

Polyurethane cans of 2-lit capacity were used for collection of samples. However, for the oil and grease samples, separate wide mouth glass bottles of 1-lit capacity were used. Samples for dissolved oxygen were collected in DO bottles during the earlier sampling whereas onsite measurements of DO, pH, TDS and conductivity were done during the latest sampling.

2.2.1.3 Number of Samples

Primarily, a three-fold sampling needs were identified i.e. first for analyzing pollution load in river stretch, second for understanding pollution inputs through nallahs entering river at various locations and third source categorization. However, a more elaborate objective of sampling & this study was to understand the contribution from various sources especially percentage contribution from industrial vis a vis domestic ones and thereby number of samples were also aligned with the needs of source receptor modeling which were computed as follows.

Taking into consideration a random variation in both the analytical procedure and the occurrence of a constituent at a point of sampling, the following formulae (Her majesty’s Stationary Off. London, 1980) shall be used to calculate the number of samples.

$$N \geq (ts / U)^2$$

Where:

N = Number of samples
t = student t- statistic for a given confidence level
s = overall standard deviation
U = acceptable level of uncertainty

Approximately 80-85 samples are required to be collected for statistically valid and representatively acceptable reporting with 95% confidence level and SD values of ±3 and acceptable uncertainty of 10%. The total number of samples collected during Monsoon of June 2013 was 18 whereas that during post monsoon of January 2014 were 14 @ approximately 2.5km stretch and that during the pre-monsoon study period of May 2014 is 243 as represented in **Table 2.1**.

Since the stretch of River is virtually divided in to 1km components, minimum of 5 samples were collected in each stretch depending upon the pollution sources in that particular stretch so as to incorporate status of upstream, downstream, confluence of entry of effluent, source potential, etc.). This formed the basis of Kaiser Meyer Olkin [KMO] test of sampling adequacy with a value >0.5 as acceptable & Bartlett's Test of Sphericity that are discussed in subsequent chapters.

Table 2.1 Sampling Domain and Numbers

Domain	Number of Samples	Frequency	Characteristics of Domain
River	June 2013 - 18 January 2014 - 14 May 2014 – 77	4 - 6 times @ each location	Up & Downstream, confluence points of major nallahs & visible industrial source discharges
Nallahs	June 2013 - 2 January 2014 - 2 May 2014 – 41	Once	Only major ones especially those contributing approachable and those that could be easily traced to sources
Vakola Nallah	May 2014 – 32	Once	Major domestic ones contributing to Vakola
At Source	May 2014 – 79	Once	Random Industrial Samples

2.2.1.4 Sample Preservation

Parameters such as DO, pH, TDS, conductivity and temperature were analyzed on site itself. However, secondary analysis of all these above mentioned parameters in laboratory was also done to support and quality check performance of on-site measurement equipments. DO samples were subsequently fixed by adding manganous sulphate and alkali azide iodide when onsite measurements were not done whereas for others, DO fixing was done in laboratory wherein all samples were ice-preserved. All samples were transferred to laboratory within 6hrsafter collection and subjected to analysis for the parameters known to vary with time.

However, the for heavy metal analysis, the samples were preserved by adding H_2SO_4 to make pH < 2.

All efforts were made to follow standard APHA/IS [APHA, 1998] methods for collection and preservation of samples.

2.3 Analysis

Collected and well-preserved samples were sent to MoEF approved Goldfinch Laboratory in Thane on daily basis whereas one co-locational sample from every stretch of river were transferred to MPCB laboratory for further analysis to characterize each of stretch. About 5% field blanks were also used as QA/QC check during the study period.

2.3.1 Sample Coding

For easy identification of sample in order to analyze it for its characteristics, a standard labeling system was established for water samples collected from river water, confluencing nallahs as well as the samples collected from industries visited during surveys.

2.3.1.1 Labeling of River Water Samples

River water samples were collected from each of the defined stretches and on either of the banks of river. Hence in order to specify the bank as well as stretch from where the sample is collected, it has also been incorporated in sample code as follows

i. For the samples being collected from bank 1 of the river, the sample codes will start from R1 where “1” is the first sample taken and so on.
ii. For the samples being collected from bank 2, the sample codes will start from R501 where “501” stands for the first sample taken from bank 2 and so on

2.3.1.2 Labeling of Confluencing Nallahs

Sampling of the nallahs entering into the river water was also carried out to understand the characteristics of incoming effluent.

For the samples taken from nallah on Bank 1, the sample code will be N1 where “1” refers to the first sample taken from the nallah on Bank 1 and so on. And for the nallah samples taken from Bank 2, the code will be N501 where “501” refers to the first sample taken from the nallah from Bank 2 and so on.

2.3.1.3 Labeling of Industrial Wastewater

For samples collected from industry situated on Bank 1 of the river, I1 will be the code where "I1" will refer to the first sample taken and so on. For samples taken from an industry situated on Bank 2, the code will be I2 and so on.

To record the details of sampling at each of the location and of each sample collection, **"Sample Description sheet"** was provided to the Sampling Team. This sheet served as a detailed information sheet regarding sample locations, sample code and other parameters that were to be observed and recorded by the sampling team at the time of sampling itself as presented in **Annexure II – 2**.

2.3.2 Parameters of Analysis

The selection of parameters for characterization is equally important and mainly depends upon the type of activity. In the present study, since it may involve industrial effluents, the parameters shall be selected depending upon their significance to the environment, toxicity levels, Pollution Control Board Standards for discharge of effluents, etc.

Table 2.2represents the parameters selected for characterization of the effluents with respect to their significance.

Table 2.2 Significance of the physico-chemical parameters selected for characterization

Parameters	Significance
pH	Affects dissolution of gases, existence of life forms
Suspended Solids	Affects treatment systems, blocks gills, reduces dissolution of gases
Dissolved Solids	Affects dissolution of gases, may be toxic depending upon the content
COD	Measure of Pollution load
BOD	Measure of biologically degradable pollutants
DO	Essential for the survival of life forms and degradation of the organic waste
Oil and Grease	Reduce sunlight and oxygen dissolution, toxic to biota
MPN	Represents fecal contamination from human excreta & thereby source of bacteriological related diseases

Along with the above-mentioned physico-chemical parameters, some heavy metals would be also selected for effective inorganic categorization of the effluents. The significance of heavy metals selected is given in **Table 2.3** [Krishna M., et. al., 1991].

Table 2.3 Significance of heavy metals selected for characterization

Metal	Toxicological significance
Cadmium	Chemical Cadmium may interfere with the metallothionein's ability to regulate zinc and copper concentrations in the body. Metallothionein is a protein that binds to excess essential metals to render them unavailable When cadmium induces metallothionein activity; it binds to copper and zinc, disrupting the homeostasis levels [Kennish, 1992]
Cobalt	Cobalt has been associated with inflammation of the larynx, cardiomyopathy, decreased body weight, and emphysema. Oral exposure can cause vomiting, cardiomyopathy, increased lung, and heart weight, renal tubule necrosis, and testicular degeneration [ATSDR, 2001b]
Chromium	The chronic adverse health effects are respiratory and dermatologic [Viessman and Hammer, 1985]. Effects that have been observed in humans are chronic tonsillitis, chronic pharyngitis, minor renal impacts, runny nose, and ulceration of nasal septum, stomach pains, cramps, ulcers, and lung cancer [ATSDR, 2001a]
Iron	Chronic exposure results in mottling of the lungs and benign pneumoconiosis. Some research is being done on the hypothesis that high iron stores (a genetic predisposition – hemochromatosis) may increase the risk of chronic disease including cancer and heart disease through oxidative mechanisms. Exposure to higher doses of iron resulted in interference with testosterone production in vitro [Goyer, et. al., 1995], stupor, shock, acidosis, hematemesis, bloody diarrhea, or coma [HSDB, 1999]. Iron plays a critical role in generating oxidative radicals that can ultimately damage the liver. Mild to moderate toxicity has been observed at blood serum levels above 350 µg/dl, and greater than 500 µg/dl was associated with coma, intestinal radiopacities, leukocytosis, and a high risk of liver failure [Fuortes, 1999; Goyer, et. al., 1995]
Manganese	Exposure to excess manganese may result in pulmonary inflammation following inhalation of particulates, Parkinson's-like symptoms, weakness,

Metal	Toxicological significance
	heaviness and stiffness of the limbs, muscle pain, nervousness, impotence, loss of libido, headache, muscle rigidity, tremors, mental disturbance, abnormal gait, etc. Mn exposure also leads to anxiety, nervousness, irritability, psychotic experiences, emotional disturbance, fatigue, lack of vigor, sleep disturbance, impulsive/compulsive behavior, and aggression hostility [Bowler, et. al., 1999]
Copper	Exposure to high levels of copper and its compounds results in burning pain in the chest and abdomen, intense nausea, vomiting, diarrhea, headache, sweating, shock, discontinued urination leading to yellowing of the skin. Injury to the brain, liver, kidneys and stomach and intestinal linings may also occur in copper sulfate poisoning [Clayton et. al., 1981]
Zinc	Inhalation of zinc has been associated with decrease vital lung capacity, nausea, increased leukocytes, impaired lung function, increased lung weight, inflammation of lung tissue, and increased pulmonary resistance. Oral exposure can result in gastrointestinal distress, diarrhea, increased serum amylase and lipase, decreased hematocrit, intestinal hemorrhage, anemia, nephrosis, and reproductive effects [ATSDR, 1994c]
Nickel	The most serious effects of nickel, such as cancer of the lung and nasal sinus, have occurred in people. Other lung effects include chronic bronchitis and reduced lung function. The International Agency for Research on Cancer has determined that some nickel compounds are carcinogenic to humans and that metallic nickel may possibly be carcinogenic to humans [IARC, 1990]

2.3.3 Reagents

All AR grade reagents and acids shall be used for the analysis

2.3.4 Methodologies

The relevant methodologies given by APHA/IS for the determination of these conventional pollutants shall be adopted [APHA, 1998]. A brief description of the analytical methods used for physico-chemical parameters is discussed below.

2.3.4.1 pH

This is a measure of the intensity of the acid or alkaline condition of the solution. It is a way of expressing the hydrogen ion concentration" It is important not only in the fields of water supplies, disinfection, chemical coagulation, water softening and corrosion control, but also in water treatments employing biological processes, and dewatering of sludges. They all require pH control within narrow limits. Because of the fundamental relationship that exists between acidity- alkalinity, a very high or a very low pH is injurious to the ecosystems. pH measurements will be done by using standardized pH meter (ELICO make) [APHA pp 4-86]. On-site measurement was done using Portable battery operated & calibrated pH Meter of Aquasol Digital make.

2.3.4.2 Total Solids, TS (ppm)

This is total of the suspended solids and Total dissolved solids as mentioned below.

I] Total Dissolved Solids, TDS (ppm)

After separation of the suspended solids, the filtrate was evaporated, dried at 100°C and weighed in a dish of known weight [APHA pp 2-56]. Also online sensor based TDS Meter was used in later part of study.

II] Total Suspended Solids, TSS (ppm)

Suspended solids were estimated after passing a known amount of thoroughly mixed sample through a pre weighed filter paper (Whatman 42). After thoroughly washing the residue and drying at 100°c, the solids will be weighed [APHA pp 2-57].

2.3.4.3 Conductivity

For measurement of water sample’s conductivity, portable and calibrated conductivity with range of 0 to 1999 µSof Aquasol Digital make was used.

2.3.4.4 Dissolved Oxygen (ppm)

When organic load of an effluent is very high, the dissolved oxygen content of the receiving water falls down very rapidly and consequently affects the aquatic organisms, which need oxygen for survival. Depletion of dissolved oxygen may also result from individual wastes containing inorganic reducing agents. When DO become NIL, septic conditions set in a foul odour starts emanating. For water in equilibrium with ambient air, saturation concentration of

DO decreases with temperature (e.g.; 14.6 ppm at 0^0C to 6.2 ppm at 40^0C). The analysis of DO is a key test for control activities and water treatment process control. APHA describes two methods for DO determinations, the Winkler Iodometric and the Electrometric method using membrane electrode. In the present work, the Winkler Iodometric method was followed. In this method, the DO was fixed in the presence of alkaline manganese sulphate solution containing potassium iodide, which on acidification liberated an equivalent amount of iodine. The estimation will be carried out by the titration with sodium thiosulphate using starch as indicator [APHA pp 4-129]. On-site measurements were carried out using the DO meter of Aquasol Digital make.

2.3.4.5 Biochemical Oxygen Demand, BOD (ppm)

BOD is amount of oxygen required by bacteria while stabilizing decomposable organic matter (interpreted as bacterial organic food) under aerobic conditions. What is generally determined as BOD at 20 °c and for 5 days represents about 70-80% of total BOD [Sawyer C. N., 1978]. Care is taken to preserve the changes in oxygen demand that would occur between sampling and testing by preserving all the samples at 4°c in a refrigerator at the earliest after the collection. The samples will be suitably diluted with aerated water, seeded and finally incubated for 5 days at 20°c in an incubator. The oxygen depletion at the end of this period will be measured as described under the method of DO determination. From the oxygen depletion value thereby obtained, BOD values will be calculated [APHA pp5-3].

2.3.4.6 Chemical Oxygen Demand, COD (ppm)

The COD determination is a measure of the oxygen equivalent of that portion of organic matter that is susceptible to oxidation by an oxidant. It also includes oxidizable inorganic substances. In this work, 0.25N potassium dichromate in acidic medium was used under reflux conditions for two hours. When the sample contains significant amount of chlorides, mercuric chloride to be added in excess to encounter the interference's of chlorides. From the amount of unreacted potassium dichromate estimated using by back titration with standard ferrous ammonium sulphate, COD value is estimated [APHA pp 5-14].COD is a measure of the oxygen equivalent of the organic content the sample. Most type of the organic matter is oxidized byrefluxing the sample with dichromate sulphuric acid mixture. Although relatively all the organic matter can be oxidized from the sample, some amount of the oxidizing agent is also used for oxidizing the chloride content of the sample This introduces uncertainty in the measurement of COD especially when the concentration of chloride is very high in the samples to be analyzed.

2.3.4.7 Heavy Metals

In case of the heavy metals, WET DIGESTION method has been adopted [Sawant A. D., 1995] using closed dissolution system. 250ml effluent sample is to be pre-concentrated through evaporation using conc. HNO_3 on a hotplate. When the volume was reduced to about 10 ml, it was treated with 5ml + 5ml + 5ml concentrated aqua regia. These treated samples were evaporated to dryness avoiding charring. The samples were evaporated to dryness by adding 1ml concentrated perchloric acid to remove the traces of bound organic residues. Samples were then extracted with 2M HNO_3. An acid blank was prepared simultaneously and the samples were analyzed using AAS against the blank.

2.4 Data Collation

Information from various local and regional sources / agencies has been gathered and collated in the present report.

Literature survey and references already gathered from various reports available with government agencies and internet has been represented with most important outcomes in previous section. It is proposed to survey surrounding areas of Mithi RoW via administering a Questionnaire to all locals to collect information/data on water supply, wastewater generation, collection, treatment and disposal. Similar exercise was carried out to collect information from all the concerned departments, BMC, MPCB, industries, residential and commercial complex surrounding the area, etc.

Equally interesting, advanced method of surveying using satellite support through Google Earth Imaging has been adopted to study land-use patterns and discharge points into Mithi River through virtually dividing Mithi into 16 components of 1km each. Data collated from the same is discussed in the subsequent Chapters of this report.

2.5 Data Processing

The collected data is scrutinized, compiled and processed to adjust for inconsistencies and to obtain area-wise status of water supply, wastewater generation, pollution sources, treatment and disposal including short term & long term measures to be adopted by all the concerned so as to improve river water quality.

2.6 Criticality of Mithi River

Attempt has been made to develop Mithi specific Criticality Indices to be applied to each stretch to represent relative & in comparison to Discharge Standards within the 15km river along with providing significant environmental determinants of every stretch. Weights are assigned to each parameter depending on its environmental significance in terms of pollution potential, toxicity, background concentration, Desirable Standards and other such review characteristics using Analytical Hierarchical Process. These weights are extrapolation of best engineering judgment based on experience of authors and can be surely challenged. Though the absolute numbers can be questioned by one and all, the concept and finality of such index needs to be considered in holistic way for assessment of relative pollution in Mithi River’s virtually classified stretches. **Chapter VII** describes entire process of Criticality in much more details along with interpretation of outputs of such attempt.

2.7 Source Receptor Modeling

One of the most important facets of this particular study is to evaluate the contribution of domestic and industrial wastewater into Mithi River. Conventional methods of COD/BOD ratios may not be a universally accepted & standalone function of wastewater characterization especially in dynamic surface water body conditions especially those under geologic leaching, high turbulence and extensive tidal influence such as Mithi River. On the other hand, similar known methods such as ground truthing through physical surveys may also not be possible in this particular case due to the vast area of influence, enormous wastewater entry points / inputs to Mithi River, many of them being piped and underground. Physical surveys would be extensively resource consuming and difficult knowing the extent of areas connected to Mithi River.

Realizing these facts about Mithi, the authors of this report have resorted to non-conventional yet globally trending & scientifically acceptable method of Receptor Modeling. Though the best approach of use of receptor models would be Mass Balance Studies, the authors are aware that within the limited resources and time & also that only major source classification of domestic v/s industrial needs to be evaluated, attempt has been made to use Principal Component Analysis [PCA] through Data Reduction with aid of Statistical Package for Social Studies [SPSS] as a source receptor model. The detailed methodology and concepts used in interpretation of the model outputs is discussed in **Chapter VIII** of this report.

Chapter III

List of Figures

Chapter III

Environmental - Physical Setting of Mithi River

3.0 Background

Originating at Powai, Mithi River is the convergence of water discharges from Powai and Vihar lakes. From Powai, it enters the Arabian Sea through Mahim creek traversing amidst industrial as well as residential premises. It is assumed that the residential areas across the Right of Way of Mithi and especially in the slums aligned at both the banks of Mithi, contribute towards the major raw sewage discharge in the river water. It is anticipated that this has resulted into severe pollution of the Mithi threatening the ecology as well as the aesthetic aspects of the river. Also, the dumping of garbage, scrap materials has reduced the carrying capacity of the river making it stagnant in some of the areas adding to its deterioration.

Mithi River passes through Powai, Saki Naka, Kurla, Mahim flowing through a distance of about 15kms where it meets the Arabian Sea at Mahim creek as represented in **Figure 3.1**. The river is narrow in initial stretch, but it widens gradually and is widest at Bandra-Kurla Complex. Mithi River is under the tidal influence of Arabian Sea at west coast. This tidal influence can be observed in river flow for about more than 5 kilometers from Mahim towards Vakola & Santacruz Airport.

Figure 3.1 Location on Reference Map of Mithi River & the Study Area

3.1 Physical Setup of Mithi

For the detailed study, whole course of Mithi was virtually classified in 1km stretches. Initiating from Vihar Lake, where the origin of Mithi is located, virtual stretches have been marked up to Mahim where Mithi converges into Arabian Sea. At Vihar Lake, latitude is 72°53’57.97” E and longitude is 19°08’26”N. **Annexure III - I**present the setup of Mithi from point of origin to Mahim.

As presented **Annexure III - I**, the width of Mithi River is very narrow at origin at Vihar Lake and it increases gradually as the river flows towards Mahim. A baseline survey was carried out which enabled the sampling team in identifying the probable sampling locations along the river stretch as well as in locating the industries in all the stretches as discussed in subsequent Chapters.

3.2 Stretch-wise Setup of Mithi

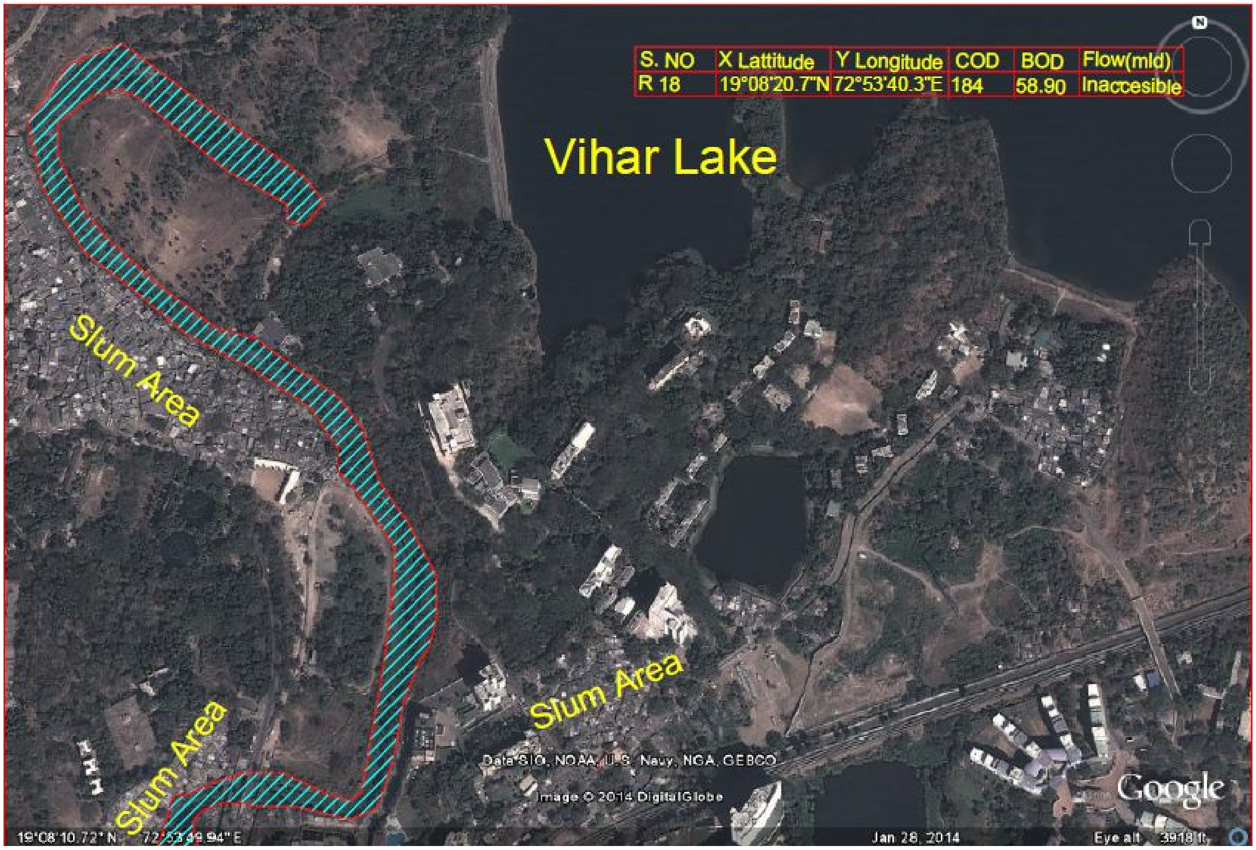
Virtually, in all 16 stretches were made and survey was conducted in each of the stretch. Survey included detailed observations so as to identify major pollution source and critical parameters those require more emphasis from pollution mitigation aspects. Information gathered through the surveys is briefed stretch-wise in the following discussionsthis chapter.

3.2.1 Stretch I – Vihar Lake to Filterpada

Stretch I define the origin of Mithi as the overflow of Vihar Lake and Powai Lake. In the stretch, the width of river is very narrow and it gradually increases as the river flows. Average width of the river is found to be about 20 m. **Figure 3.2** represents Google image of Stretch I

Along the RoW of 200 m along the river stretch, three thickly populated slum habitations are observed. According to the survey, about 2000-3000 is the population in those three slum habitations. In this particular stretch, the river flows as an open nallahwithout channeling as seen in some parts of Mithi. Flow of the river is so miniscule that flow could not be measured at the sampling location due to miniscule levels.Along the river stretch, direct discharge of sewage in river water has resulted into severe eutrophication, which in turn has made the river flow marginal & inappropriate for measurements as seen from **Photoplate III – 1**. Dumping of solid waste is another issueprominent in this section. Residents of the nearby slums dump the solid waste into river that causingflow obstructions.

Figure 3.2 Stretch I Vihar Lake to Filterpada



According to the preliminary survey, the discharge of sewage from the slum areas is not properly channelized in the slum area that forms the only source of pollution here.There are no industrial activities observed in this stretch. Along with solid waste dumping and discharge of sewage, open defecation along the river banks is also one of the prominent features observed. Wash the cloths (laundry), open bathing are other sources of grey water discharge contributing towards potential pollution load.

3.2.2 Stretch II – Filterpada to Gautam Nagar

Stretch II begins from Filterpada slums and extends up to the downstream of the Gautam Nagar Bridge. Compared to Stretch I the width of river is increased in stretch II averaging to about 24m though varies from about 14 m to 35 m.Several water pipelines are a prominent physical feature of this section as shown in **Photoplate III - 2**.Gauatm Nagar essentially inhabits slum area with about 500 tenements harboring about 2000 to 3000 residents.

Figure 3.3 Stretch II Filterpada to Gautam Nagar

There are open earthen channels without any concrete banking till almost half of the stretch. However, almost 500m on either side of the Gautam Nagar Bridge on the river both banks are lined with RCC walls. Flow of the river increased as compared to Stretch I. At upstream, the flow river is about 2MLD whereas at downstream it is about 4.7MLD due to several waste discharge streams on way from the origin to this point that were not visibly or otherwise accessible.

Though there are numerous nallahs entering Mithi especially forming rivulets from underground channels in later half of Gautam Nagar, only the major ones physically accessible was surveyed revealingamounting to a total of 7 nallahs. Out of 7 nallahs, 6 of the nallahs are on left bank whereas the other is on right bank. It was observed that those 7 nallahs are all sourced from slum areas and mostly carrying sewage. Flow and the environmental characters of those nallahs are discussed in Chapters IV,V and VI of this report.

Similar to Stretch I, this stretch too severely eutrophicated due to discharge of untreated sewage.Dumping of solid waste is again a prominent feature in the Gautam Nagar slum area. During discussions with residents of slum areas, it has been brought to the notice that earlier there were separate community toilet facilities provided by Municipal Corporation in this area for men and women dwellers. However, over a period of time those for Women have been tampered and thereby only one of it remains used thereby leading to open defecations. Similarly, survey reveals that door to door solid waste collection system which is no more functional and thereby dwellers are left with no other options but to dispose of the same into river.

There is a prominently located and activelarge scale batching plant downstream of the right bank beyond Gautam Nagar Bridge which was observed discharging raw effluents directly into Mithi.

3.2.3 Stretch III - Gautam Nagar to JVLR Bridge

From Gautam Nagar, the river flows through the JVLR area withan average width of river being 25m. The river is narrow upstream and gradually increases downstream ranging from 18 to 31m whereas water flow is restricted only about 15m on the left bank section. **Figure 3.4**shows the path of river in Stretch III.

Figure 3.4 Stretch III Gautam Nagar to JVLR Bridge

S. NO	X Lattitude	Y Longitude	COD	BOD	Flow(mld)
R 9	73 28'36.27"E	19 13'01.91"N	62	13.8	5.760
R 17	73 28'36.27"E	19 13'01.91"N	62.00	21.70	Inaccesible
N 12	72 53'48.9"E	72 07'57.0"N	133	29.3	0.04
N 13	72 53'48.9"E	19 07'57.0"N	86	18.8	0.049
N 14	72 53'48.9"E	19 07'57.0"N	514	138	0.216
N 509	73 28'40.4"E	19 12'00.8"N	775	260.5	0.810
R 508	73 28'40.4"E	19 13'30.8"N	71	20	7.200
R 509	73 28'40.4"E	19 13'30.8"N	139	54.4	9.969

As seen in most of the river stretches till now, slums form prominent habitation on one of the banks of JVLR Bridge and Vettar Patta slum. Discussions with locals reveal 350 tenements in 2 prominent slums with approximate population amounting to be around 2500. Both banks of the river are prominently walled with RCC and several underground pipes discharge effluents into the river as shown in **Photoplate III - 3**.

Flow of the river gradually increases from upstream to downstream as 4 major nallahs identified add up from the nearby residing areas. Three of them are on left bank whereas the fourth is on right bank of the river. This area is prominently connected by discharge from nearby SEEPZ industrial area. There is also a large scale RMC plant which is continuously discharging ample volume of raw wastewater into Mithi. Buffalo harboring sheds(Gothas) discharging raw cow dung waste from 3 such prominent ones are mixed with flow from MIDC area and directly discharged into right bank of downstream of Mithi in this section. It seems that the nallahson left bank carried sewage from nearby dwelling slums. This stretch being connected to the huge MIDC area of SEEPZ, representative industries of MIDC along with common STP was identified and monitored. Though most of the large scale industries had effluent treatment plants, it was observed that several of the small & medium scale ones especially jewellery manufacturers lacked wastewater management infrastructure and some of those which had ETP were not in operation.

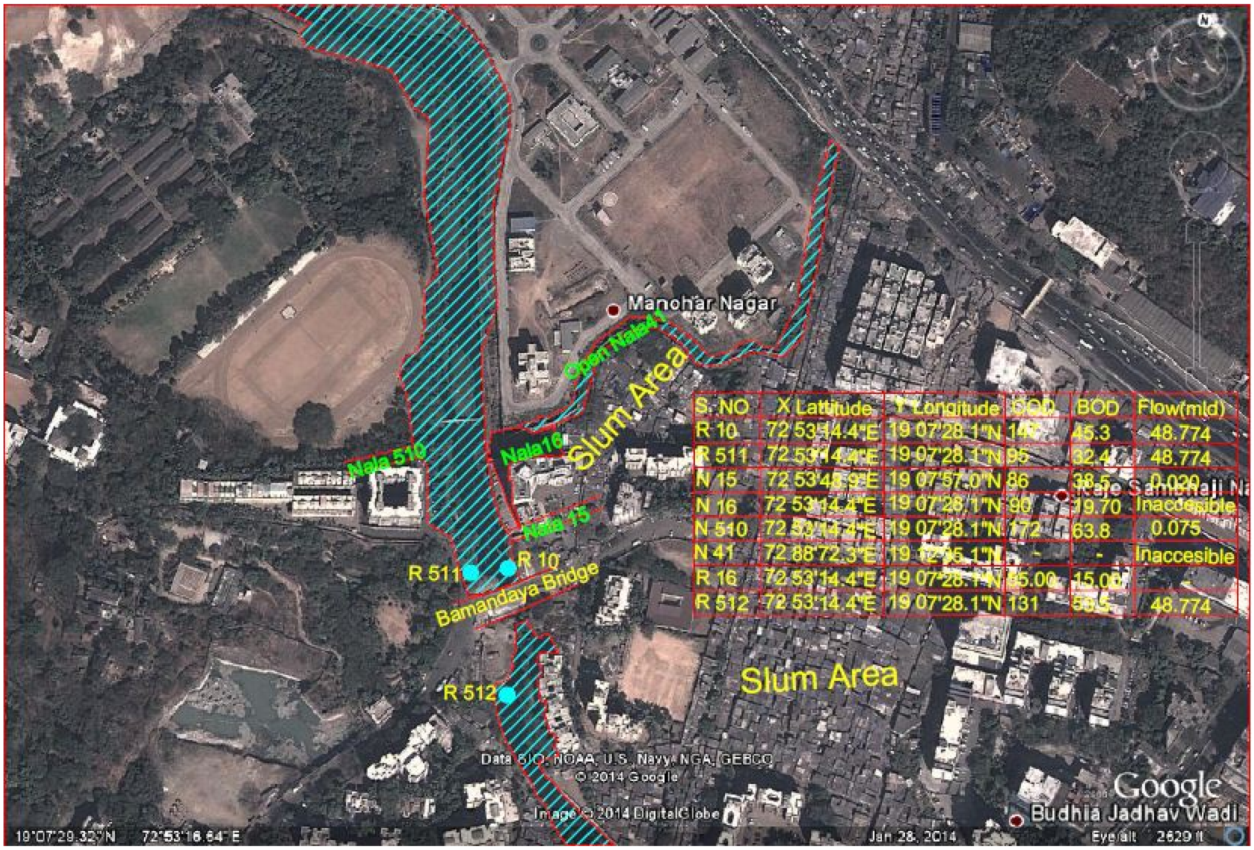
Comparatively only few patches of this Stretchwere found to be eutrophicated though open defecation is again an underlying feature. Solid waste dumping resulting into heaps segregating / bifurcatingriver flow especially near the JVLR Bridge into effective streams of 15m each.

3.2.4 Stretch IV – JVLR Bridge to BamandayaPada

Stretch IV originatesfrom downstream of JVLR Bridge and traverses up to the residential area of BamandayaPada with width ranging from 17m to 37m, averaging about 32m.**Figure 3.5** represents the Google Imagery of Stretch IV.

BamandayaPada is a mostly residential area with several housing complexes surrounding the 500m stretch across the bridge where sampling was carried out as presented in **Photoplate III – 4**where there are two prominent residential complexes viz. Nilgiri Towers and Customs colony both having septic tank and discharging domestic sewage through underground pipeline into Mithi on either banks of the river. Along with those complexes, Shankar Nagar Aadiwasi slumis located in this area downstream of the bridge. Customs colony comprise of 126 tenements with population of 1000 whereas Nilgiri Tower harbours800 tenements in about 111 flats. In the Shankar Nagarslum area, the population is expected to be around 3500.

Figure 3.5 Stretch IV - JVLR Bridge to BamandayaPada



4 major nallahswere identified entering river along source from slums as well as the residential complexes though it is expected that several of them may have joined the river along 1km stretch during its path from JVLR as reflected in higher flow than upstream. A nallah from Manohar Nagar on the right bank of river, additional two nallahsfrom sources that could not be verified, one nallah is enters the river from left bank.

Twoindustries had been identifiedin Stretch IV during the surveys which are AVK – Ford and The Go discharging treated effluent into public sewer. Since most of the housing complexes are well to do with, solid waste dumping was not at all an issue though downstream slums do have practice of disposing household inert and plastics in some part of the river. The extreme upstream of river shows high eutrophication though the flow past this section is mostly unrestricted.

3.2.5 Stretch V – BamandayaPada to KBM Compound

Stretch V Starts at the downstream of BamandayaPada Bridge and extends up to the KBM compound Bridge which is mostly addressed as industrially active area of Mithi as presented in Google Image (**Figure 3.6**).

Width of river increases as it traverses from upstream with average width of about 20m reaching maximum width of about 52m near KBM compound Bridge. Residential areas at Raje Shivaji Nagar and Ashok Nagar harbours about 1000 people in addition to 500 slum tenements amounting to about 2500 slum dwellers in this stretch.

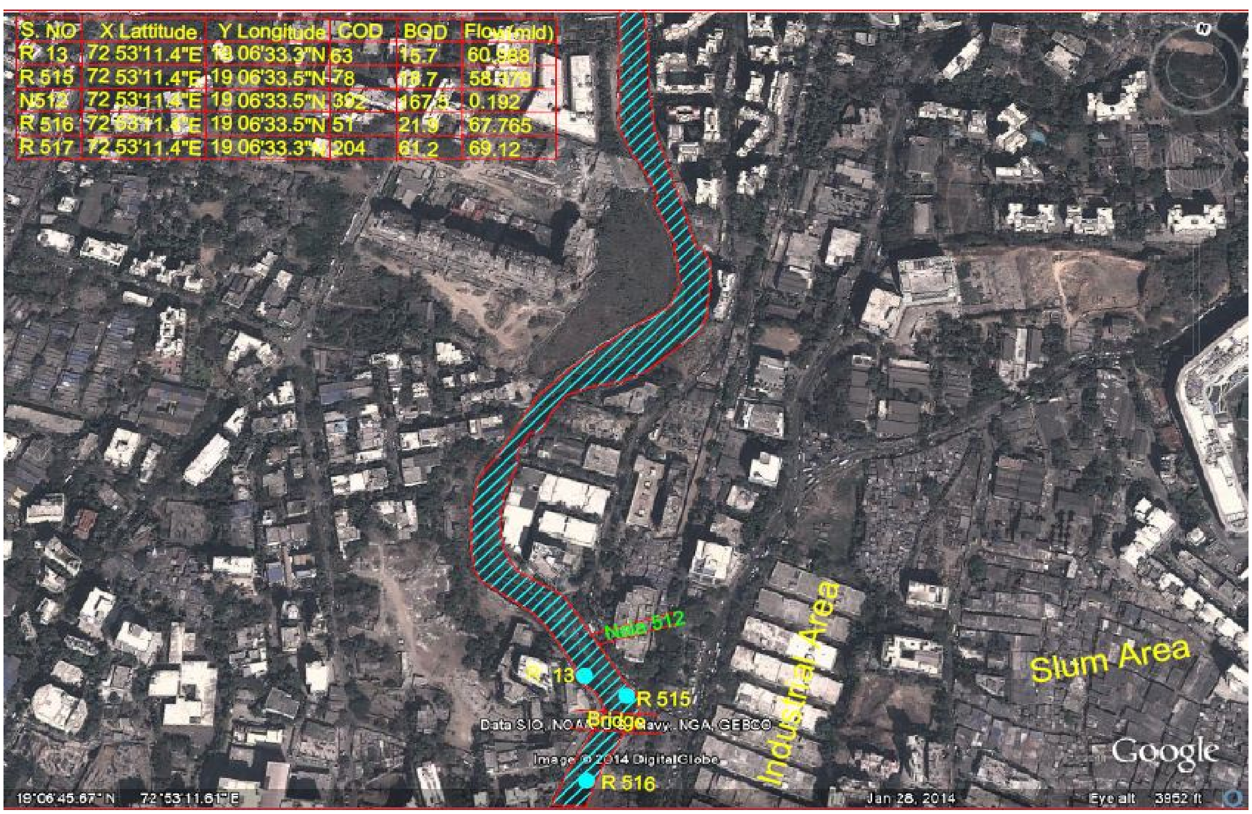
Figure 3.6 Stretch V –BamandayaPada to KBM Compound

Underground piped flow contributing to extremely dark coloured visually appearing raw effluents from KBM Compound were observed that harbours several small scale unorganized as well as organized industrial units. Out of the several ones within KBM premises, few representative units were identified for survey purpose that included3 major referred as laundry &dry cleaning units but actually possessing bleaching & dyeing processes intermittently discharging extremely dark coloured visually appearing raw effluents into the right bank of river through underground pipelines in addition to wastewater being discharged from surrounding restaurants on to the left bank of river. The downstream of KBM Compound had several water discharges through open and closed pipelines mainly contributing to the domestic wastewater as shown in **Photoplate III – 5**. There were several other sources contributing in various sections of upstream of KBM Compound such as L&T, Pepsi Aquafina, 21 Honda – 2 Wheeler Washing, Gen Next – 4 Wheeler Washing centre, Chandra Cleaners, Appat Chandrat, Super Cleaners, M.J Chemicals &Jayshree Metals that were also identified and surveyed revealing extreme variety of industrial activities around this stretch.

3.2.6 Stretch VI - KBM Compound to Marol

Stretch VI virtually originates downstream of KBM compound and terminates at Marol. Marol is known to be an industrial area also comprising of several residential clusters. The industrial area is mostly situated at the downstream of the stretch near the Marol Bridge. As shown in **Figure 3.7**, the river in this stretch has average width of about 10m to maximum width is measured to be 20m along the river path.Flow of the river is increasing at the downstream mainly due to underground discharge sources entering the river as shown in **Photoplate III - 6**.

Figure 3.7 Stretch VI - KBM Compound to Marol



Limited survey in the area of upstream of the stretch revealed residential area with about 2000 population in approximately 300 slum tenements.In the stretch, only one major nallah was visually identified on the right bank of the river though it is surely anticipated that there would be several other underground nallahsthat are contributing to river flow. In the Marol area, 10 out of the many existing industries were surveyed as representative units comprising of automobile units, jewellery, Pidillite, Seven Hills Hospital, Wah Bakery and others for understanding flows and contribution into Mithi River. Though several of them had ETP units such as Wah Bakery &Pidilite, other small scale unit's especially automobile washing centre & jewellery discharged raw effluents into the river. Very limited eutrophication was observed along with walled banks restricting solid waste dumping and open defecation in this section of river.

3.2.7 Stretch VII - Marol to Sakhinaka

The Stretch VII starts at downstream of Marol Bridge and terminates at Sakhinaka. **Figure 3.8**shows width of river decreasing from upstream to downstream ranging from 20m to 10m & an average of about 15m.

Figure 3.8 Stretch VII - Marol to Sakhinaka

Flow of the river increases from upstream to downstream mainly due to 6 major nallahsidentified & surveyed entering the river. Out of 6, four nallahs are located on right bank of the river whereas two are on left bank.

Sakhinaka area represents mixed land use withresidential, commercial and industrial areas identified.Few major industrial units located upstream of the river on the left bank while the residential area is situated at the downstream of stretch. Around 400 slum housing is also witnessed in the residential area harbouring population of about 4000-5000. In the industrial area, 5 industrial units have been identified during surveys which include automobile unit, a chemical industry unit and dry cleaning / laundry. Hotel Five Spice and Mittal complex – a small IT park were identified as commercial units& surveyed along with sampling.

No prominent eutrophication was observed though the flow of river was again segregated due to mounds of soil & vegetation downstream Sakhinaka Bridge. Dumping of solid waste is minimal &river flows without any obstructions in the path. Being majorly an industrial and commercial area, open defecation is not observed in this stretch as presented in **Photoplate III –7**.

3.2.8 Stretch VIII - Sakhinaka to Domestic Airport

From downstream of the Sakhinaka, the Stretch VIII extends up to the downstream of Domestic Airport.**Figure 3.9**reveals that width of river decreases from upstream of 40m to downstream of 25m. Flow of the river is found to be decreased a bit from upstream to downstream probably due to crude method of measurement.

Very limited eutrophication was observed in this stretch and the river flow is continuous without any obstacles. One prominent nallah sourced from outlet of STP of Airport enters Mithi in this region. It is an area with mixed land use harbouring many residential and several unorganized industrial clusters on either banks of river. Industrial area is mainly represented by logistics including mega units of movers and packers.

In the RoW of 200m in this stretch, neither open solid waste dumping nor Open defecation was observed. Some of the important features of this stretch is presented in **Photoplate III –8**.

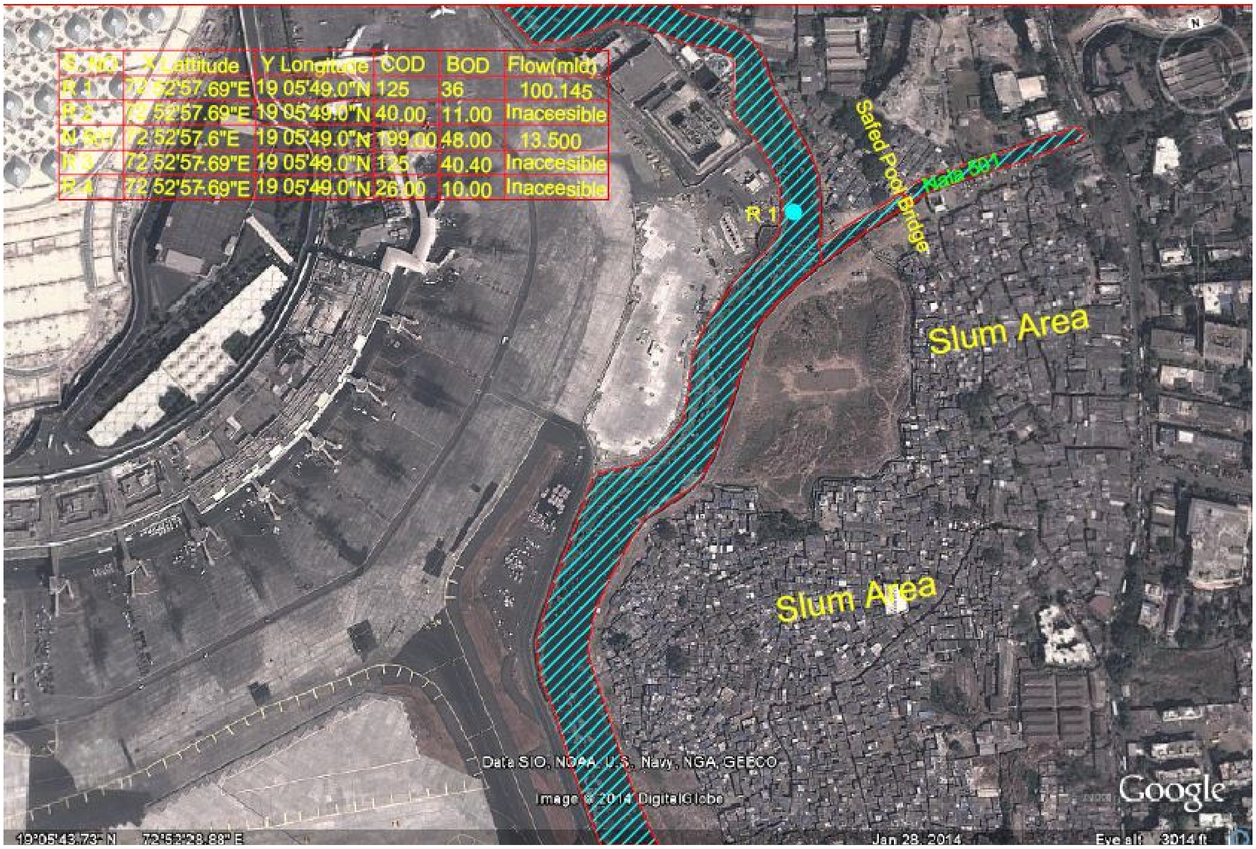
Figure 3.9 StretchVIII - Sakhinaka to Airport

3.2.9 Stretch IX - Airport to Safed Pool

Stretch IX represents the confluence of Safed Pool open nallah into the river. This is one of the major input nallahs located on the right bank of the river and contributing to its hydraulics. **Figure 3.10**represents the Google Image for Stretch IX depicting that the width of river is increasing from 23mupstream to about 40m downstream with an average width of about 36m. On the right bank of the river, two thickly populated slum establishments are observed with population of about 5000-6000.

Open nallahs flowing from the Safed Pool area is expected to be carrying sewage as well as industrial effluent from the nearby slums and industrial units. Almost dark black colored wastewater is observed in the Safed Pool nallah. There were hundreds of small rivulets adding to the Safed Nallah across its length though within the limited survey of just 25m, almost 15 to 20 inlets through piped underground sources entering RCC walled banks of Safed nallah were identified as presented in **Photoplate III - 9**.

Figure 3.10 Stretch IX - Airport to Safed Pool



In Stretch IX, two representative industries were identifies during the survey which include engineering unit named Pentex Engineering and a Soap Manufacturing unit.

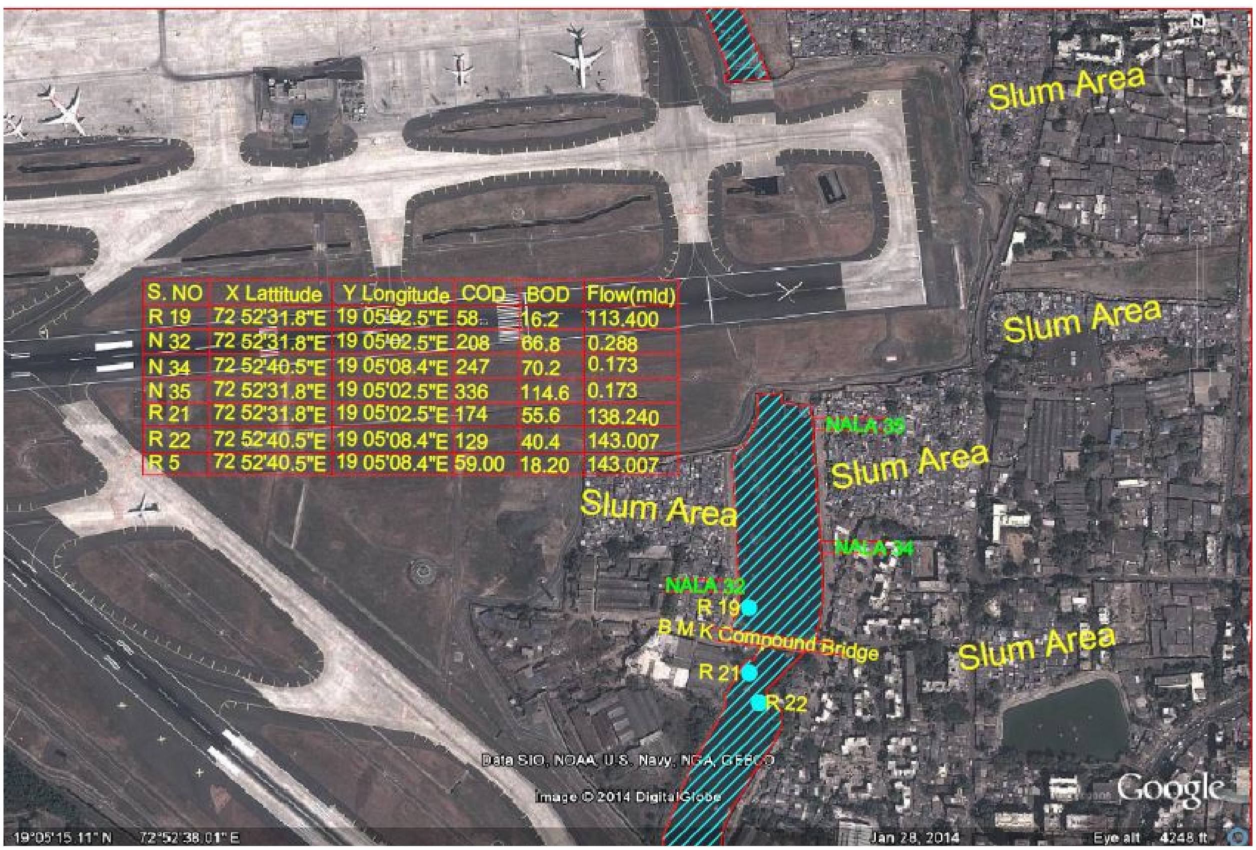
This nallahwas influenced heavily with flow ranging from depth of 0.3m or more in several part of the nallahthereby causing turbulences within itself and also at convergence into the river thereby restricting eutrophication in the centre of river whereas patches of vegetation were observed on either of the banks that are RCC walled. The slums dwellers were provided with toilets and solid waste collection facility in this area thereby the river seemed to be free of such mal-practices as observed in the earlier stretches of river.

3.2.10 Stretch X - Safed Pool to BMK Compound

Stretch X virtually starts from downstream of Safed Pool and ends at BMK Compound Bridge as shown in**Figure 3.11.**The average width of river in this stretch is about 20m and is consistent throughout the 1km stretch. Visually it was observed that the flow increases from upstream to downstream.Approximate depth of the river was observed to be approximately 0.3m and this is probably the most uniformly distributed stretch of river across its width (**Photoplate III – 10**).Thickly populated slum establishments, Sandesh Nagar and Kranti Nagar are located on either sides of river. In all about 5000 slum tenements are expected to be housed amounting to a population of approximately 35000. This is a purely residential area with no signs of industries as confirmed during survey.

Three prominent nallahsenter into the river out of which 2 of them are located on the right bank. Being a residential zone, it is believed that these nallahswould carry the sewage from the slums.All nallahswere open earthen ones though the river embankment is completely RCC walls along both its banks.

Figure 3.11 Stretch X Safed Pool to BMK Compound



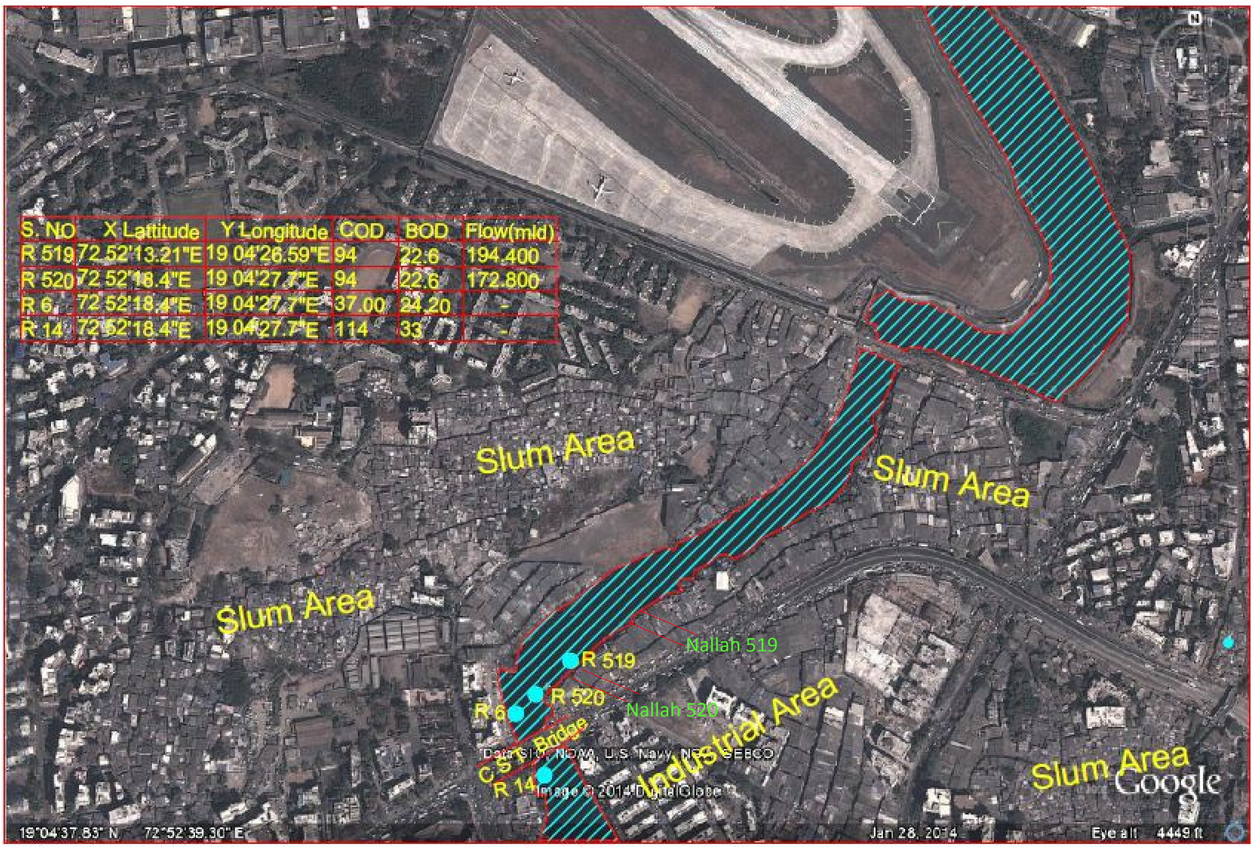
3.2.11 Stretch XI - BMK Compound to CST Bridge

Stretch of Mithi from downstream of the BMK Compound to the CST Bridge is referred as the Stretch XI. **Figure 3.12**shows the Stretch XI indicating width of the river to increase from 42mupstream to 53m downstream of river. Average width of the river is approximately48m.

Visually it was observed that flow of river at both upstream and downstream does not vary much. Depth of the river in this stretch is about 0.17m with flow of water 15m within the RCC embanked walls presented in **Photoplate III - 11**.

Survey carried out along 200m RoW reveals mixed land use in this stretch. Slum establishments are observed at the downstream of the stretch i.e. representative survey of Kismat Nagar and Kapadia Nagar inhabiting population of about 5500.

Figure 3.12 Stretch XI - BMK Compound to CST Bridge



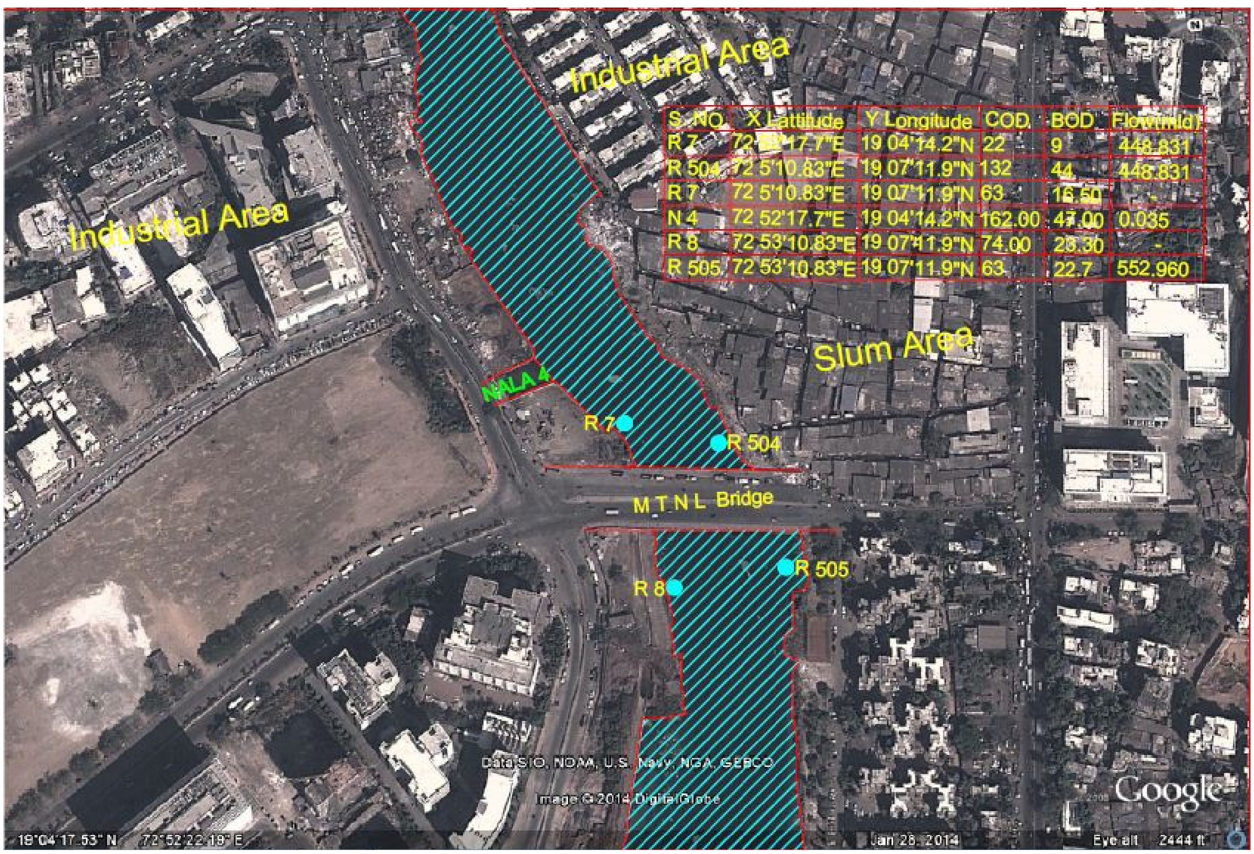
In this stretch, two prominent visible nallahswere observed carrying black coloured wastewater probably coming from the large industrial zone mainly unorganized.Few of industries are scaling from large to extremely small units at the downstream of the stretch. Various types of industries such as bottle & drum washing, wire processing, chemicals manufacturing and others were identified but sampling could not be carried out in this are due to security reasons.

River in this stretch has been provided with the RCC walls on the both banks.There was absolutely no eutrophication neither solid waste dumping observed in the river in this stretch. This part is the last portion under the tidal influence.

3.2.12 Stretch XII - CST Bridge to MTNL Bridge

Stretch XII virtually begins at the downstream of the CST Bridge terminating at MTNL Bridge. **Figure 3.13** represents the Google Image of Stretch XII clearly pointing out that the width of river remains unchanged in entire length of this portion. Average width of the river is approximately 80m at both upstream and downstream of the stretch. Average depth observed in the stretch is about 0.4m.

Figure 3.13 Stretch XII - CST Bridge to MTNL Bridge



On the left bank of the river, industrial area was identified whereas the right bank houses residential areas.Survey of representative areas reveals about 2000 population being harbored near the MTNL Bridge area in approximately 250 flats in the residential complexes therein. In the industrial area, survey was carried out in representative industryof United Metal industries dealing in scrap activity. Several other manufacturing units such as cement boards, resale of furniture and others mainly housing dry processes were observed in this section.

RCC wall embankment is provided only on the left bank.Due of the tidal influence, high salinity &turbulencesno eutrophication was observed. Solid waste dumping and open defecation are not carried out in this stretch which makes the river flow unrestricted as shown in **Photoplate III - 12**.

3.2.13 Stretch XIII - MTNL Bridge to Bandra - Kurla Complex

The stretch of Mithi from MTNL Bridge to BKC area is referred as the Stretch XIII as shown in **Figure 3.14**. It can be observed that width of the river is increases from 156m upstream to 426m downstream computed from Google Image. However, severe eutrophication is observed downstream of the river where the flow gets fragmented near the eutrophicated area. Hence, it can be inferred that even if the width of river visually looks large the effective width through which the river water actually flows is about 80m as presented in **Photoplate III – 13**.

Figure 3.14 Stretch XIII CST Bridge to MTNL Bridge

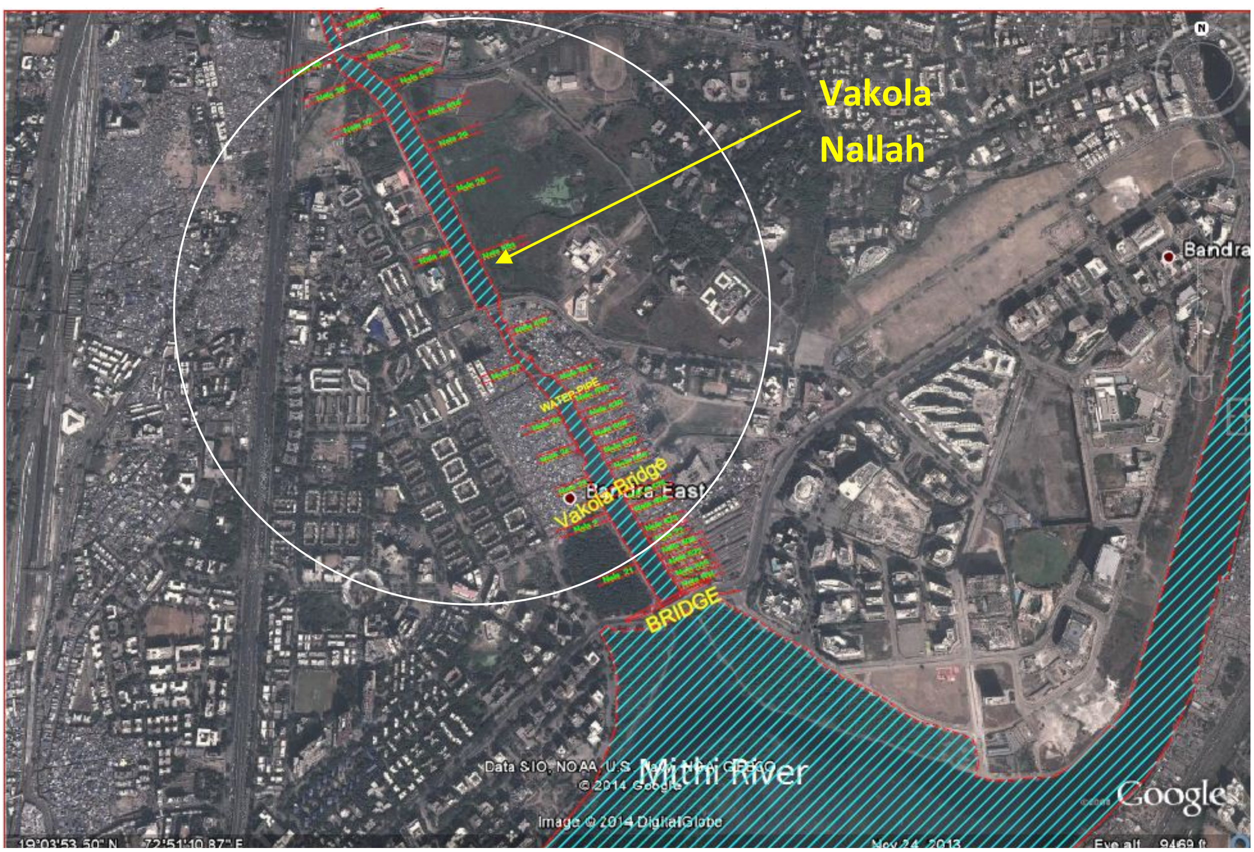
Flow of the river increases tremendously from upstream to downstream as Vakolanallahenters in the river in this stretch. Other than Vakolanallah, two small nallahsenters the river from left and right bank.On the right bank of the river, Ambedkar Nagar residential area is situated where the population is about 35000 inhabitedin 7000 slum houses. Along the Sion-BandraLink Road, residential establishments with population of approximately 5000 was identified.Prem Nagar an industrial area housing numerous unorganized small scale activities such as Bottle washing, Scrap merchants, tile cutting, etc. was also surveyed.

Eutrophication levels in this stretch werevery prominent segregating flow of river into several streams within the width of river. RCC wall is provided on the left bank of the river only and this stretch is not witnessed with solid waste dumping practices.

3.2.14 Stretch XIV –VakolaNallah

Though not direct part of the Mithi River, but being one of the most exclusive source of wastewater from the left bank of the river near BKC, Vakolanallahenters the river. Vakolais essentially a 3.5km nallahwherein numerous small sources enter as it merges into Mithi.

Figure 3.15 Stretch XIV VakolaNallah



From origin of the Vakola to the confluencing point at Mithi, the width of nallahincreases gradually withaverage being about 60m. During survey, it was observed that about hundreds of small nallahsenters in the Vakolanallah as it propagates from the origin though many of them were inaccessible being underground and entering at various depths through punctured inlets of the RCC lined banks. There were 32 such major nallahs that were surveyed.

Slum establishments observed along the banks of Vakolaserved to a population of about 5000 and more. Maharashtra Colony located on the left bank about 1km from convergence of it with Mithi housed about 22,000 people in about 4500 tenements. No prominent industrial units were identified though discussions with individuals during survey did mention some bakeries and small scale food processing units.

Eutrophication along the Vakola is very much limited but yet observed at some patches along its path.The zone of Vakola is literally free of solid waste dumping though sporadic instances of plastic and paper materials in the nallah were observed.

3.2.15 Stretch XV- BKC to Kalanagar

From BKC, river flows through Kalanagar area which is referred as the Stretch XV of river. Average width of the river in this stretch is approximately 60m however, because of the extreme eutrophication in the stretch, the actual width of river flowis only 600m as computed from Google Image presented in Figure 3.16though the actual flow of water is restricted only in the central most 60m portion of this width as evident from Photoplate III – 15.

Flow of the river increases from upstream to downstream as the stretch is under tidal influence. Along the river, thickly populated slums were observed with estimated population of about 20,000. Dharavi slums are located on the right bank of the river which is expected to house a population of more than 50,000. Though Dharavi is anticipated to be one of the most active industrial zones of Mumbai, detailed survey of the area and discussions with residents revealed the fact that most of the industries have been closed down and only secondary processing in form of tailoring of leather is operation now. Tanning is totally closed and few small slaughter houses along with bakeries catering to the needs to residents were present in this area.

In all about 30 to 40units majority of them involved in dyeing, few chemical Drum & Bottle washing, and very limited soap manufacturing industries were located in entire Dharavi area. Being sensitive area, information gathering was extremely difficult and few samples from common drains expected to source from nearby industrial units were collected. However most of the drains were closed pipes carrying sewage from slums and residential areas of Dharavi.

Figure 3.16 Stretch XV BKC to Kalanagar

3.2.16 Stretch XVI - Kalanagar to Mahim

The last stretch of the Mithi referred to as the convergence point of river into Arabian Sea is presented in**Figure 3.17**adopted from Google Image virtually beginning from Kalanagar& terminating at Mahim Bay. Maximum width is observed upstream though while crossing Mahim Bridge, the flow is automatically constricted within the boundary of this bridge to approximately 50m and depth is about 1.0 to 1.5m under tidal influence.

Mangrove plantation is observed on both banks in several patches and this stretch is the least eutrophicated part of river being under massive tidal influence almost throughout as presented in **Photoplate III - 16**. Residential areas located along side this section is expected to house a population of about 3000 located in 400 slum houses along with several residential complexes.

In this stretch, one major nallahentering the river from right bank carries greyish wastewater mainly appearing to be sewage from surround areas. One Dyeing industries was surveyed as representative industrial activity though this portion is devoid of any known such sources. This part of river is naturally low lying and do not have artificial embankments as done for rest of the Mithi River. Most prominent issue in this area is open defecation alongside both the banks and people were found to be having contact with this water especially during low tides for fishing activity.

Figure 3.17 Stretch XVI - kalanagar to Mahim

S. NO	X Lattitude	Y Longitude	COD	BOD	Flow(mld)
R 4	72 50'18.3"E	19 03'01.5"N	184	47	3456.00
R 502	72 50'20.0"E	19 02'51.4"N	140	44	4320.00
R 13	72 50'20.0"E	19 02'51.4"N	92	41.60	-
N 502	72 50'18.4"E	19 02'54.0"N	44	10	0.016
R 3	72 50'18.7"E	19 02'53.9"N	162	48.3	4665.600
R 14	72 50'20.0"E	19 02'51.4"N	474	156.40	-
R 501	73 30'04.1"E	19 13'27.1"N	0	0	4712.727
R 15	72 50'20.0"E	19 02'51.4"N	331	124.60	-

Chapter IV

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Flow Assessment in Mithi River

4.0 Background

In the assessment of river pollution, flow measurement forms a major part with a view to determine pollution load entering into the river.It is the most essential part of any monitoring or pollution status identification. Though there are several inlets to the River, it is essential to classify the sources and river water stretches based on flow of nallahs into the river as well as the existing river water flows in order to assess the potential of impacts in terms of pollutant loading as well as the extent of carrying capacity and/or dilution potential. Flow in river as well as sources of pollution contributing the river were measured using simple manual process of velocity of water flow and dimensions of nallah.

Though a crude method, several earlier studies have also been carried out by MCGM & MMRDA / IIT to assess flow of major inlets based on which recommendations of citing STP’s are in consideration. Nevertheless, this study essentially considers flow as a measure of pollution load potential measurement rather than just a way of deciding capacities of treatment units and thereby conventonal method justifies it. Furthermore, the natural cleansing property of Mithi due to tidal influence reuslting in high dilution potential is also studied through flow analysis. Along with the river, flow measurements of all possible major confluencing nallah along both the banks were studied. All major nallahs contributing to Mithi are discussed in one section whereas wastewater contributors to Vakola Nallah on the other hand is considered as a separate section as outlined in this Chapter. The previous studies carried out by MPCB though did not include this part and thereby it makes it even more essential to take into account various aspects of flow here.

4.1 Flow Measurement Methodology

For measuring the flow rate in the river as well as in the confluence points of individual open or otherwise nallahs, a piece of light weight material (Floatable) was allowed to flow in the river for a known distance. Time required by that material to travel that distance was measured with the help of stopwatch and the flow rate was calculated using following mathematical formula

$$\boxed{q = \text{Distance/Time (m/s)}}$$

Total flow was computed using width of active water flow x depth of flow x flow rate. However, for those locations where floatables could not be used i.e. in case of closed pipeline discharging wastewater, a vessel (mostly graduated bucket or otherwise) of known volume was allowed to fill and the time required to fill the bucket to desired known volume was determined using stopwatch. Thereby, the flow rate was calculated as

$$\boxed{q = \text{Volume of the bucket/ Time } (m^3/s)}$$

Figure 4.1 delineates the flow variations across different stretches of Mithi River as measured during the month of May 2014 i.e. pre-Monsoon studies. Mithi River originally was supposed to be fed by overflow from Vihar and Powai lakes although this is not the case as of now. The river is mostly fed with wastewater from several residential and many slum dwelling units located in the vicinity of Mithi and directly discharging wastewater either through open nallahs or recently developed closed pipelines. Three or four sections of the river also receives industrial wastewater which either flows directly through closed pipelines or mixes with sewage from other areas and drains into Mithi.

The physical survey along banks of Mithi prominently showed discharges from hotels and restaurants, the large scale ones having full-fledged wastewater treatment units whereas the smaller ones directly discharging effluents. Flow measurement was also critical since along the origin to almost half of the stretch of Mithi, the flow was affected by solid waste open dumping restricting smooth and uniform passage of water throughout the width and also most of the initial part of Mithi having low flow formed central or peripheral streams within the width of river.

Mithi entails about 2MLD wastewater from its origin at Filterpada / Gautam Nagar and ends up carrying about 450MLD wastewater near MTNL Bridge after convergence of Vakola Nallah into it as shown in **Figure 4.1**. From downstream of Bandra-Kurla Complex [BKC] stretch, the river under influence of tides carries a maximum of 4600MLD as measured at downstream of Mahim stretch as presented in **Figure 4.2**.

Tidal influence most importantly seems to be the heart of Mithi’s natural cleansing process wherein the high tide from Arabian Sea through Mahin Creek results into high dilution to almost 5 to 6kms inland affecting the major Vakola Stretch and the low tide in turn tends to carry the waste loads into sea thereby adding to the carrying capacity of Mithi River. Thereby, **Figure 4.2** is earmarked as those under flushing effect of tides carrying almost 4000 - 5000MLD of sea water into Mithi every day.

Figure 4.1 Flow Variations Across Mithi River without tidal influence

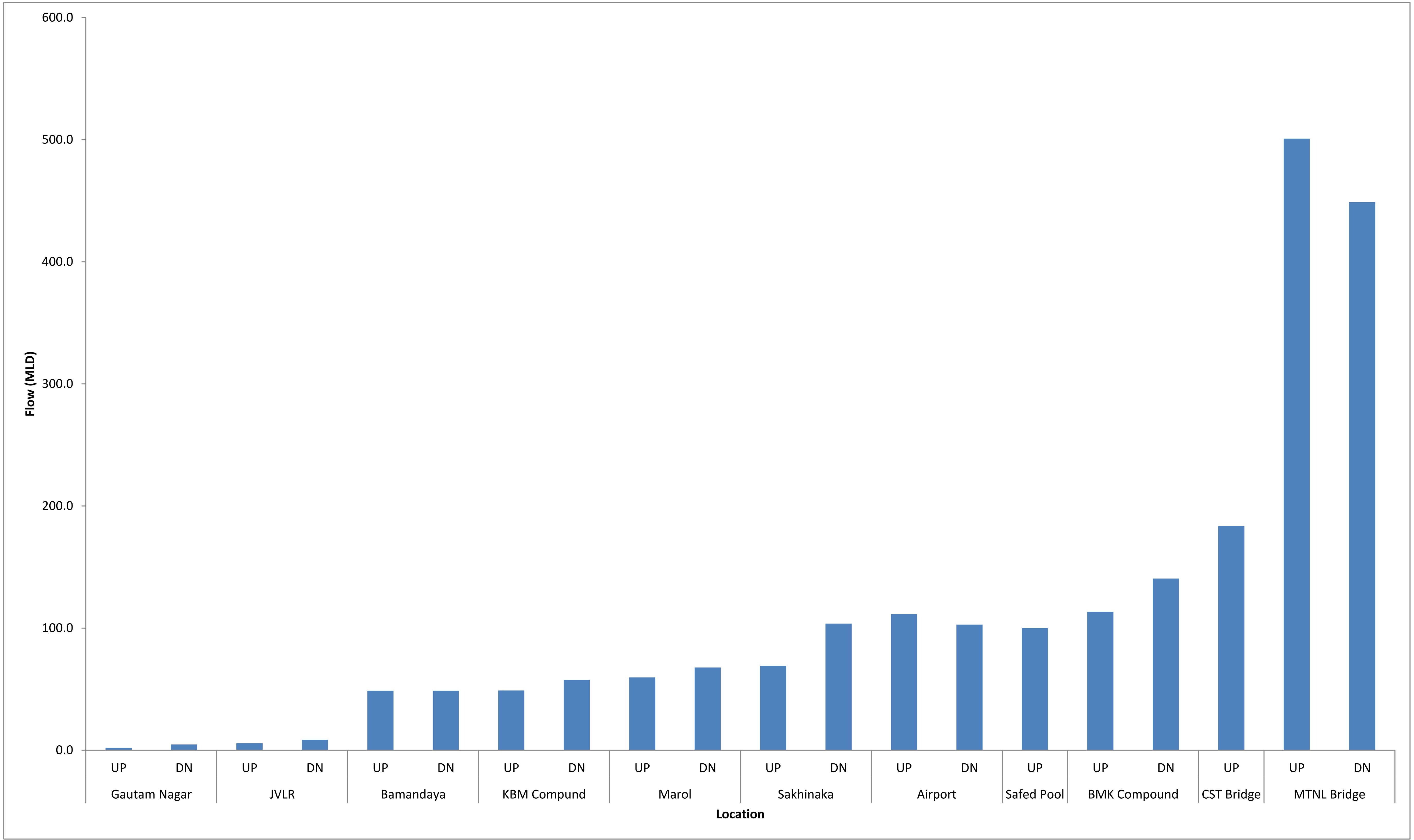
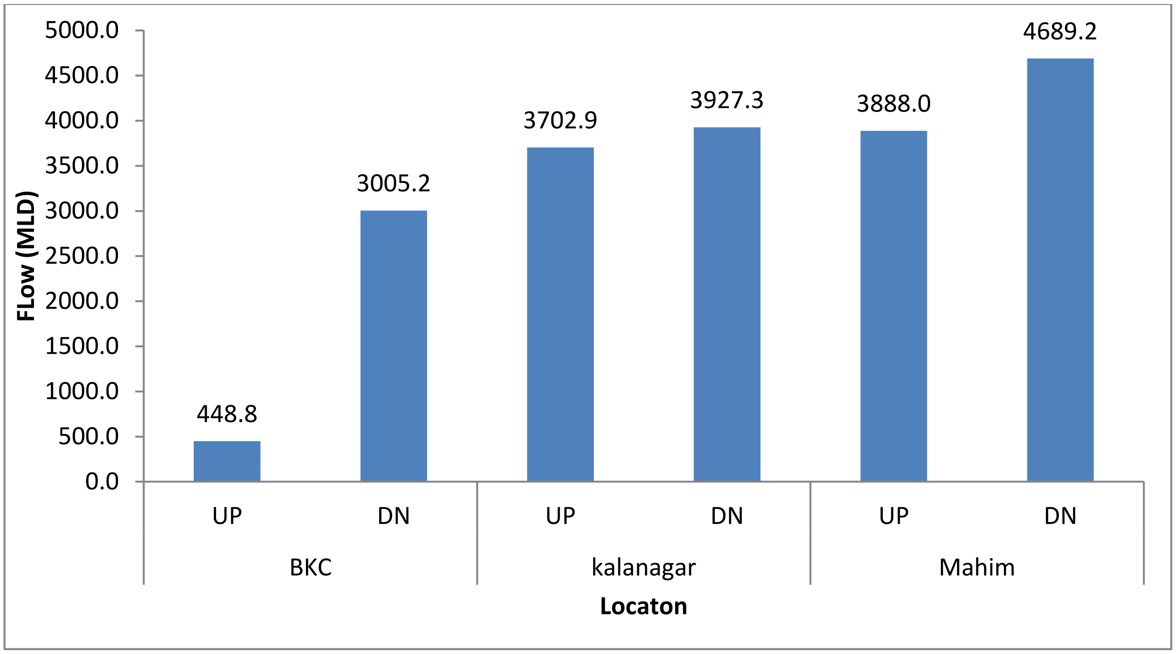


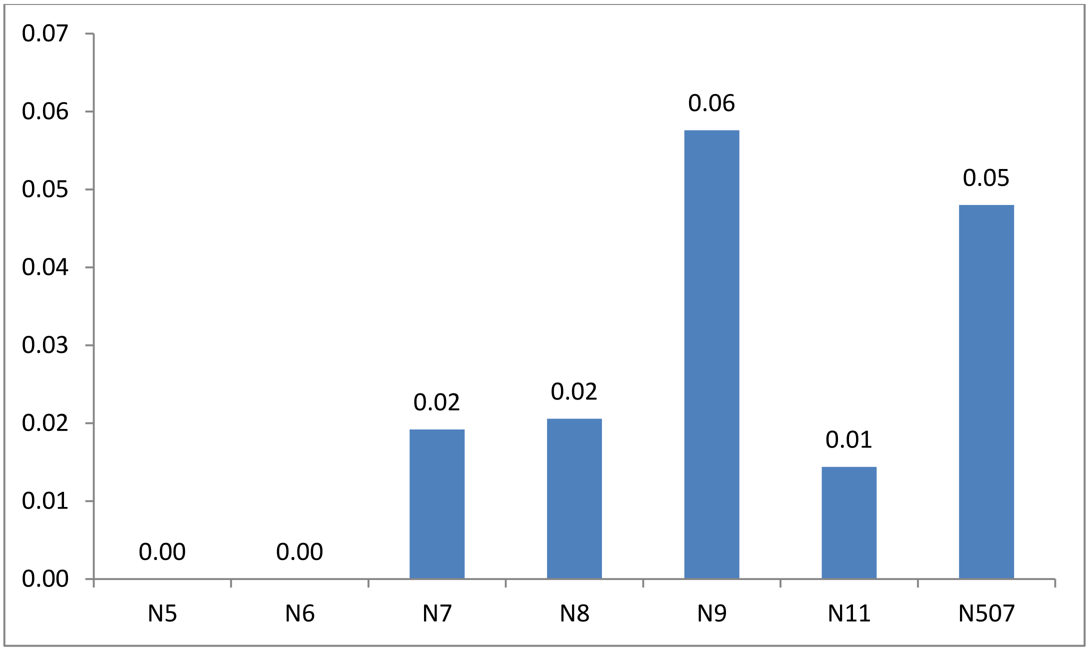
Figure 4.2 Flow at tide influenced locations



Though an exact mass balance for flow could not be established with limited measurements of nallahs that were visually observed and accessible, the flow in river is used as appropriate method to understand inputs of wastewater entering from surrounding area. Furthermore, these nallahs have been marked only at possible locations at intervals of 1km or less whereby several of the streams / drains entering Mithi during its course from one stretch to other may have been missed out due to mere inability to physically assess the locations. For example in Gautam Nagar stretch, only 7 nallahs that could be identified contributed to about 0.16MLD as shown in **Figure 4.3** though the overall addition of total flow was about 2.7MLD.

Numerous flow contributors in stretch II though visually identified could not be approached for measurements being underground through RCC wall embankments and also carrying very small amounts of wastewaters and appearing almost 500m upstream from the Gautam Nagar Bridge.

Figure 4.3 Flows in MLD of Nallahs along Gautam Nagar Stretch



Subsequent to Gautam Nagar, Mithi at JVLR Bridge had upstream flow of 5.8MLD which is about 1.1MLD more than that of at the downstream of Gautam Nagar probably due to the unidentified nallahs enroute. At the downstream of JVLR, the flow of river increased to 8.6MLD. Out of the total difference of 2.8MLDbetween upstream and downstream of the river almost 1.2MLD were accounted for by those measured as shown in **Figure 4.4**.

Figure 4.4 Flows in MLD of Nallahs along JVLR Stretch

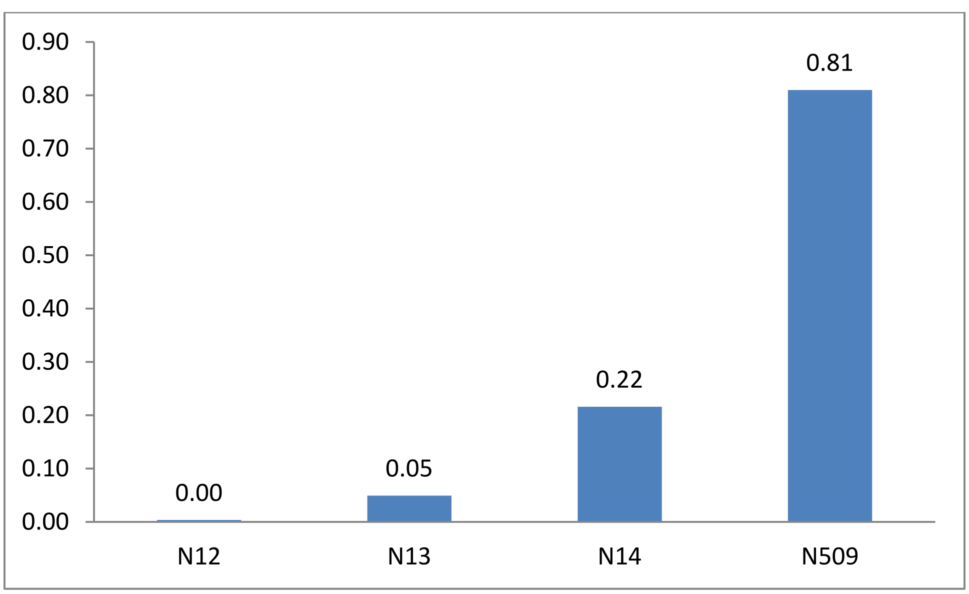
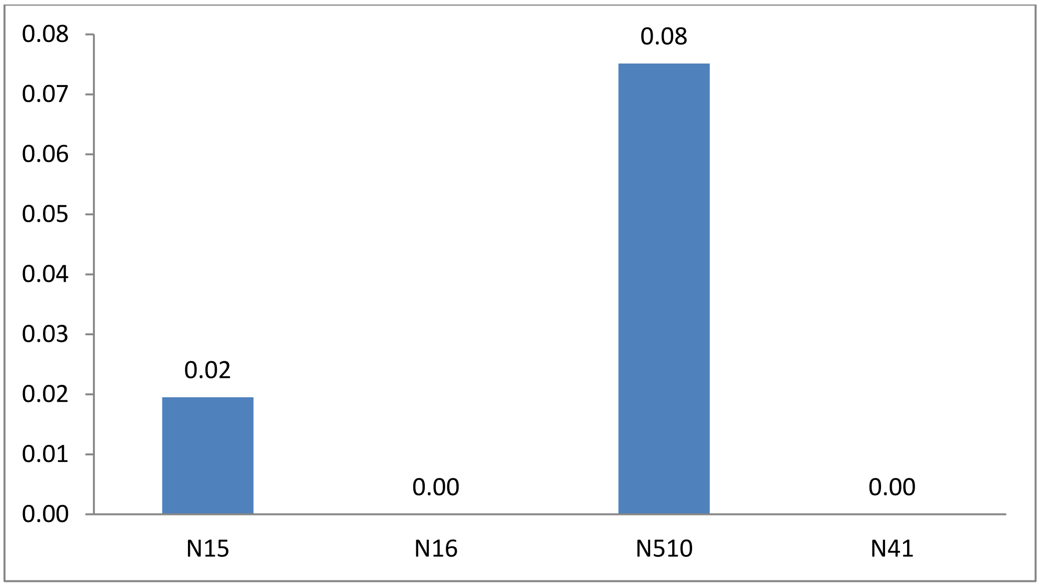


Figure 4.5 presents that the flow upstream & downstream of Bamandaya Pada is 48.8MLD i.e. constant. Most of the flow is added enroute of the river from JVLR to Bamandaya Pada which was practically impossible to be surveyed. However, only 2 nallahs with minimal flow from upstream to downstream were identified adding to about 0.1MLD of wastewater from adjoining residential complexes.

Figure 4.5 Flows in MLD of Nallahs along Bamandaya Pada Stretch

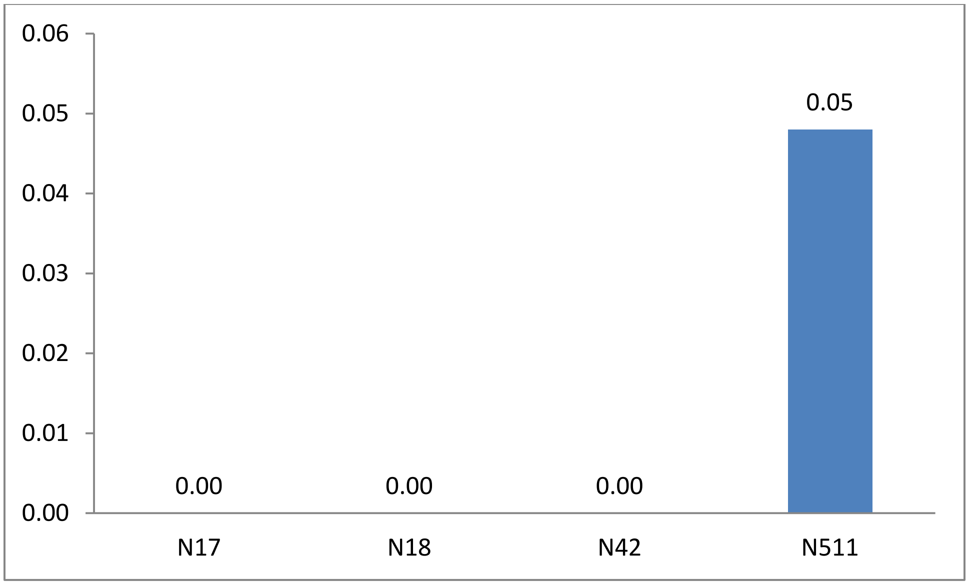


Followed by Bamandaya Pada, at upstream of KBM Compound marginal addition of about 0.1MLD is observed making the flow to 48.9MLD while additional contribution of about 7MLD in the downstream of river amounting to 57.6MLD was measured probably due to the some of the identified and several enroute non-identified nallahs ultimately entering Mithi. In this particular stretch four nallahs as depicted in **Figure 4.6** adds about 0.05MLD wastewater.

Traversing to next location i.e. at Marol, river has upstream flow of there seems to be an addition of about 8.1MLD flow making downstream flow to 67.8MLD. Though there is only one identified nallah in this area located on the right bank of the river, whose flow was measured to be 0.19MLD.

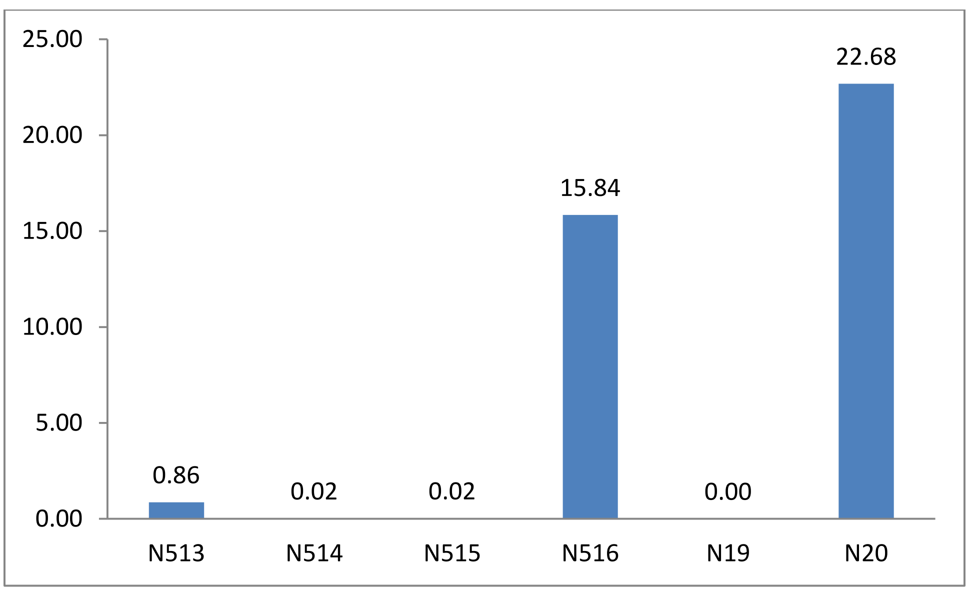
The flow upstream of the Sakhinaka is 69.1MLD & that downstream was found to be 103.7MLD. Contributed by 6 identified nallahs the difference in the flow of upstream and downstream locations is of 34.6MLD. **Figure 4.7** indicates the flows of nallahs here near Sakhinaka.

Figure 4.6 Flows in MLD of Nallahs along KBM Compound Stretch



Almost entire flow in the river is totally accounted by the 6 nallahs in Sakhinaka which is about 39.4MLD .Two of the nallahs i.e.N516 and N20 have comparatively high values of flow i.e. beyond 10MLD. It is inferred that the river bed sees some seepage along this stretch or due to cross-sectional difference in depths of river bed the flow needs to be considered in accordance with those balanced by nallahs and to be computed as 108MLD instead of 103MLD.

Figure 4.7 Flows in MLD of Nallahs along Sakhinaka Stretch

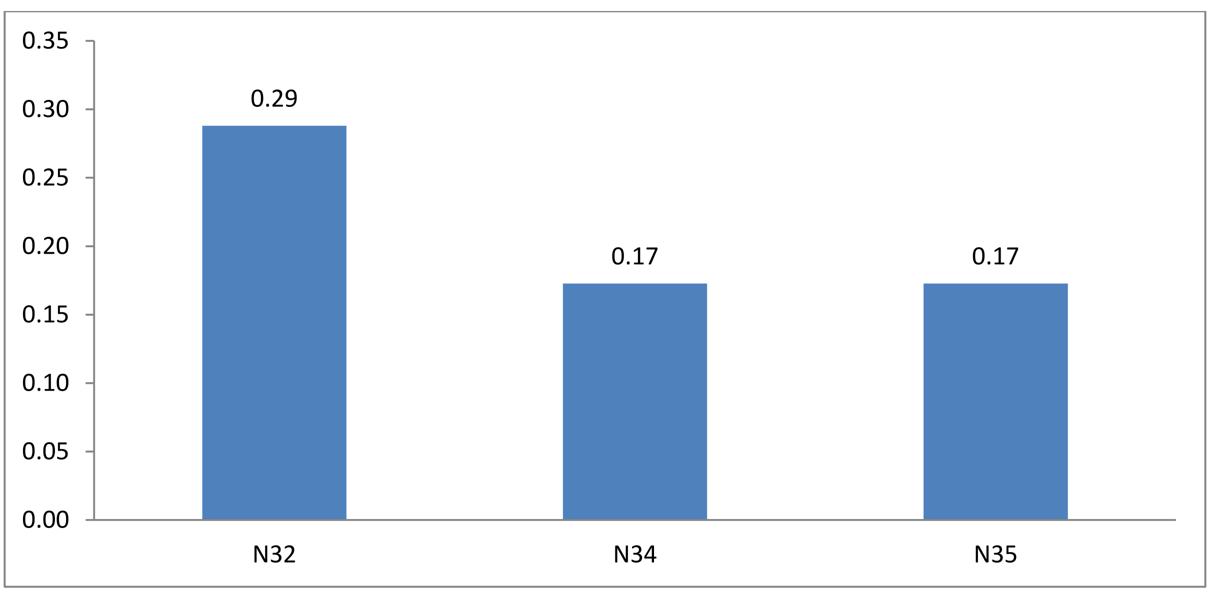


Subsequent to Sakhinaka, the next location of river analyzed for flow was near Domestic Airport having an upstream flow of 111.5MLD & downstream flow of the same was about 102.9MLD. Nallah from the sewage treatment facility of airport enters the river from left bank. Flow of this is found to be about 57.6MLD. However, as shown in **Figure 4.1**, there is decrease of 8.6MLD in the river flow from upstream to downstream flow which might be due errors in measurement of cross-sectional depth of river.

As represented in **Figure 4.1**, the upstream flow of the Safed Pool stretch was measured to be 100.1MLD though the downstream of the same couldn't be estimated due to the approach constraints. In this stretch, the open Safed pool nallah from nearby residential area is mixing in the river with a flow of about 13.5MLD and is identified as the only major nallah adding to river flow in this stretch thereby amounting to downstream flow of 113.6MLD.

Followed by Safed Pool, the flow of river measured at BMK Compound was 113.4MLD and that of downstream found to be 140.6MLD. Though addition of about 27MLD wastewater is observed from along this stretch, only 3 nallahs could be identified adding about 0.63MLD as shown in **Figure 4.8**. There were several drains entering into the river stretch through piped sources that were visually inferred to carry sewage but could not be approached for measurements.

Figure 4.8 Flows in MLD of Nallahs along BMK Compound Stretch



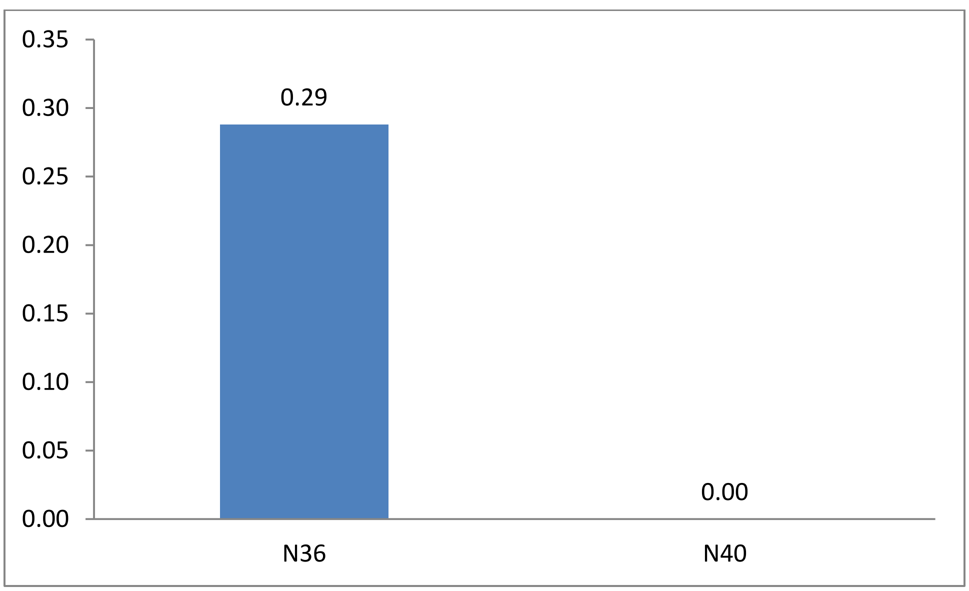
Reverse flow suggesting peripheral impacts of tide was also observed in this section that may be responsible for such high flow.

As the **Figure 4.1** indicates the upstream flow of CST Bridge was found to be 183.6MLD whereas downstream flow was not measured due to the limited approach. At CST Bridge, the tidal impact was prominently observed causing exponential increase in the flow. Though two nallahs were identified in this section of the river, flow of those nallahs could not be measured. It is supposed that additions of wastewater from unidentified sources may not be ruled out.

Followed by CST bridge, flow measured at downstream of MTNL Bridge was 448.8MLD. This section is under constant tidal influence and the irregularity in flow of up & downstream in this section is merely due to the cross-sectional variations in depths across the large width of river. Only one nallah carrying wastewater with flow of about 0.03MLD adjoins the river from left bank of the river.

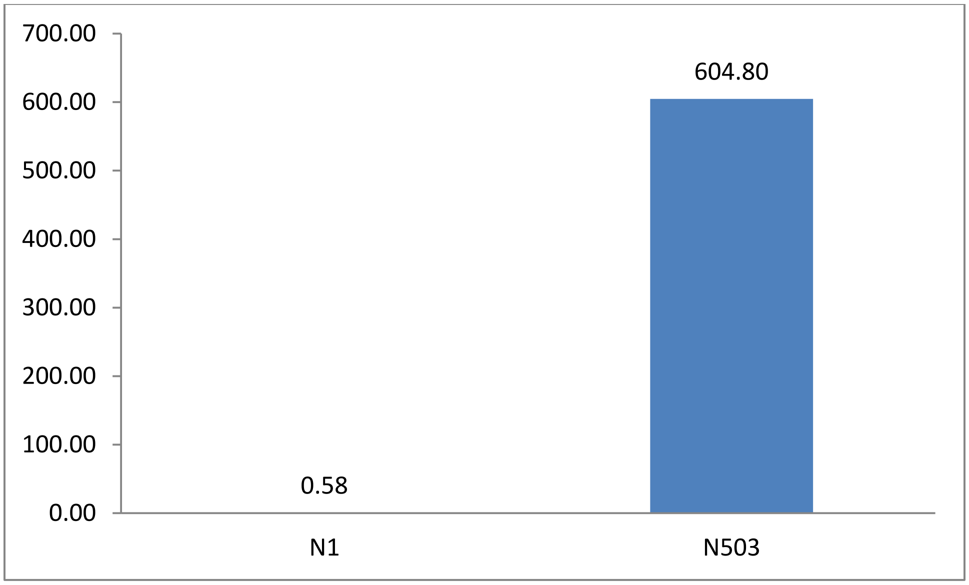
The flow does not change from MTNL to upstream of BKC though there is a drastic tidal influence with time of measurements at these two locations prominently marked by exponential flow of 3005.2MLD downstream of the river. Also, two nallahs adding into the river from left bank of the river at BKC area contributes to about 0.3MLD as depicted in **Figure 4.9**.

Figure 4.9 Flows in MLD of Nallahs along BKC Stretch



Similarly, being under tidal influence the flow of the river at upstream of Kalanagar is about 3702MLD which increases upto 3927MLD at the downstream only due to the time lag of measurements. Along with the tidal influence that contributes to high volume of water to mix in the river, two nallahs that enter the river, one from left and other from right bank of the river as shown in **Figure 4.10** contributes about 605MLD that may also have sea water intrusion inland.

Figure 4.10 Flows in MLD of Nallahs along Kalanagar Stretch



Flow of river at Mahim where it meets the Arabian Sea is about 3888MLD upstream and about 4689MLD downstream and is under the highest impact of tides being the convergence point of river with Arabian Sea through Mahim Creek. Small rivulets in form of 2-3nallahs identified in Mahim area adds to about 0.02MLD flow from nearby residential areas though the expected flow from nearby slums in this area is about 0.3 – 0.5MLD.

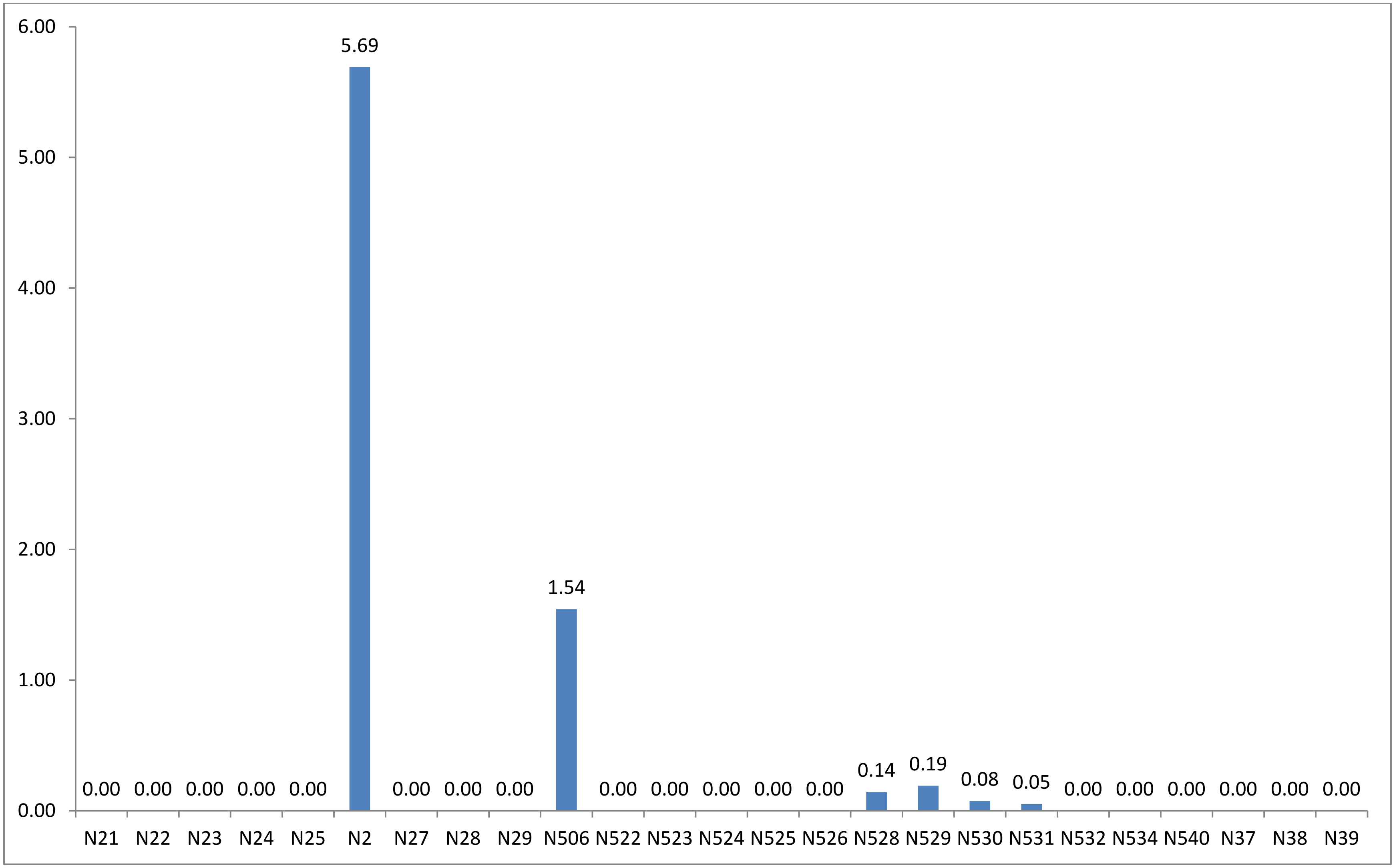
4.2 Flow in Vakola Nallah

Vakola nallah has been presented separately in this section of the chapter for its flow characteristics. Though there are numerous nallahs that enter Vakola adding to the overall volume, only 32nallahswere sampled though only about 21 had proper approach &could be monitored for flow as outlined here. These small nallahs are sourced from adjoining slum areas and mostly carrying domestic wastewater as shown in **Figure 4.11.**

The average upstream flow measured at 4 different locations almost 2 to 2.5kms inland from MTNL Bridge shows flow of 72.7MLD whereas downstream flow just before MTNL Bridge is found to be 89.6MLD.Thereby overall about 90MLD flow is contributed into Vakola Nallah by drains / rivulets measured for flow in Vakola Nallah section whereas there were few others very small ones too adding into it that ultimately leads Vakola to Mithi and indeed to Arabian Sea. Vakola is also impacted by tidal influence and this may also be one of the major reasons for such high flow measured in this section though most of the nallahs connected from slum areas were directly carrying sewage.

From mere hydraulics of Mithi River point of view, it is clearly evident that the entire stretch can be classified into 2 sections wherein the first from origin to upstream of KBM Compound carries direct wastewater either from residential or industrial sources and the other from downstream of KBM to Mahim Bay including Vakola sections that along with the majority of domestic and few industrial contributors is highly influenced by tides. The overall flow of sewage into Mithi before sea water intrusion is about 450MLD whereas Vakola adds to another 89MLD thereby amounting to a total of about 540MLD of wastewater. Additionally the stretch from MTNL to Mahim based on the nearby areas and especially Dharavi pouring domestic wastewater seems to amount for additional 100MLD in its course till entering Arabian Sea thereby leading to about 640MLD of wastewater from varied sources being carried by Mithi River in its course of about 15km from origin to Mahim in addition to the 3.5km of Vakola Nallah.

Figure 4.11 Flow variations n Vakola Nallah



0.00 represents those nallahs that were unapproachable

Chapter V

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Chapter V

Organic Load in Mithi River & Nallahs

5.0 Background

This chapter is essentially one of the most important since it attempts at understanding the organic load in Mithi River which would not only help evaluate the extent of pollution but also provide foundation for the subsequent chapters in terms of criticality of river stretches and receptor modeling. It has been established that COD and BOD are interrelated and dependent variables and that the part of COD concentration is actually BOD. Since the surveys carried out throughout Mithi River reveal enormous raw sewage inputs in almost every section whereas sporadic inputs from industrial wastewater, it would be interesting to elaborate on the extent of variability in organic loads in terms of both COD and BOD.

5.1 Baseline Monitoring During Monsoon [June 2013]

The preliminary survey of 12 such potentially polluted and known impacted locations of Mithi were sampled and analyzed for concerned parameters during 2 different seasons by MPCB. The sampling has also objectively helped to get better understanding of the present status of pollution in Mithi River as well as strategize the need for further sampling. Sampling Locations for Monsoon & Post Monsoon carried out by MPCB is represented in **Annexure V – I** whereas **Table 5.1** depicts statistical analysis of same.

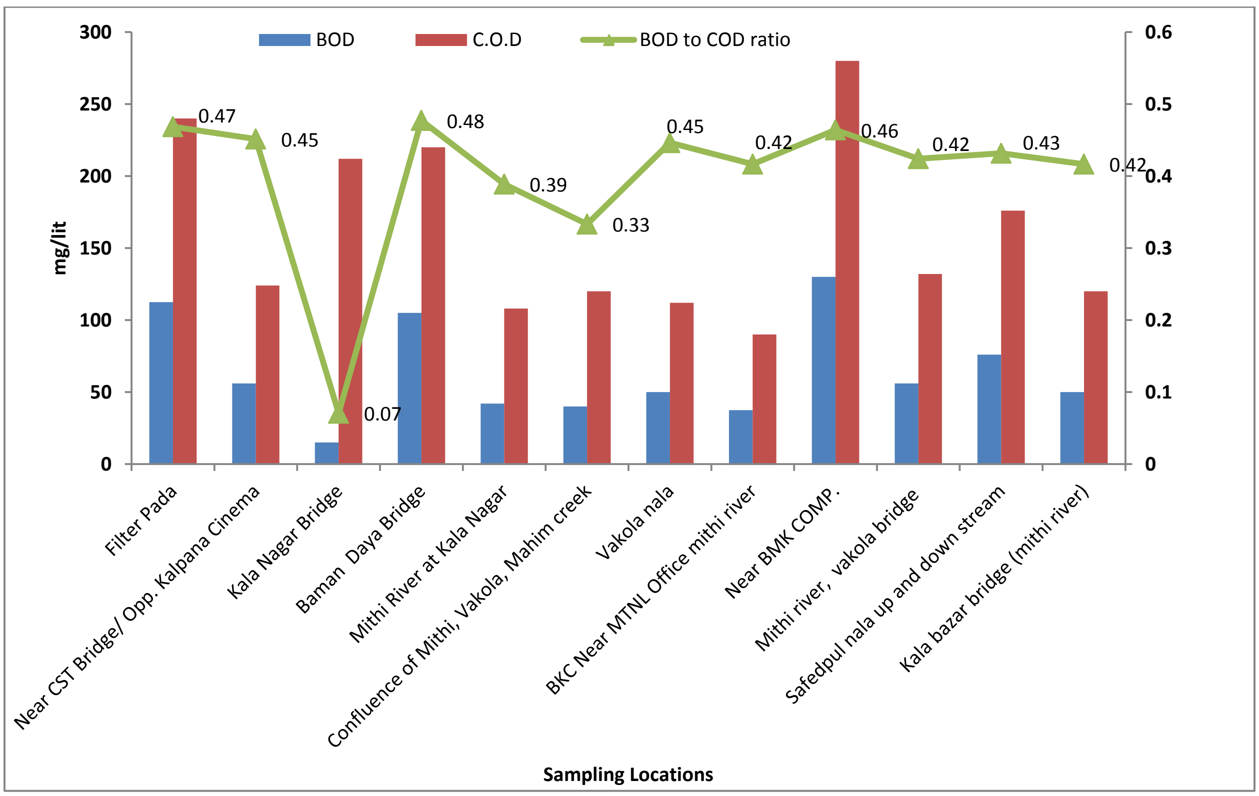
Table 5.1 Statistical Analysis of Organic Parameters of Mithi River during Monsoon

Parameters	Minimum	Maximum	Average	SD	Std. (ISF - a)
BOD (mg/l)	15	130	56	34.7	30
COD (mg/l)	90	280	148	62.1	250
BOD to COD ratio	0.07	0.47	0.36	0.11	NA

It is interesting to note that the organics in form of biodegradable BOD shows a minimum of 15mg/lit to maximum of 130mg/lit whereas COD that represents the entire organics section of both degradable and non-biodegradable ranges from 90 to 280mg/lit. Interestingly the values observed averages at 56mg/lit and 148mg/lit for BOD & COD respectively and are well within Schedule VI - General Discharge Standards (Designated Use) as presented in **Annexure V - II**. Though there is a possibility of precipitation accounting for low values of organics in water, the interesting point is the measurement of BOD to COD ratio ranging from about 0.07 which reveals definite intermediate sources of industrial wastewater to 0.47 representing peculiar domestic sewage inputs. Standard Deviation values are found to be very high vis-à-vis averages showing high variability in the water characteristics and also suggesting multiple sources at different intervals and locations of river stretch. DO levels in several of the sampling locations show BDL values suggesting water unsuitable for any purposes as per the Schedule VI - General Discharge Standards. Comparison of various linked / associated parameters are represented in **Figures 5.1** for an elaborate and better understanding of extent of pollution in different stretches of Mithi River during Monsoon period.

Two important locations needs to be specifically marked from the figure i.e. Bamandaya Bridge and confluence point of Mithi with Vakola nallah that show lower COD to BOD ratio which also means that these 2 locations are under the influence of industrial effluent sources to certain extent.

Figure 5.1 Organics Trend Across the Stretch of Mithi River during Monsoon



5.2 Baseline Monitoring During Post-Monsoon [January 2014]

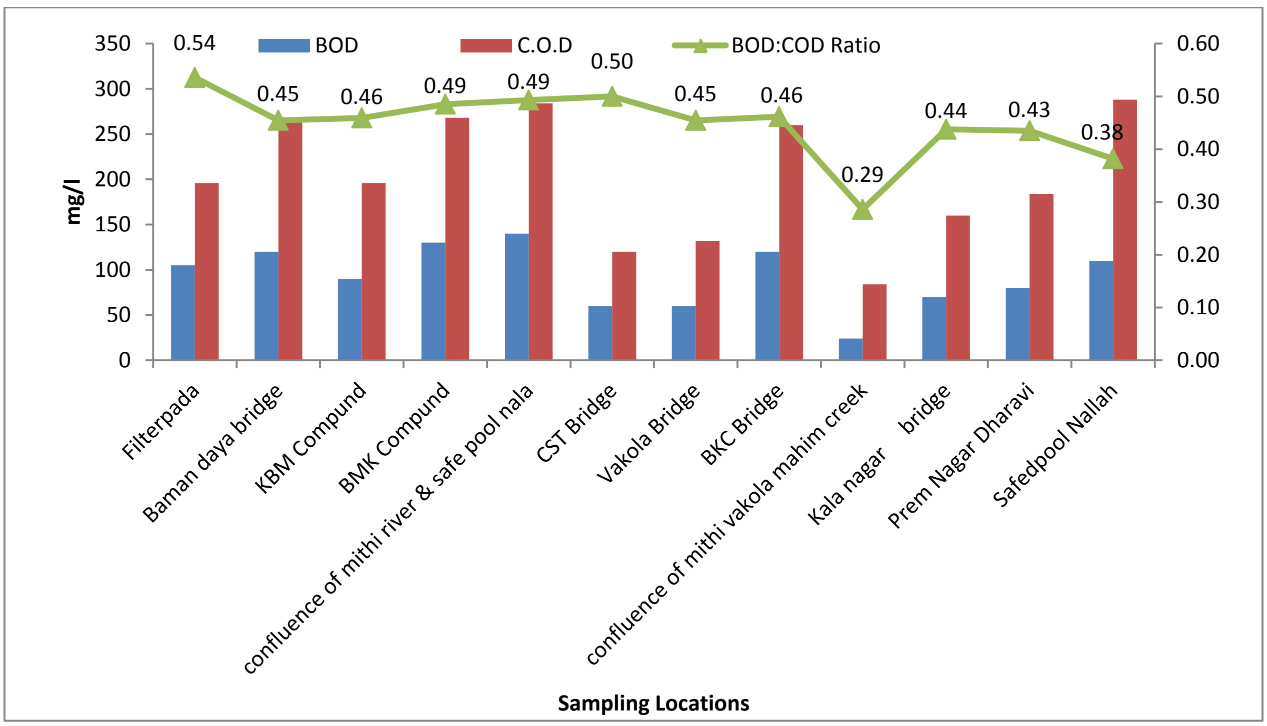
MPCB on its own have been carrying out regular monitoring of Mithi River with the view to assess pollution load and variability through seasonal changes. Post monsoon monitoring at 12 locations was carried out as represented in the statistical analysis drawn in **Table 5.2** whereas a more elaborate view of individual sampling locations for organic content is represented in **Figure 5.2**. Organic load seems to have shifted its ratios during post monsoon season which is quite expected and this also confirms influence of precipitation observed during the monsoon season.

Table 5.2 Statistical Analysis of Organic Parameters of Mithi River during Post Monsoon

Parameters	Minimum	Maximum	Average	SD	Std. (ISF - a)
BOD (mg/l)	24.0	140.0	92.4	66.4	30
COD (mg/l)	84.0	288.0	203.0	118.5	250
BOD to COD ratio	0.29	0.54	0.45	0.07	NA

During the post monsoon season, BOD concentrations range from minimum of 24.0mg/l to maximum of 140mg/l averaging about 92.4mg/l again well within the Schedule VI - General Discharge Standards of 250mg/l for Inland Water Discharges.

Figure 5.2 Organics Trend Across the Stretch of Mithi River during Post Monsoon



Similar is the COD concentration which varies from 84mg/l to 288mg/l with average of 203mg/l well within the criteria standards of 350mg/l. Other than one sample located at Vakola confluence point of Mithi which represent industrial influence as per the ratio of BOD to COD, all other locations depict major influence of domestic wastewater inputs. High Standard Deviation also reveal the fact that the variations in characters of sources are extremely high though they represent mostly domestic waste that may be due to dilution impacts based on the quantity of water supply in particular areas.

Influence of precipitation at these locations on an average can be accounted for by using simple empirical calculations during these two seasons which reveals BOD being affected by incremental factor of 1.6 whereas COD by a factor of 1.4 post monsoon. Since sampling was carried out in the early months of monsoon, the impacts can be accounted for about 30 to 40% on the organic load.

Since flow measurements were not carried out during these periods, the loads of organics may not be computed. However, attempt to calculate the same is done in next sampling season.

5.3 Baseline Monitoring During Pre-Monsoon [May 2014]

A more elaborate & scientifically chalked out comprehensive monitoring network plan was prepared to compliment the already existing studies of MPCB. A thorough investigation of existing locations of sampling along with the parameters of analysis and missing links was established following dialogue with concerned officials & consensus was brought out regarding additional sampling locations to be considered during this particular study. Limitations of past studies, data gaps and interpretation needs were identified and thereby the whole exercise of network to include nallahs and source sampling was formulated with a view to evolve framework and processes that would ultimately lead to resolving main issue of determining source contribution to Mithi River. The previous chapter already enumerates flow measurements and influence of tides in Mithi whereas this chapter attempts to evaluate organic content in form of BOD and COD.

5.3.1 Organics Load in River Water

In all 77 samples of river water were collected during the pre-monsoon period of May 2014, the sampling map for same is presented in **Annexure V – III**. Thereby overall 4 to 5 times samples have been collected from each of the locations in various seasons to assess the variability not only during the season but also during different seasons. Statistical analysis for sampling adequacy as discussed in **Chapter VIII** of this report also reflects ample evidence of validity of overall numbers of samples as also substantiated in **Chapter II**.

Figure 5.3 Organics in Mithi River Water Samples during Pre-Monsoon

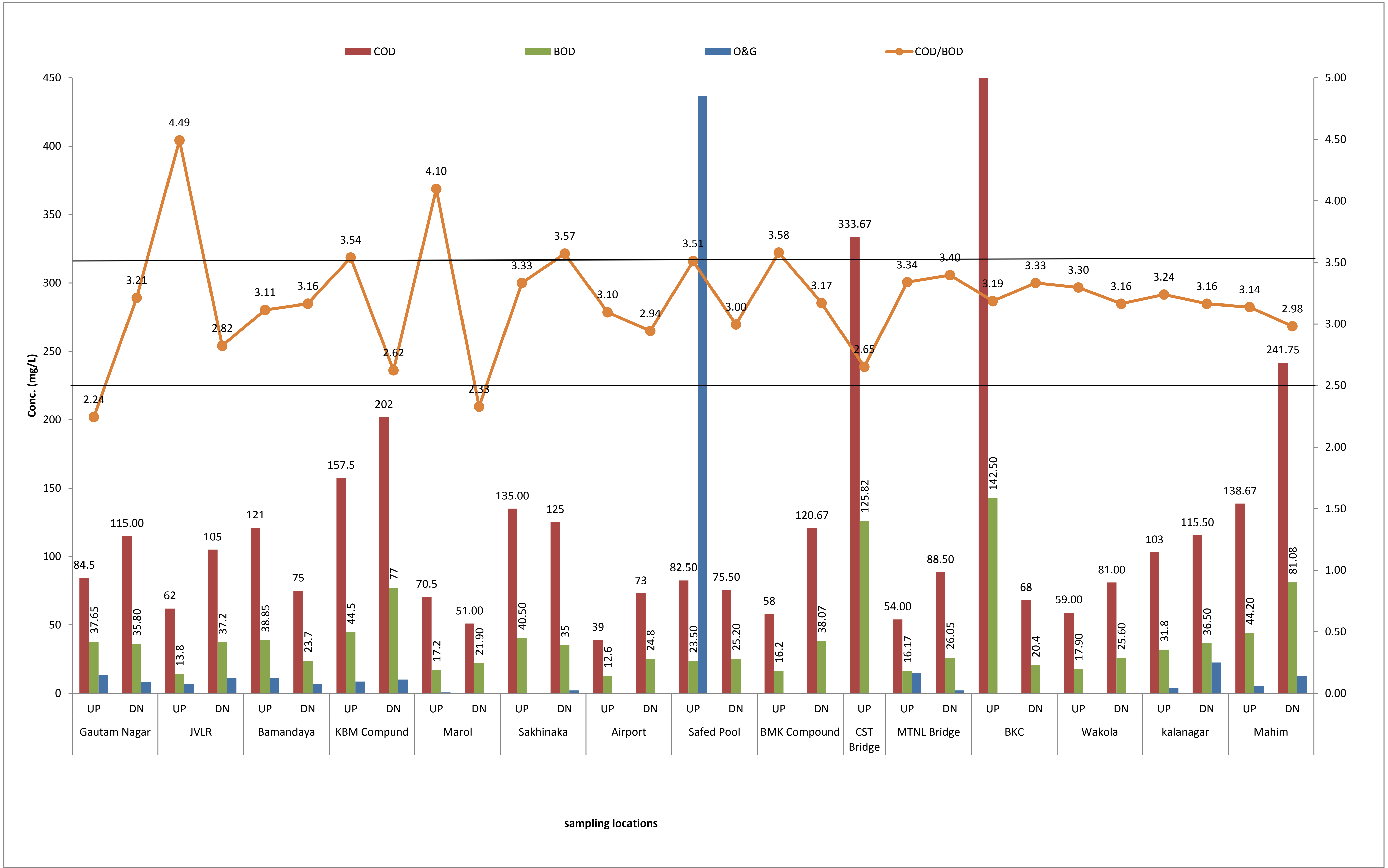


Figure 5.3 represents organics in river water classified by presence of COD, BOD and O&G which are known to be the responsible parameters of organic origin along with ratio of COD to BOD. Except for 2 of the samples that show values of COD/BOD ratio in range of >3.5 i.e. at JVLR & Marol, all other samples range between values of 2.5 to 3.5 suggesting domestic wastewater sources other than those two wherein influence is clearly evident of industrial sources and is also substantiated by survey details of industrial discharges, in these 2 areas of Mithi. Prominent O&G peak is observed at Safed Pool may be due to accidental discharge which otherwise has not been the trends in any of the earlier studies. However, O&G are found to be present in almost all the samples and several of them are found to be critically high above the Schedule VI - General Discharge Standards.

Table 5.3 depicts statistical analysis of river water data for organics which reveals that BOD & COD ranges from minimum of 12.6mg/l & 39.0mg/l at Upstream of Airport to maximum of 142.5mg/l & 454mg/l at Upstream of Bandra-Kurla Complex (BKC) averaging about 39mg/l & 120.3mg/l respectively. The standard deviations once again show very high values suggesting high variability in the contents of inputs entering Mithi River. O&G on the other hand shows minimal concentrations Below Detection levels (BDL) to maximum of 436.9mg/l at Safed Pool with average of 19.7mg/l. Extremely high Standard Deviation (SD) values even more than the average suggest outlier in this case as only one of the samples actually reflect such high O&G concentration.

Table 5.3 Statistical Analysis of Organic Parameters of Mithi River during Pre Monsoon

Parameters	Minimum	Maximum	Average	SD	Std. (ISF - a)
BOD (mg/l)	12.6	142.5	39.0	30.9	30
COD (mg/l)	39.0	454.0	120.3	89.5	250
O&G (mg/l)	0	436.9	19.7	80.4	10
COD to BOD ratio	2.24	4.49	3.20	0.45	NA

When computed for organic loads based on the flow in river, **Table 5.4** delineates average COD load in each stretch. The sections having prominent tidal influence are not included in order to avoid redundancy in data and mis-representation of loads. Thereby, maximum load of 109 tons/day for COD and 63.9 for BOD is observed at Upstream of BKC whereas minimal load is observed at Gautam Nagar i.e. 0.12tons/day for COD and 0.07tons/day for BOD which is virtually the first point since flow measurements at Filterpada was not possible.

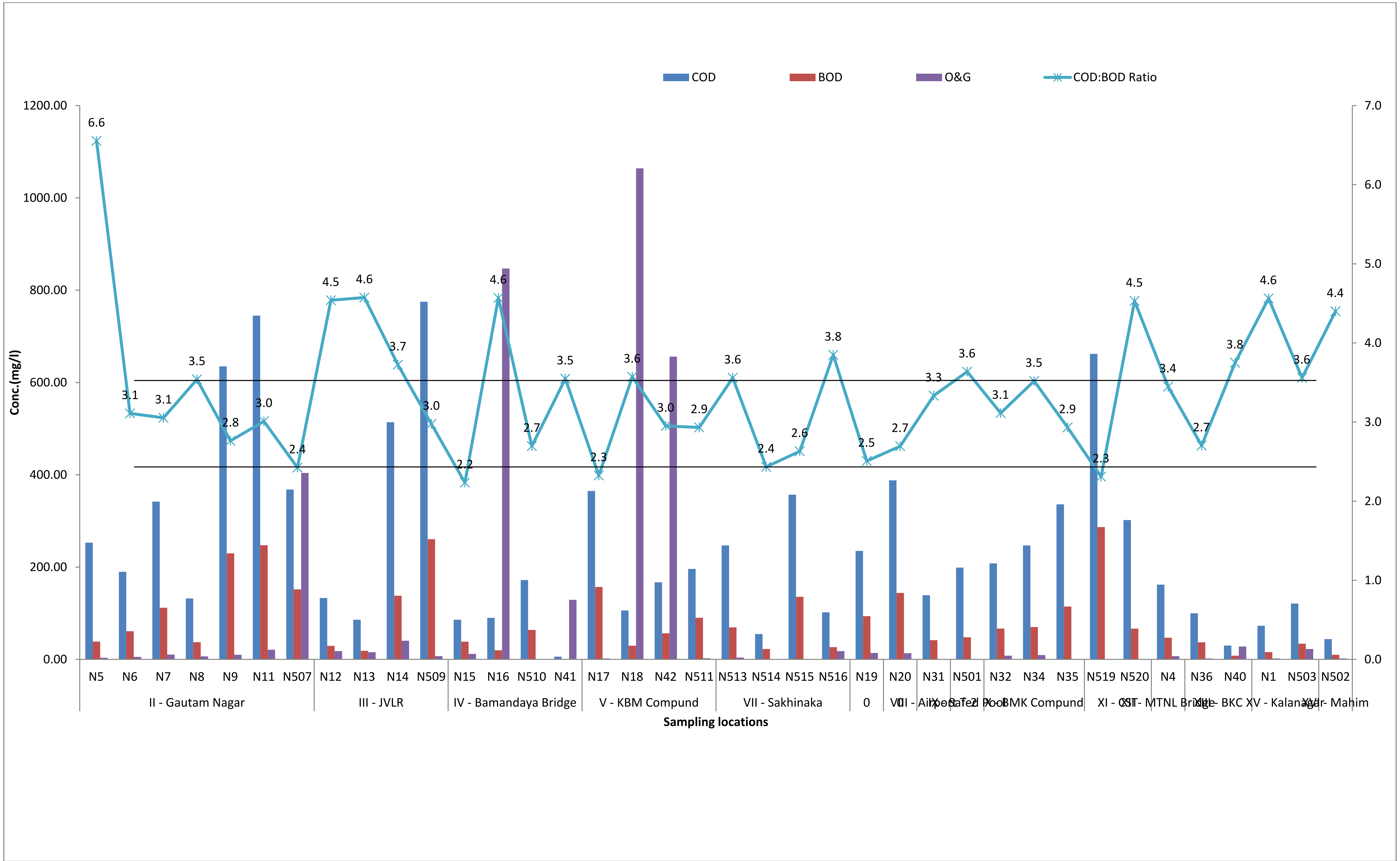
Table 5.4 Organic Loads in Each Stretch of Mithi River

Location		Flow (MLD)	BOD (Tons)	COD (Tons)
Gautam Nagar	UP	1.97	0.07	0.12
	DN	4.71	0.17	0.67
JVLR	UP	5.76	0.08	0.94
	DN	8.58	0.32	1.13
BamandayaPada	UP	48.77	1.89	12.19
	DN	48.77	1.16	6.58
KBM Compound	UP	48.91	2.18	5.06
	DN	57.60	4.44	4.44
Marol	UP	59.68	1.03	3.46
	DN	67.76	1.48	3.59
Sakhinaka	UP	69.12	2.80	11.85
	DN	103.68	3.63	37.01
Airport	UP	111.48	1.40	22.30
	DN	102.86	2.55	12.34
Safed Pool	UP	100.15	2.35	40.86
BMK Compound	UP	113.40	1.84	18.94
	DN	140.62	5.35	17.86
CST Bridge	UP	183.60	23.10	149.70
MTNL Bridge	UP	500.90	8.10	45.25
	DN	448.83	11.69	109.96
BKC	UP	448.83	63.96	1189.40

5.3.2 Organics Load in Nallah Water

There are numerous nallahs that feed into Mithi River and almost every stretch of 1km that has been virtually classified & used for the report purpose shows them ranging from 5 to 15. In fact Vakola Nallah itself has feeding from almost 100 small nallahs and most of them being closed pipelines making it even more difficult to determine sources of inputs to these nallahs. Many of them though were inaccessible or showing minimal flows, all those that were possibly major sources and within the ambit of approaching physically have been accounted for in this study. For the ease of analysis and interpretation nallahs that contribute to Vakola are presented separately in relevant sections of this chapter. The major factor affecting organics i.e. COD, BOD and O&G are presented in **Figure 5.4** whereas statistical analysis of the same is depicted in **Table 5.5**.

Figure 5.4 Organics in Nallah Water Samples during Pre-Monsoon



Similar to river water characteristics, Nallahs too show interesting trends with COD to BOD ratio during Pre-monsoon season. Out of the 41 nallahs that were monitored directly discharging into Mithi, almost 90% of them show values between 2.5 to 3.5 with several of them marginally above or below the mark. However there are 5 to 6 such nallahs 2 located in JVLR, 1 each in BamandayaPada, Sakhinaka, Kalanagar & Mahim that show >4.4 values thereby suggesting industrial source influence in them. This also is reflected very clearly in river water quality as described in earlier sections. BOD values range from minimal of 8mg/l to maximum of 286.65mg/l averaging about 84.9mg/l whereas COD varies from 30mg/l to 775mg/l averaging about 253.2mg/l. The average BOD & COD concentrations in nallahs is almost 2 times than that observed in river.

Oil and grease shows important trends that shall form the basis of several assumptions and interpretation in subsequent chapter on receptor modeling wherein extremely high values are observed at several locations such as KBM Compound, Bamandaya Bridge and Upstream of JVLR which are known to be industrially active zones around Mithi River. Though the lowest concentrations vary from BDL to highest being 1064mg/l, the average concentrations of O&G are observed to be 80.4mg/l. Extremely high variations in SD values almost equal to averages for BOD and COD whereas higher than average in case of O&G reveals the fact that these nallahs are highly source dependent and each one of them are characterized by variable concentrations of these parameters. Since O&G shows only 3 such values that are extremely high, the SD too is marked by higher values.

COD to BOD ratio in case of nallahs entering Mithi show vast variations though most of them are representative is sewage. The ratio varies from 2.2 representing domestic wastewater to 6.6representing industrial source. Average ratio of 3.3 substantiates the fact that most of nallahs other than those 6 mentioned above carry domestic wastewater. SD values though about 20% of average further support the say that most of nallahs have common source with minimal variability in terms of ratio.

Table 5.5 Statistical Analysis of Organic Parameters of Nallahs during Pre Monsoon

Parameters	Minimum	Maximum	Average	SD
BOD (mg/l)	8.0	286.6	84.9	71.4
COD (mg/l)	30.0	775.0	253.2	187.0
O&G (mg/l)	0.0	1064.0	80.4	233.6
COD to BOD ratio	2.2	6.6	3.3	0.9

Statistical details of organic characters for Vakola nallah is presented in **Table 5.6** showing that BOD concentrations range from 4mg/l to 438mg/l with average of 103.5mg/l. COD on other hand show concentrations ranging between 11mg/l to 935mg/l with average of 268mg/l. O&G shows concentration ranging from BDL to 35mg/l with average of 8mg/l which also reveals the fact that the 3.5km of Vakola nallah do not harbor vehicle washing centre as seen in case of nallahs that contribute to Mithi River. As seen in all earlier cases, SD values are very high and almost surpassing the average concentrations for all 3 organic parameters in this case marking the very fact of extremely high variability in sources of these nallahs though most of them are domestic in nature.

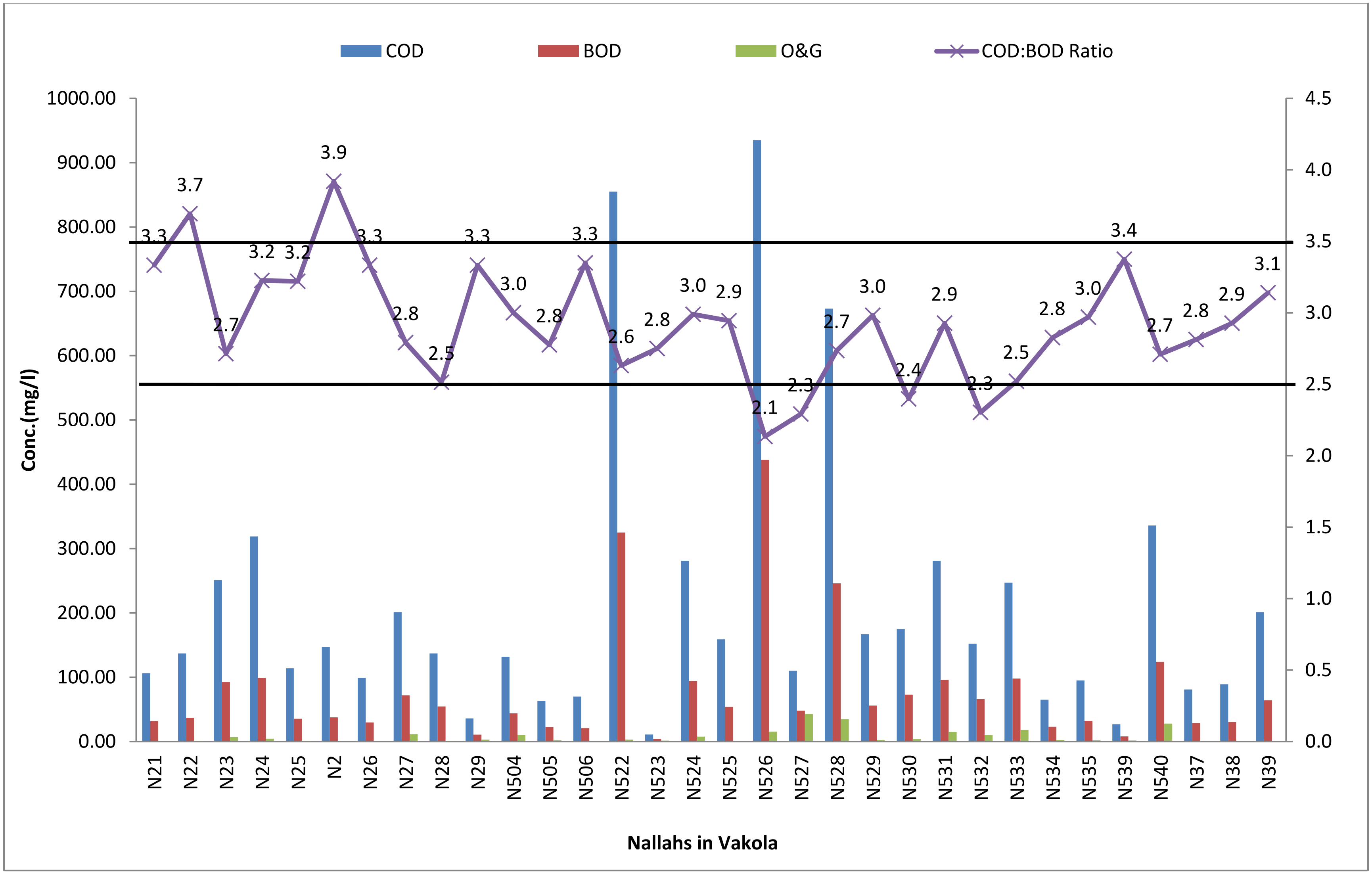
Table 5.6 Statistical Analysis of Organic Parameters of Vakola Nallah during Pre Monsoon

Parameters	Minimum	Maximum	Average	SD
BOD (mg/l)	4.0	438.0	103.5	123.7
COD (mg/l)	11.0	935.0	267.3	277.5
O&G (mg/l)	0.0	34.9	8.1	10.4
COD to BOD ratio	2.1	3.9	2.9	0.5

Only 2 of the 32 nallahs entering Vakola shows COD to BOD ratio of >3.5 thereby substantiating the fact that industrial source contribution to Vakola nallah is minimal. Though COD to BOD ratio is considered as universal indicator of industrial sources, absolute concentrations of these organics need to be also assessed in order to confirm the assumption. In case of Vakola, there are almost 3 such nallahs which show very high COD>500mg/l & BOD>250mg/l concentrations thereby also pointing to the fact that there might be industrial sources in form of food processing / bakeries etc that are forming entry into these nallahs and ultimately contributing to Vakola nallah. Details of the individual nallahs and their organics loads are presented in **Figure 5.5**.

In conclusion, only about 5 to 6% of the nallahs in case of river concentrated in regions of industrial activities as per the survey details are contributing to high COD to BOD ratios as well as 3 to 4 nallahs that contribute to prominent sources of O&G whereas only 3 sources in Vakola that seem to be from industrial origin. In case of river too, only about 4 to 5 nallahs show resemblance of industrial sources whereas majority of all other source contributions are domestic in nature.

Figure 5.5 Organics in Vakola Nallah Water Samples during Pre-Monsoon



5.3.3 Organics Load in Industrial Wastewaters

Mithi is surrounded by numerous industrial activities mostly unorganized sectors ranging from a variety of hotels and restaurants, bakeries and eateries right in the RoW (actually on the Banks of River), drum washing in slums, jewellery & multiple manufacturing/engineering units in MIDC area of SEEPZ, dying, bleaching and laundry in BMK and KBM Compounds, car washing centre in almost all parts of the river, limited plating units, beverages especially Sakhinaka and Marol, RMC units in Gautam Nagar & similar units along with animal farms / housing in JVLR and several others. Seemingly such a complex source of industrial areas around, it was assumed that at least a few of these industries would add to the overall pollution of Mithi River and thereby monitoring of industrial sources was incorporated in the overall study design. 79 such samples from variety of representative industrial sources were collected with a premise to understand polluting potential of such industries and input variability of river with respect to characteristics of these effluents.

Several of these samples were either raw effluent whereas most of them especially from the large scale organized industries were either sewage or outlets of ETP or combined treated wastewater, statistical analysis of which is presented in **Table 5.7**.

Table 5.7 Statistical Analysis of Organic Parameters in Industries

Parameters	Minimum	Maximum	Average	SD
COD (mg/l)	BDL	21468.0	1002.9	3426.4
BOD (mg/l)	BDL	7256.0	348.7	1168.4
TSS (mg/l)	BDL	3143.0	408.9	491.2
O&G(mg/l)	0.5	5109.0	386.7	1127.6
COD to BOD Ratio	0.0	4.0	2.9	0.8

Both COD & BOD values have a wide variation with BDL concentrations observed mostly with the outlets of ETP of LSI such as L&T Gate No. 7 to 7256mg/l. Similarly TSS too is found to be extremely low in these LSI but higher in those unorganized industries and car washing centre reaching to maxima of 408.9mg/l. O&G is extremely important in organics though averaging only about 386.7mg/l shows maximum concentration of 5109mg/l with similar high concentration trends in almost all the auto-care centre both in Sakhinaka and Marol areas. COD to BOD ratios reaches peaks of 4.0 which is characteristics of industrial waste as have been explained throughout this chapter and assumed for interpretation of industrial sources though the averages for both Cod and BOD are found to be higher than the general consented values for industries in coastal areas i.e. 475mg/l and 180mg/l respectively. Though the average ratio seems to be around 2.9, it is to be considered in relation with the types of samples used for such averaging. The authors would like to put forth that when analysis of industrial wastewater samples pertaining to only effluents from industrial areas are considered, the COD to BOD ratios seem to be >3.5 as is also evident from nallah wastewater analysis from those areas connected to industrial activities.

The other 2 parameters representing organics too show concentrations higher than the General Standards prescribed in Coastal region industries though the conditions may be much more stringent for such industries located on the banks of Mithi River being classified as RRZ II. Average concentration of TSS and O&G are found to be 408.9mg/l and 386.7mg/l respectively which seem to pose critical cause of concern. Extremely high concentrations of O&G in case of auto-care related industries which are about 8 out of the 79 samples and can be extrapolated to be representative of almost all similar units around Mithi.

5.3.4 Comparative Account of Organics Load

A unconventional concept of using cluster / association of various parameters through computing ratio in various samples of River : Nallah : Vakola Nallah : Industries is used to understand proximity and probable source determinants into Mithi River as presented in **Table 5.8**and illustrated as base of proximity pyramid. It is also important that this concept need not be considered in isolation but shall be used as just another way of interpreting data and be approached in accordance with all other computations described earlier. Thereby COD & BOD appears nearest to Nallahs with a factor of 2 v/s factor of 4 for industries. TSS shows its relevant proximity to nallah as well as industrial sources with almost similar factor or 0.7.

O&G possess a very unique feature contrary to the fact that most of it remains floating and unchanged under influence of other sources which is not the case with other outlined organics in this comparison. A ratio of 25 times to 1 represented by Industries v/s River water seems to only suggest that the major contributor of O&G in river is industry. Conductivity too shows varying facts with respect to both nallahs and industries and thereby in itself may be contributed by sources within the river itself.

The most prominent relationship established by this method is of COD to BOD ratio for river and nallahs exactly coinciding to 1.0 which shows maximum proximity whereas industries are a bit lower to 0.81 though may not be overruled for its proximity especially also further demonstrates the fact that certain part of the industrial samples were obtained from sewage water.

Table 5.8 Comparative Account of Parameters Contributing and Representing Organics

Parameters	River	Nallahs into Mithi	Nallah into Vakola	Industries
COD (mg/l)	120.3	233.4	211.0	475.4
COD Ratio of River:Nallah:Vakola:Industry			***1.00 : 1.94 : 1.75 : 3.95***	
BOD (mg/l)	39.0	76.2	78.0	179.8
BOD Ratio of River:Nallah:Vakola:Industry			***1.00 : 1.95 : 2.00 : 4.60***	
TSS (mg/l)	402.8	306.4	143.3	289.4
TSS Ratio of River:Nallah:Vakola:Industry			***1.00 : 0.76 : 0.36 : 0.71***	
O&G (mg/l)	19.9	71.1	7.2	498.7
O&G Ratio of River:Nallah:Vakola:Industry			***1.00 : 3.57 : 0.36 : 25.06***	
Conductivity (mS/cm)	3689.0	1110.0	1285.3	7390.9
Conductivity Ratio of River:Nallah:Vakola:Industry			***1.00 : 0.30 0.34 : 2.00***	
COD to BOD Ratio	3.1	3.1	2.7	2.9
COD/BOD Ratio of River:Nallah:Vakola:Industry			***1.00 : 1.00 :0.87 : 0.93***	

5.4 Dissolved Oxygen Content in Mithi River

Dissolved oxygen in the water plays a vital role in the degradation of organic load present in the water as well as is very much essential for the survival of all life forms. Though DO forms an essential part of the organics behavior especially BOD, it was essentially one of the aspects that do not form essential part of the Water Quality Standards for Discharge Schedule VI (Part A) though it is part of the Designated Base Use Limits prescribed i.e. Class C or D, by competent authority which is considered in this case as 4mg/l being either drinking water source after conventional treatment or propagation of wildlife fisheries which rather should be the adopted concentration for Mithi. Thereby since it is the most important aspect to show health of the river water in terms of supporting life forms, all the samples collected during study were measured for DO variations both by Online Meters and also in laboratory by conventional method.

Figure 5.6outlines variations in the DO concentrations observed in the river wherein all the DO values are less than the 4mg/l mark thereby raising concerns of serious nature and also reflecting that most of DO is already consumed due to BOD load. The maximum concentration of DO is observed at the upstream of the Sakhinaka which is 3.3mg/l whereas the minimum of 2.2mg/l observed at upstream of KBM Compound &downstream of the Safed Pool.

Figure 5.7 represents the DO concentrations in the nallahs adjoining river in each of the stretches revealing that the maximum concentration of DO is 4.8mg/l which is observed at Safed Pool. The minimum concentration of 2.2mg/l is observed at the three of the nallahs, two near BamandayaPada and one in Sakhinaka. Interestingly Safed Pool nallah which carries one of the high hydraulic loads into river seems to have the highest DO levels. The main reason for this kind of behavior is not only the highly diluted organics load in this section but also due to extremely high turbulence that in inherent in the path of this nallah which probably contributes to natural oxygen replenishment process leading to reduction in BOD as well as increase in DO levels.

Dissolved Oxygen levels in Vakola Nallah are shown in **Figure 5.8**revealing that the maximum concentration observed was of 3.5mg/l in N23 whereas the minimum is 2.2mg/l observed in N39 that represent small nallahs entering Vakola. Though there is no specifically prescribed standard limit for public sewer discharge, it is assumed that these low oxygen concentrations would aggravate the already deteriorating conditions of Mithi at least in certain portion of the river. The only savior to this low oxygen content is sea water intrusion that helps aid the natural rejuvenation process of the nallah to a certain extent.

Figure 5.6 Dissolved Oxygen Concentrations in Mithi River Samples

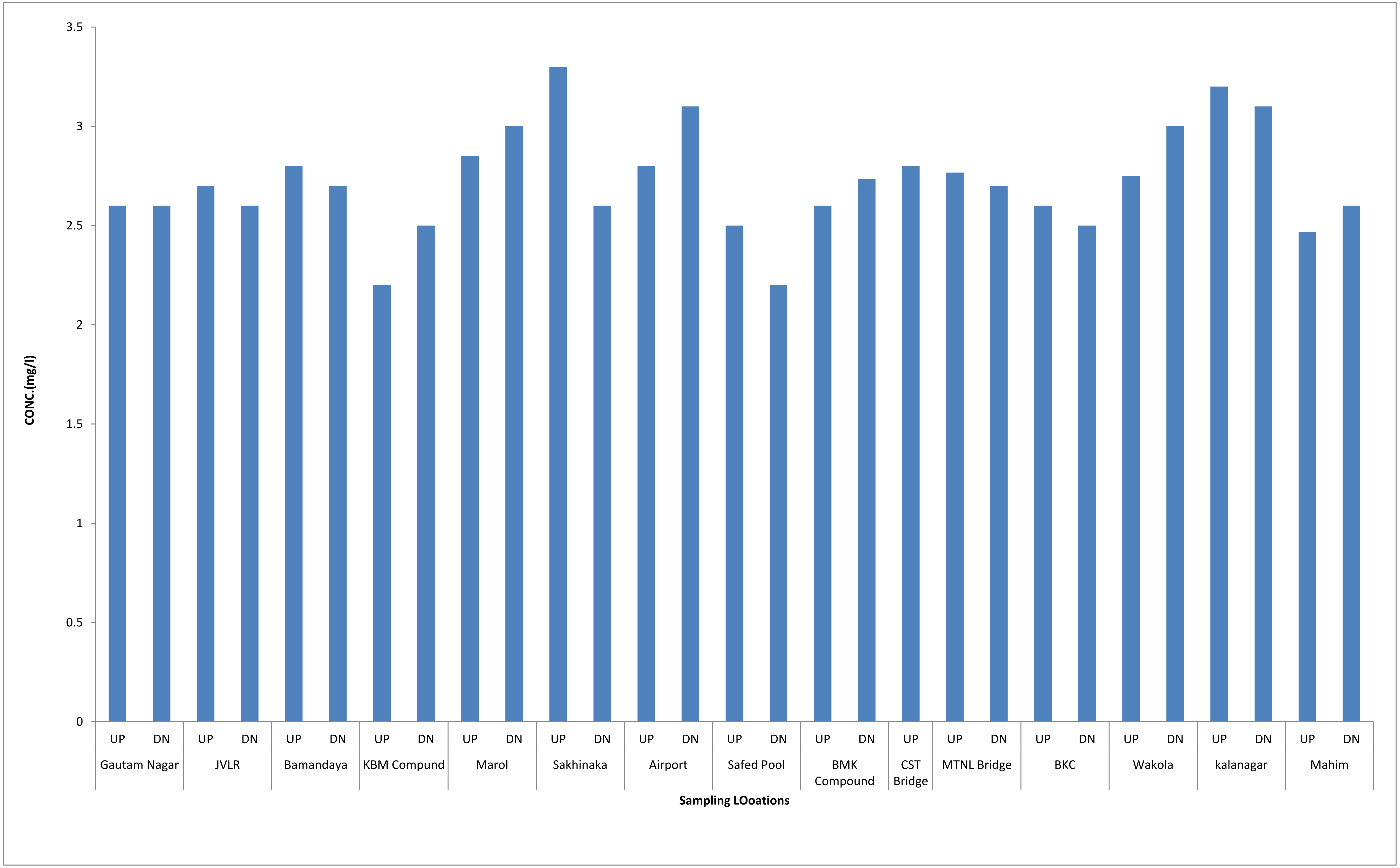


Figure 5.7 Dissolved Oxygen Concentrations in Nallahs Entering Mithi River

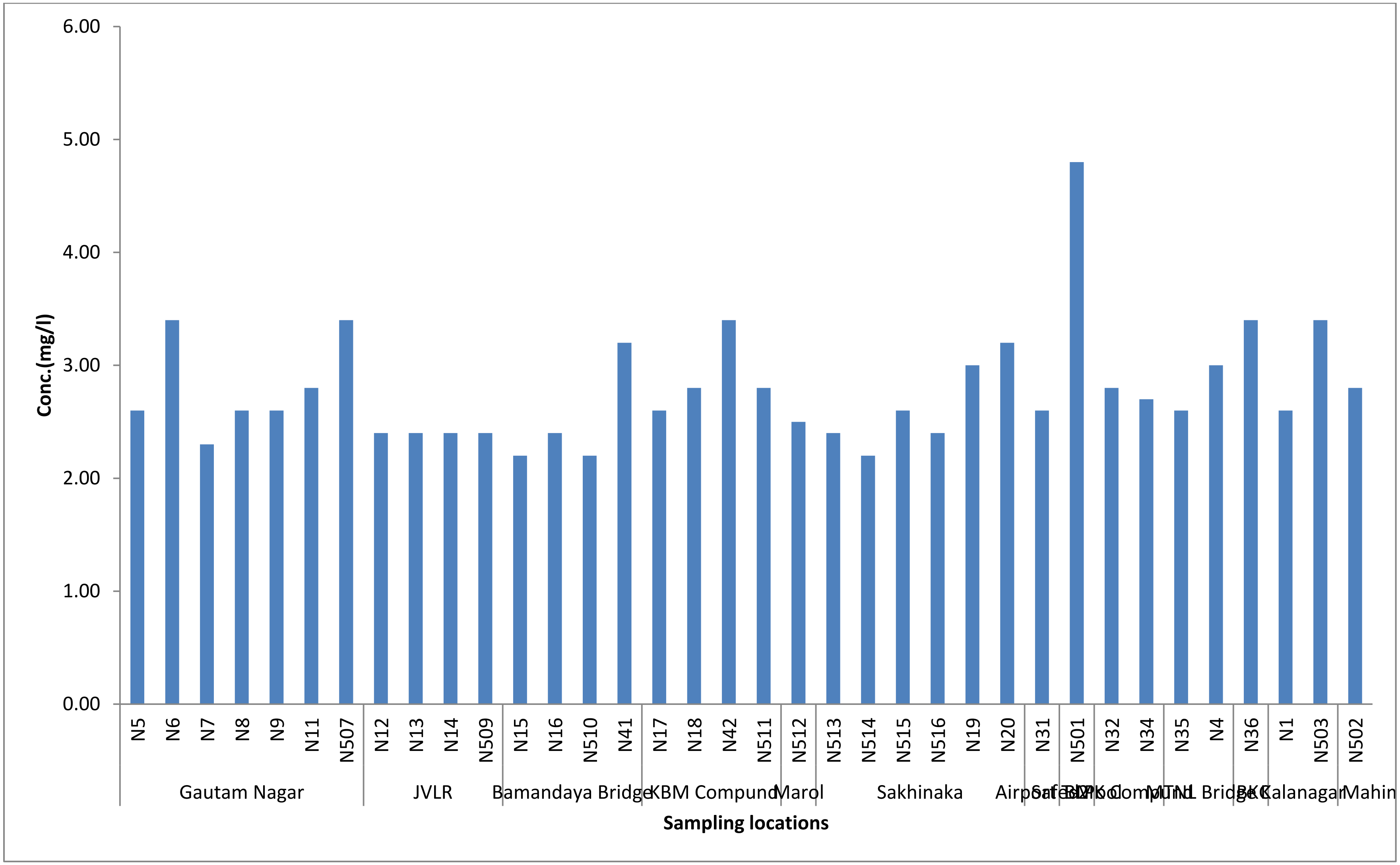
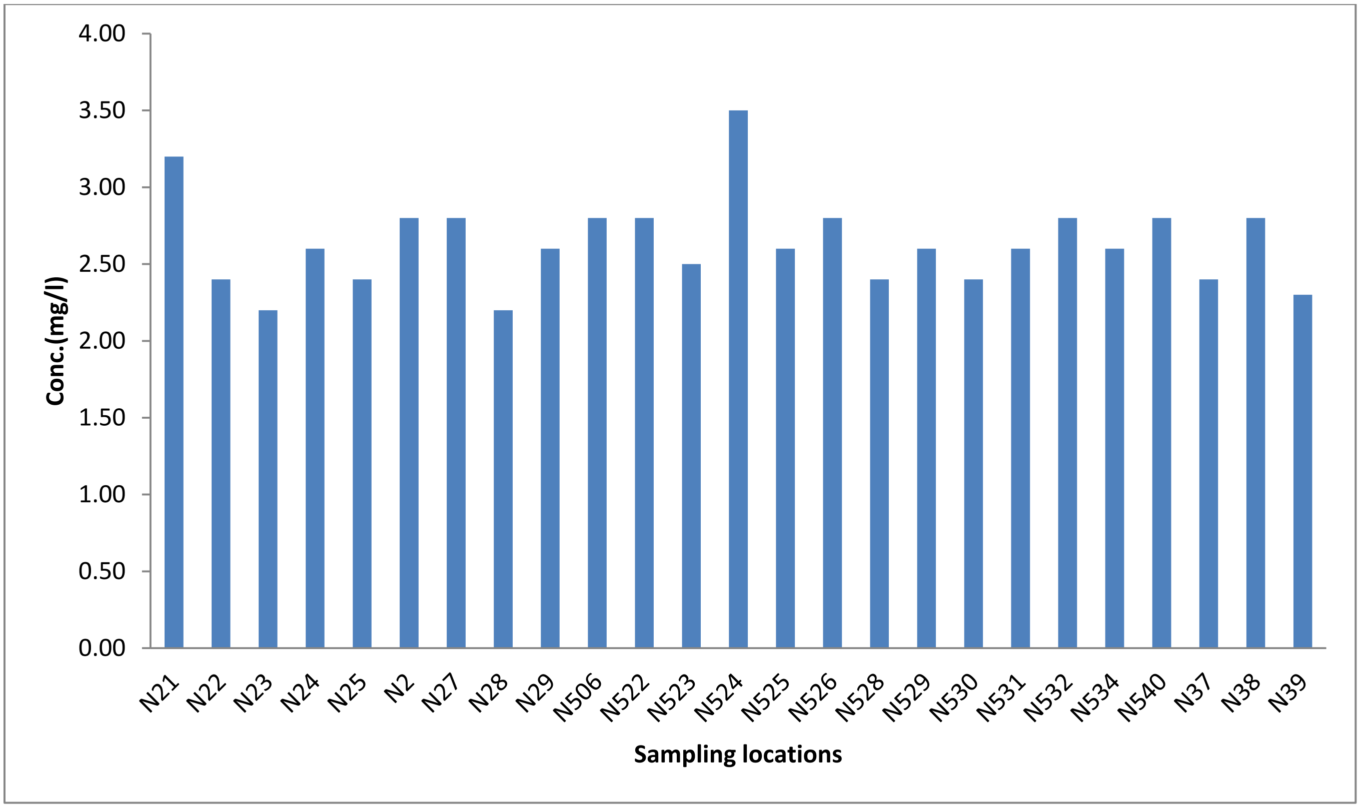


Figure 5.8 Dissolved Oxygen Concentrations in Vakola Nallah Samples



Chapter VI

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Chapter VI

Physico-Chemical Characterization of Mithi River& Nallahs

6.0 Background

The previous chapter outlined parameters that add to the organic content of Mithi River along with description of probable sources responsible. As also described in earlier chapters, there are 19 other parameters that were measured during the pre-monsoon period of study. In previous schedule of monitoring, very few parameters other than organics were measured and such as TDS, chlorides, O&G, nitrates, phosphates during Monsoon whereas still fewer such as MPN, Suspended solids, O&G thereby making it inconsistent to compare & report the same.

6.1 Physico-chemical Characterization of Mithi River

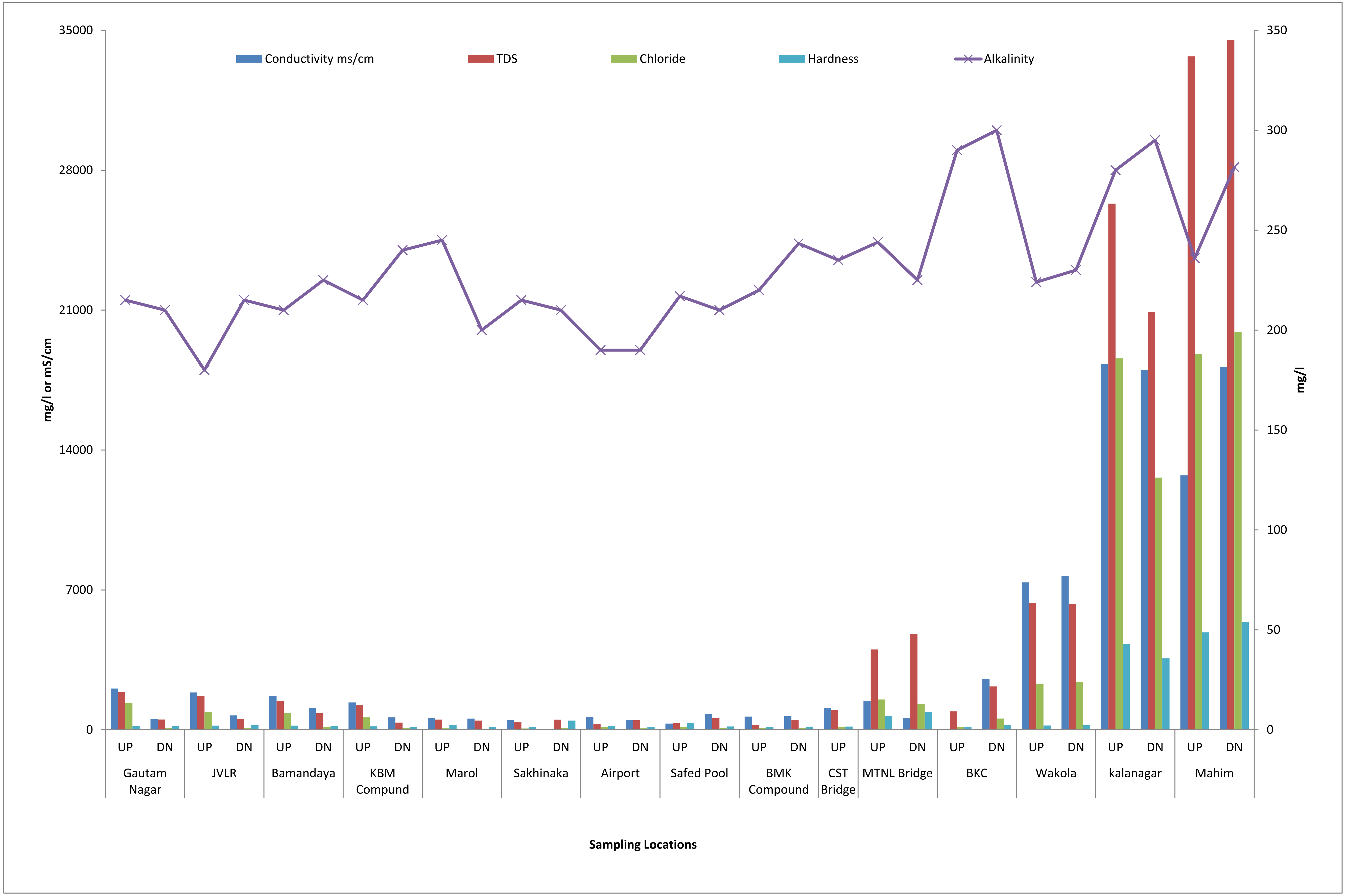
Thereby this chapter describes all such physico-chemical parameters of interest and accountable to pollution potential in Mithi as well as their probable source contributions through nallahs entering the river only for monitoring period of pre-monsoon i.e. May 2014. For the ease of interpretation, these parameters are classified into those that contribute and represent conductivity, cations, anions or nutrients and special parameter of interest such as MPN and phenols.

6.1.1 Major Parameters Contributing &Representing Conductivityin Mithi River

Conductivity is a direct measure of ionic content and thereby in relation to Mithi River the major reflection of Total Dissolved Solids [TDS]. Extremely high conductivity is observed in some parts of the river due to tidal influence with maxima reaching to 18297.2mS/cm as a prominent mark of sea water intrusion which is mainly constituted by TDS as evident from very high concentration of maxima at 35506.3mg/l and majorly contributed by chlorides @ maxima of 19919.3mg/l. This trend is observed almost 5 to 6kms inland from the last point where Mithi converges into the Arabian Sea through Mahim Creek. The variability of these parameters at individual monitoring locations is presented in **Figure 6.1**.

Locations where sea water is not impacting Mithi shows low conductivity of 0.7mS/cm with equally low TDS of 245mg/l and mainly contributed in these sections by hardness @ 180mg/l. There is a wide variation in characteristics of these parameters due to prominent differentiation based on sea water intrusion as depicted in **Table 6.1**.

Figure 6.1 Major Parameters Contributing and Representing Conductivity in Mithi River



Standard deviations equally reflect the same being higher than the averages itself which for conductivity is 3688.9ms/cm, TDS is 5303.4mg/l, Chlorides is 2880.0mg/l and hardness is 845.5mg/l. Alkalinity which is a measure of capacity to equate acidity ranges from ranges from 180mg/l to 300mg/l with average of 230.7mg/l and may also be contributed mainly due to sea water impacts.

Table 6.1 Statistical Analysis of Major Parameters of Mithi River Contributing TDS during Monsoon

Parameters	Minimum	Maximum	Average	SD	Std. (ISW - a)
Conductivity (mS/cm)	0.70	18297.2	3688.9	5813.6	NA
TDS (mg/l)	245.0	34506.3	5303.4	9963.3	2100
Chloride (mg/l)	59.0	19919.3	2880.0	6078.3	1000
Alkalinity (mg/l)	180.0	300.0	230.7	31.7	NA
Hardness (mg/l)	146.0	5392.3	845.5	1532.6	NA

6.1.2 Major Parameters Contributing & Representing Anions in Mithi River

On the other hand sea water does impact concentrations of sulphates bringing it inland via tidal impacts which range from 13.4mg/l to 4279.4mg/l with average of 917.7mg/l as delineated in **Table 6.2**. The minimum values are observed mainly in regions in upper half of the river starting from origins which are mostly dominated by sewage sources and few industrial ones. It is quite evident through univariate analysis that hardness is mainly represented in SO_4 form and that is brought by sea water since no other domestic or industrial sources account for such high SO_4 concentration.Nutrients in form of nitrates and phosphates are minimal in concentrations ranging from BDL to 24.6mg/l and 1.3mg/l averaging about 12.1mg/l and 0.2mg/l respectively as presented in **Figure 6.2**. Interestingly, all those parameters such as nutrients where sources are consistent show low SD values whereas those where variability is inherent due to sea water intrusion show very high SD values much beyond averages as seen in both cases discussed here.

Table 6.2 Statistical Analysis of Anionic Parameters of Mithi River during Monsoon

Parameters	Minimum	Maximum	Average	SD	Std. (ISW - a)
SO_4(mg/l)	13.4	4279.4	917.7	1267.4	1000
PO_4(mg/l)	BDL	24.6	12.1	6.0	NA
NO_3(mg/l)	BDL	1.3	0.2	0.3	NA

Figure 6.2 Parameters Contributing and Representing Anions in Mithi River

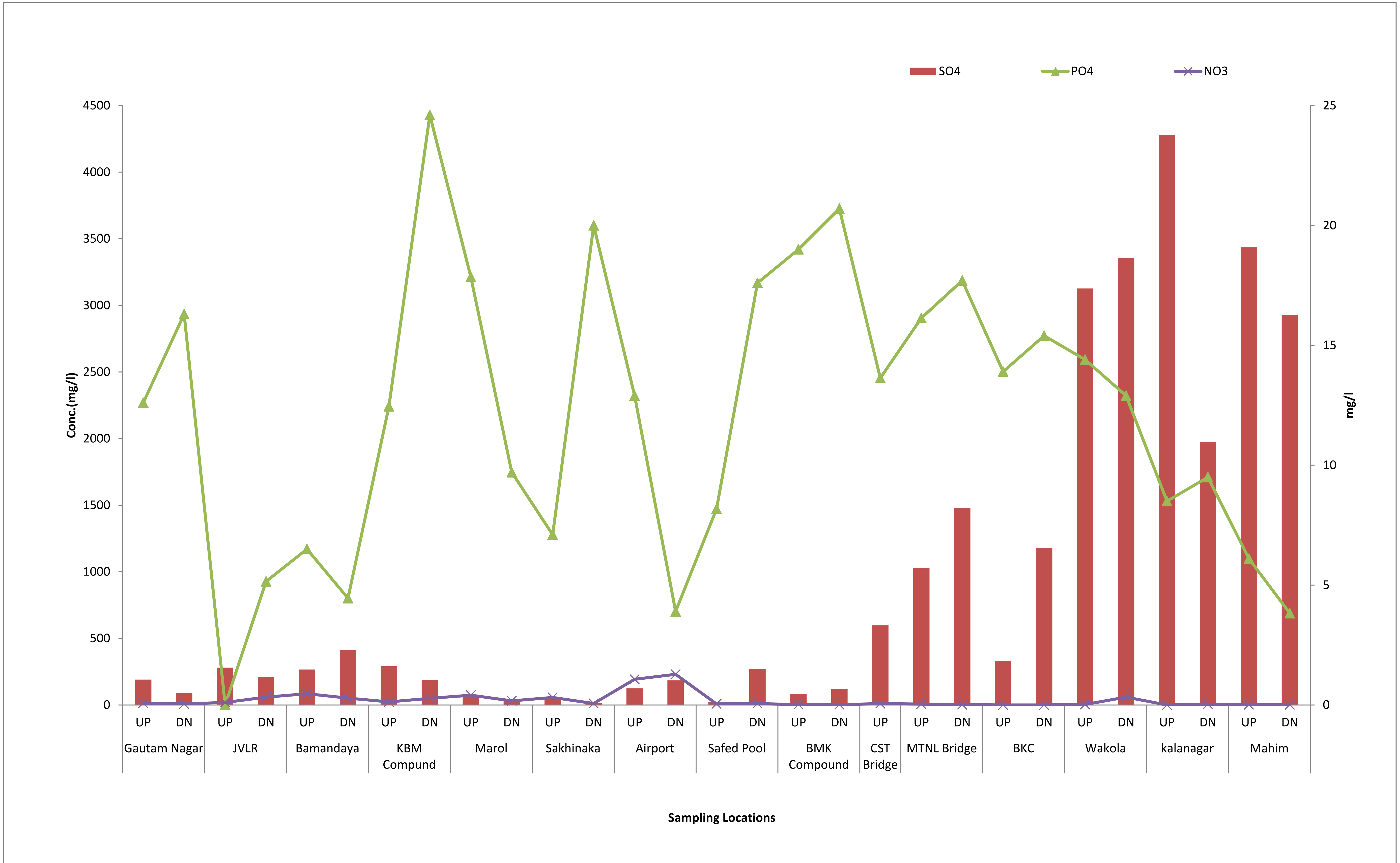
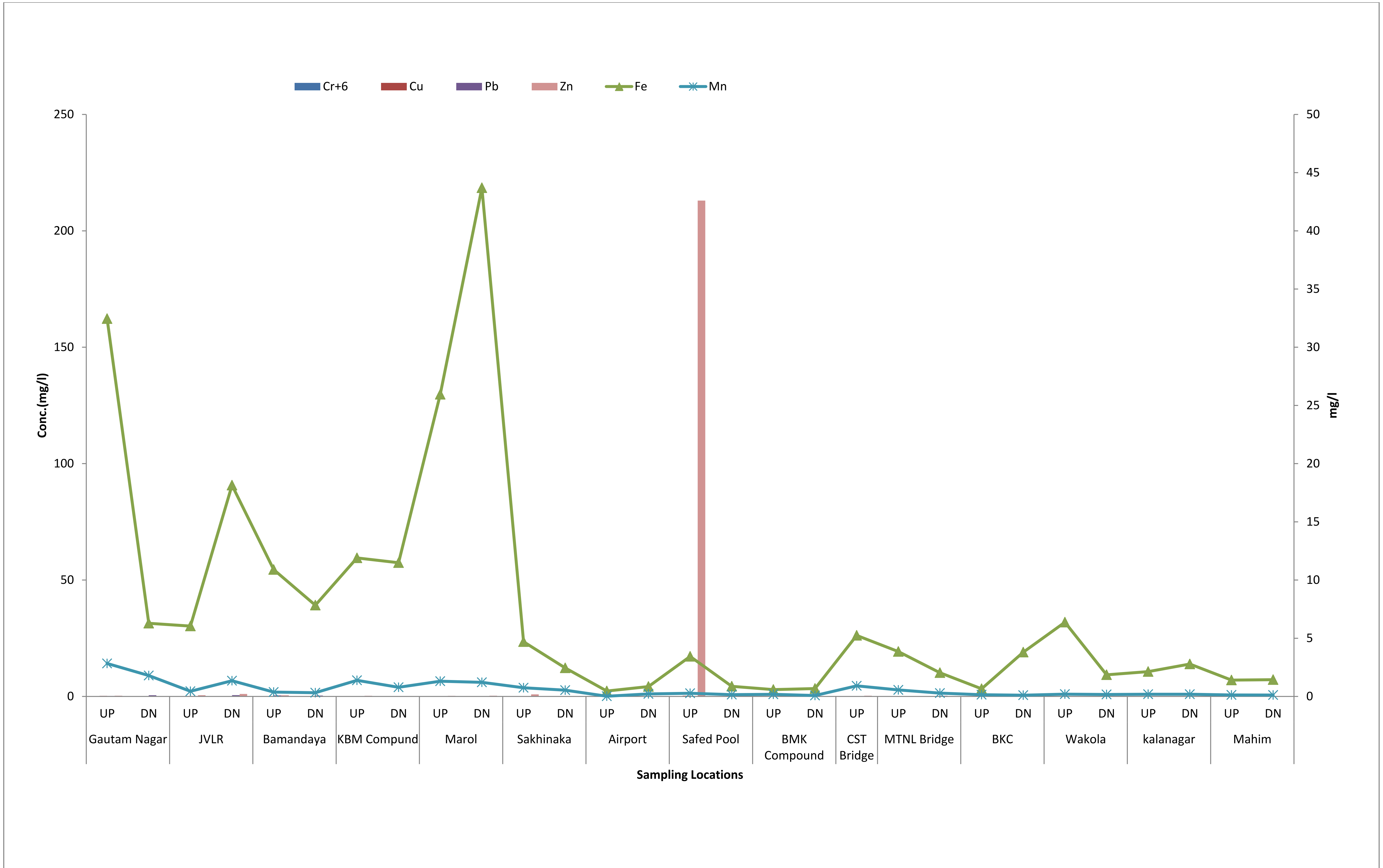


Figure 6.3 Parameters Contributing and Representing Cations in Mithi River



When compared to Schedule VI - General Discharge Standards [*Best Designated Use for Inland Surface Water (a) classification*] for available parameters, average values for TDS & chlorides are extremely higher than 2100mg/l & 1000mg/l respectively whereas that for SO_4 is just lower than 1000mg/l prescribed limits.

6.1.3 Major Parameters Contributing & Representing Cations in Mithi River

Metal concentrations (**Figure 6.3**) are found to be extremely lowthroughout the section of Mithi River as presented in **Table 6.3**. All metals show minimum concentration BDL except Fe which has minimum of 0.5mg/l concentration whereas Cr^{+6}, Cd and Co are found to be BDL in all sections of the river. Maximum concentrations of Cu, Fe Pb, Mn and Ni are found to be 0.3mg/l, 43.7mg/l, 0.6mg/l, 2.8mg/l and 1.3mg/l which are higher than the standards though almost all of them show average concentrations below Inland Surface Water Standards. Zn is the only metal that shows very high concentration in some parts of the river stretches with maxima reaching to 213.0mg/l and average of 7.5mg/l which is almost 1.5times higher than the standard of 5.0mg/l.

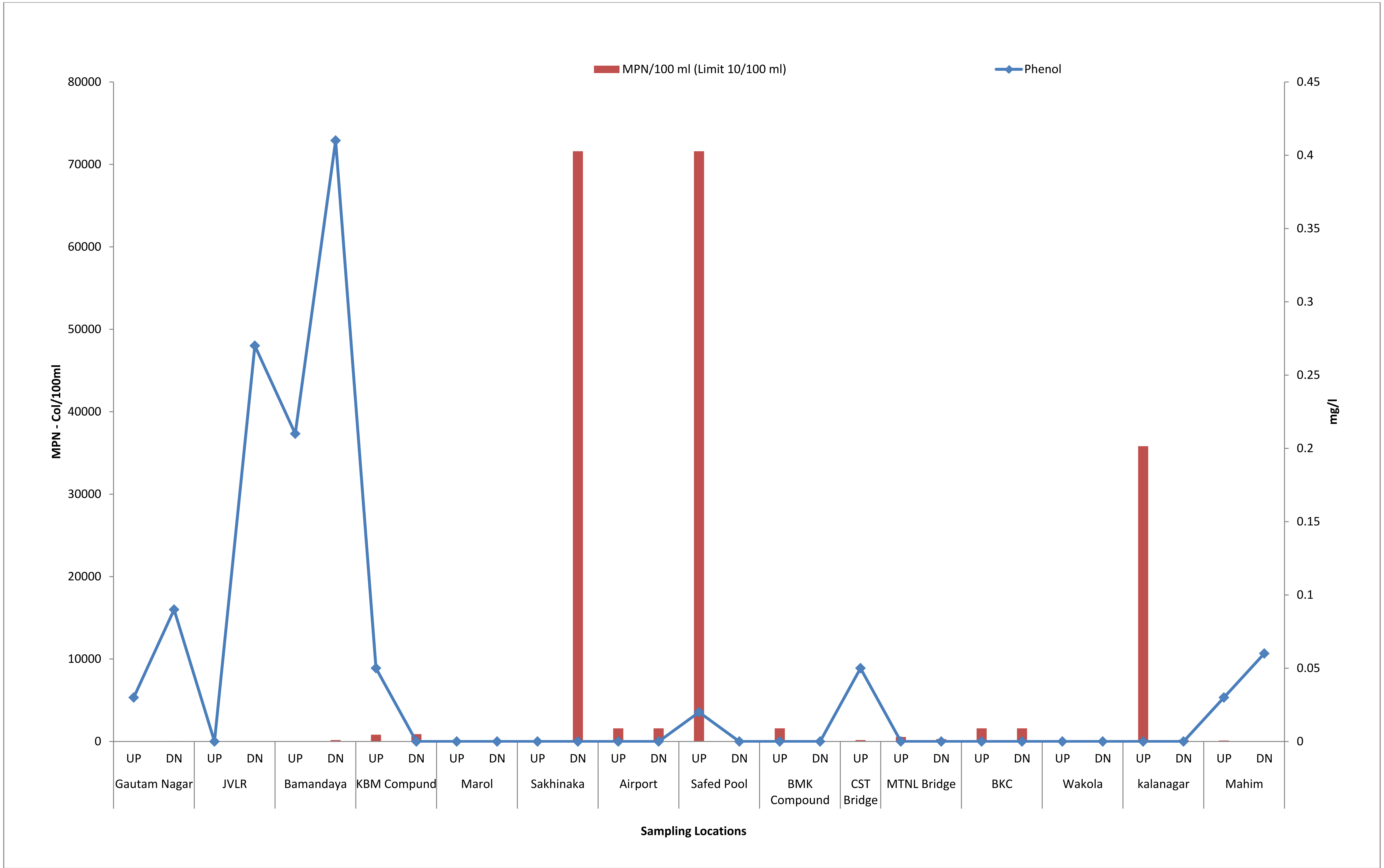
Table 6.3 Statistical Analysis of Cationic Parameters of Mithi River during Monsoon

Parameters	Minimum	Maximum	Average	SD
Cr^{+6}(mg/l)	BDL	BDL	BDL	BDL
Cu (mg/l)	BDL	0.3	0.1	0.1
Fe (mg/l)	0.5	43.7	7.6	10.3
Pb (mg/l)	BDL	0.6	0.1	0.2
Mn (mg/l)	BDL	2.8	0.6	0.6
Ni (mg/l)	BDL	1.3	0.1	0.3
Cd (mg/l)	BDL	BDL	BDL	BDL
CO (mg/l)	BDL	BDL	BDL	BDL
Zn (mg/l)	BDL	213.0	7.5	39.5

6.1.4 Special Parameters Representing Characters of Mithi River

Two such parameters the variability of which is presented in **Figure 6.4**i.e. MPN which represents fecal contamination seems to be extremely high probably due to direct discharge of raw sewage at several entry points into Mithi River as represented in **Table 6.4** with values ranging from 19col/100ml to 71,600col/100ml and average of 8028col/100ml probably due to practices of open defecation directly adding to the fecal coliforms into river.

Figure 6.4 Special Parameters Representing Characters of Mithi River



In fact most of the domestic inputs to Mithi show values more >1600col/100ml and since Inland Surface Water Standards do not specify limits for MPN and Mithi often being used for human contact purpose when compared with IS10500, the average values are extremely critical though may not be the ideal way of comparison.

Table 6.4 Statistical Analysis of Special Parameters of Mithi River during Monsoon

Parameters	Minimum	Maximum	Average	SD	Std. (ISW - a)
Phenols (mg/l)	BDL	0.41	0.04	0.09	1.0
MPN (Col/100ml)	19	71600	8028	21383	10 (IS10500)

And the second one i.e. phenols which may find its source from industrial discharges and also many a times from raw sewage due to recent and exponential use of disinfectants containing phenols, the presence of phenol is marked in several sections of Mithi thought eh concentrations are much below the prescribed limits as defined by Schedule VI - General Discharge Standardslimit of 1.0mg/l. The average concentration of phenols is found to be mere 0.04mg/l.

6.2 Physico-chemical Characterization of Nallahs Contributing to Mithi River

The 41 major attributable nallahs discharging wastewater into Mithi River monitored during May 2014 are described already in earlier sections of this report. Most of them are found to be laden with domestic wastewater, which are further substantiated with the description of physic-chemical characterization outlined hereunder.

6.2.1 Major Parameters Contributing & Representing Conductivity in Nallahs

As seen in case of river, under the influence of tides, many of the nallahs too show very high concentrations of parameters that add to TDS and thereby resulting high conductivity though the same are found to be much lower than those observed in river itself. **Figure 6.5** presents individual characteristics of nallahs that show marked variations in conductivity at the extreme end of river i.e. towards Arabian Sea through the last 5kms of stretch from Vakola to Mahim Creek i.e. in only 4 to 5 nallahs. Otherwise most of the other nallahs contribute to very little conductivity and related parameters.

Conductivity reaches to maxima of 15210ms/cm averaging about 1110mS/cm whereas TDS shows maxima of 39385mg/l mainly due to the contribution from chlorides to the extent of 11812mg/l and hardness of maximum concentrations reaching about 5813mg/l.

Figure 6.5 Major Parameters Contributing and Representing Conductivity in Mithi River

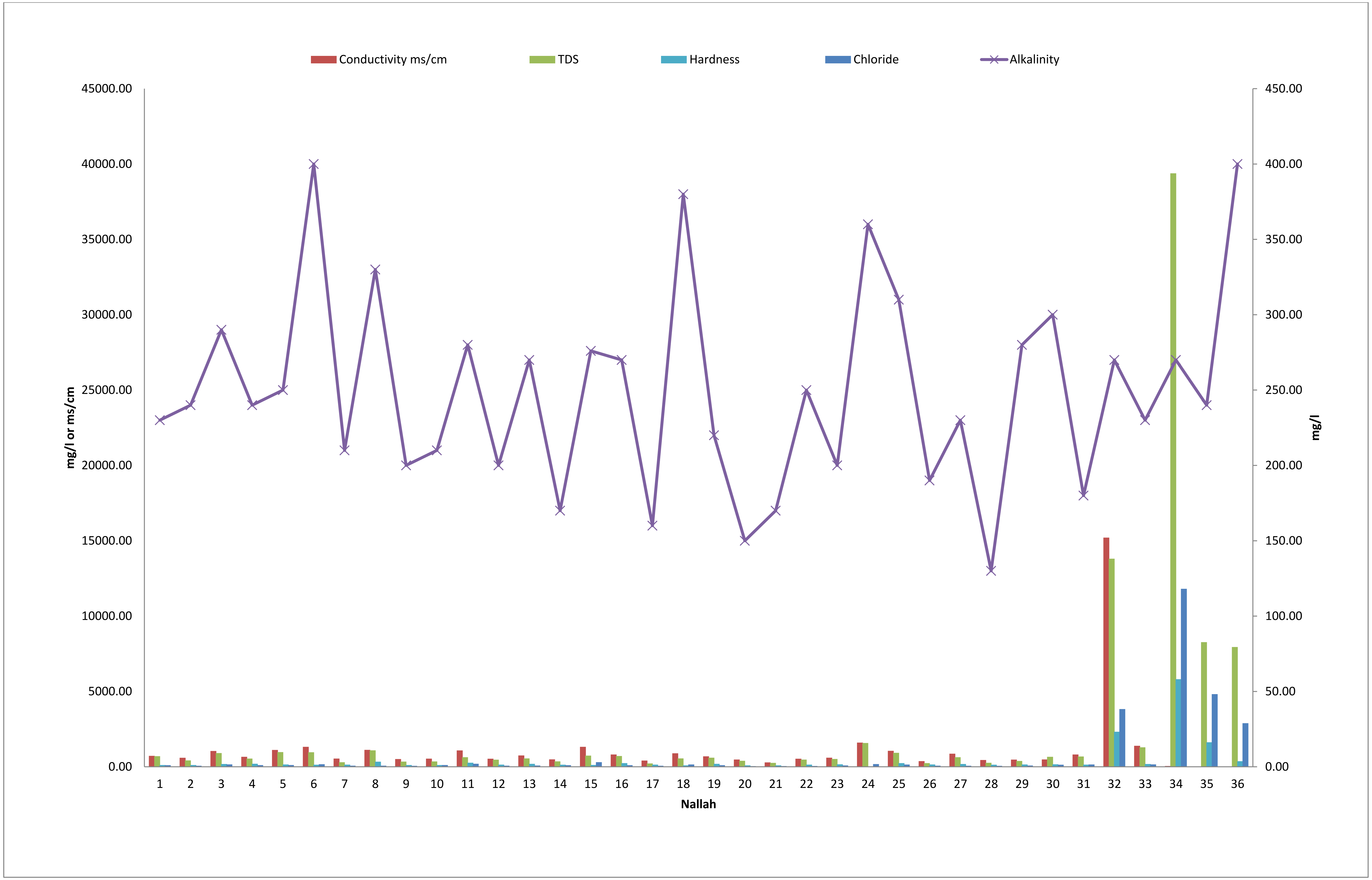


Table 6.5 Statistical Analysis of Major Parameters of Nallahs Contributing TDS during Monsoon

Parameters	Minimum	Maximum	Average	SD	Std. (PS - b)
Conductivity (mS/cm)	1.4	15210.0	1110.0	2446.9	NA
TDS (mg/l)	225.0	39385.0	2479.1	6902.9	2100
Chloride (mg/l)	41.0	11812.0	748.4	2178.9	1000
Alkalinity (mg/l)	130.0	400.0	249.6	67.4	NA
Hardness (mg/l)	29.0	5813.0	422.9	1020.8	NA

Average concentration of TDS is 2479.1mg/l which is equated with mainly average chlorideconcentration of 2178.9mg/l and hardness of 1020.8mg/l all of which contribute to the average conductivity observed as 1110mS/cm. Interestingly it is evident in nallahs too that only a few of them as stated earlier are responsible for such high variations as well as higher values of parameters as substantiated with extremely high SD values again beyond the averages itself. Alkalinity however shows very limited concentration ranging from 130 to 400mg/l with an average of 67.4mg/l. When compared to standards, since some of the nallahs contribute to the extreme concentrations, the averages too are impacted in such a manner as to be beyond the prescribed limits of Inland Surface Water for both TDS and chlorides under the influence of tides.

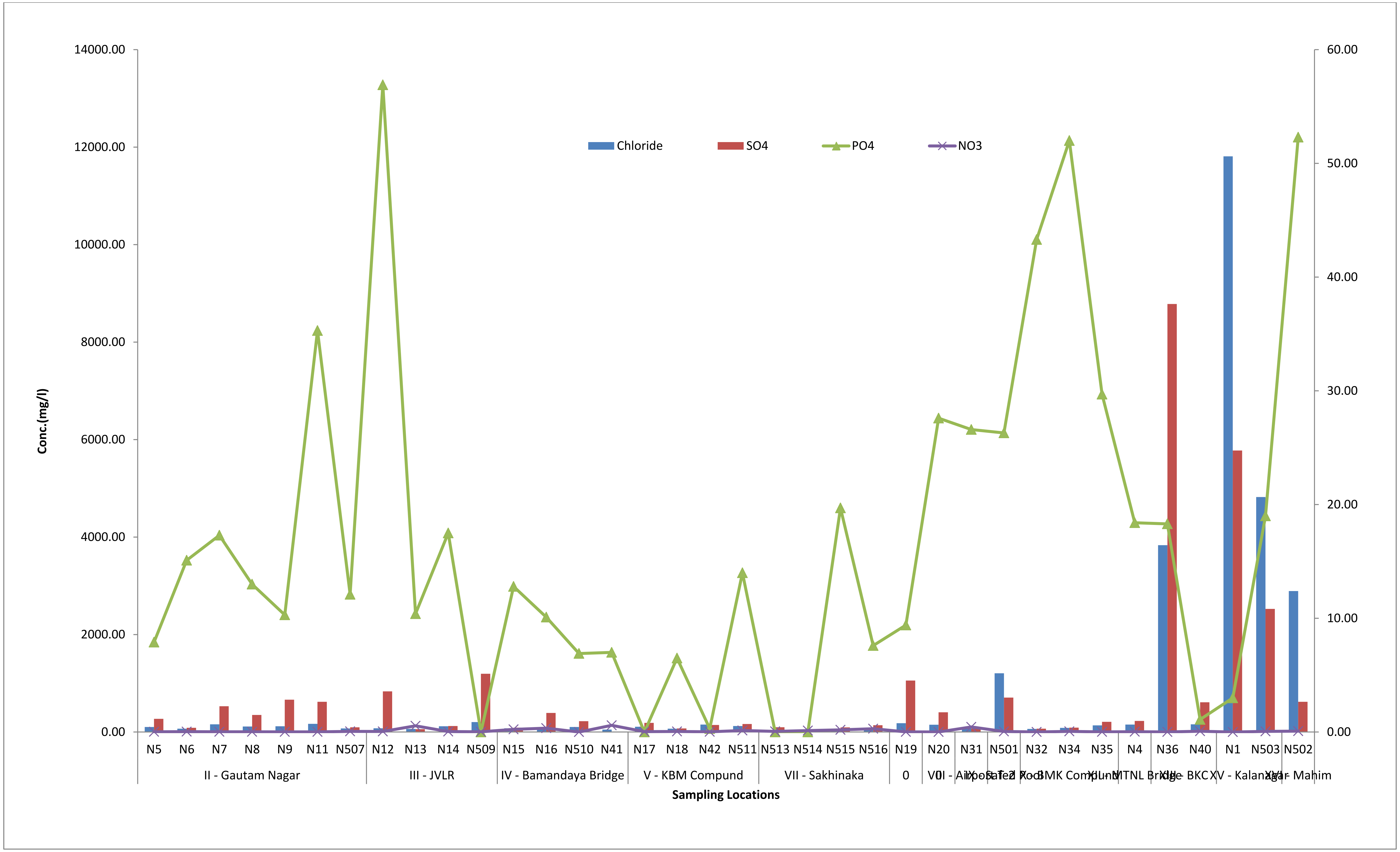
6.2.2 Major Parameters Contributing & Representing Anions in Nallahs

Statistical analysis of anions are depicted in **Table 6.6** which shows that sulphate concentration raging from 21.8mg/l to 8787.3mg/l with average of 771.4mg/l though well within the prescribed limits of Inland Surface Water Criteria exceed by a factor of 8.7 at maxima values and probably also mainly contributes to hardness. Nutrients on other hand are very limited in concentrations with averages of NO_3& PO_4 found to be 16.2mg/l & 0.2mg/l respectively. This also reveals the fact that these nutrients are contributed mainly through the raw sewage water and there are no such prominent agricultural or other sources. Individual characteristics of each nallah are represented in **Figure 6.6**.

Table 6.6 Statistical Analysis of Anionic Parameters of Mithi River during Monsoon

Parameters	Minimum	Maximum	Average	SD	Std. (ISW - a)
SO_4(mg/l)	21.8	8782.3	771.4	1705.7	1000
PO_4(mg/l)	BDL	56.9	16.2	15.4	NA
NO_3(mg/l)	BDL	2.4	0.2	0.4	NA

Figure 6.6 Parameters Contributing and Representing Anions in Nallahs



6.2.3 Major Parameters Contributing & Representing Cations in Nallahs

As observed in case of river samples, most of the nallah water samples reflect similar trends wherein minimum concentrations are found to be BDL for almost all metals except Fe, Mn& Zn which are found to be 0.6mg/l and 0.1mg/l as delineated in **Table 6.7**. On the other hand Cr^{+6}, Ni, Cd and Co are absent in any of the nallahs. The average concentrations of those that are found to be present in small quantities in these nallahs are Cu @ 0.1mg/l, Fe @ 10.6mg/l, Pb @ 0.1mg/l, Mn @ 1.0mg/l and Zn @ 0.4mg/l. Fe is found to be the highest probably originating from nature and also from leaching of most plumbing materials commonly found in Indian households. The variability of each of these metals in individual nallahs is presented in **Figure 6.7**. All those metals for which Schedule VI - General Discharge Standards for Inland Surface Water are defined are found to be well within prescribed limits.

Table 6.7 Statistical Analysis of Cationic Parameters of Nallahs during Monsoon

Parameters	Minimum	Maximum	Average	SD	Std. (PS - b)
Cr^{+6}(mg/l)	BDL	BDL	BDL	BDL	0.1
Cu (mg/l)	BDL	0.5	0.1	0.1	3.0
Fe (mg/l)	0.6	43.4	10.6	10.3	NA
Pb (mg/l)	BDL	0.7	0.1	0.1	0.1
Mn (mg/l)	0.1	6.6	1.0	1.5	NA
Ni (mg/l)	BDL	BDL	BDL	BDL	3.0
Cd (mg/l)	BDL	BDL	BDL	BDL	2.0
CO (mg/l)	BDL	BDL	BDL	BDL	NA
Zn (mg/l)	BDL	9.2	0.4	1.5	5.0

6.2.4 Special Parameters Representing Characters of Nallahs

Surprisingly the MPN values in most of the nallahs are found to be >1600 as represented in **Figure 6.8**. Though the averages are found to be low compared to those in the river which is probably because most of the slum areas surrounding Mithi Rivers are not equipped with toilet facilities and thereby the nallahs that carry raw sewage are probably few of human excreta which otherwise is expected to be transferred via closed pipelines in urban areas and for those urban habitants connected to Mithi River have septic tanks that probably result in reducing such coliform numbers in nallahs. Thereby MPN numbers range from 10 to 1600col/100ml with average value of 817.9col/100ml as shown in **Figure 6.8** whereas statistical analysis of same is depicted in **Table 6.8**.

Figure 6.7 Parameters Contributing and Representing Cations in Nallahs

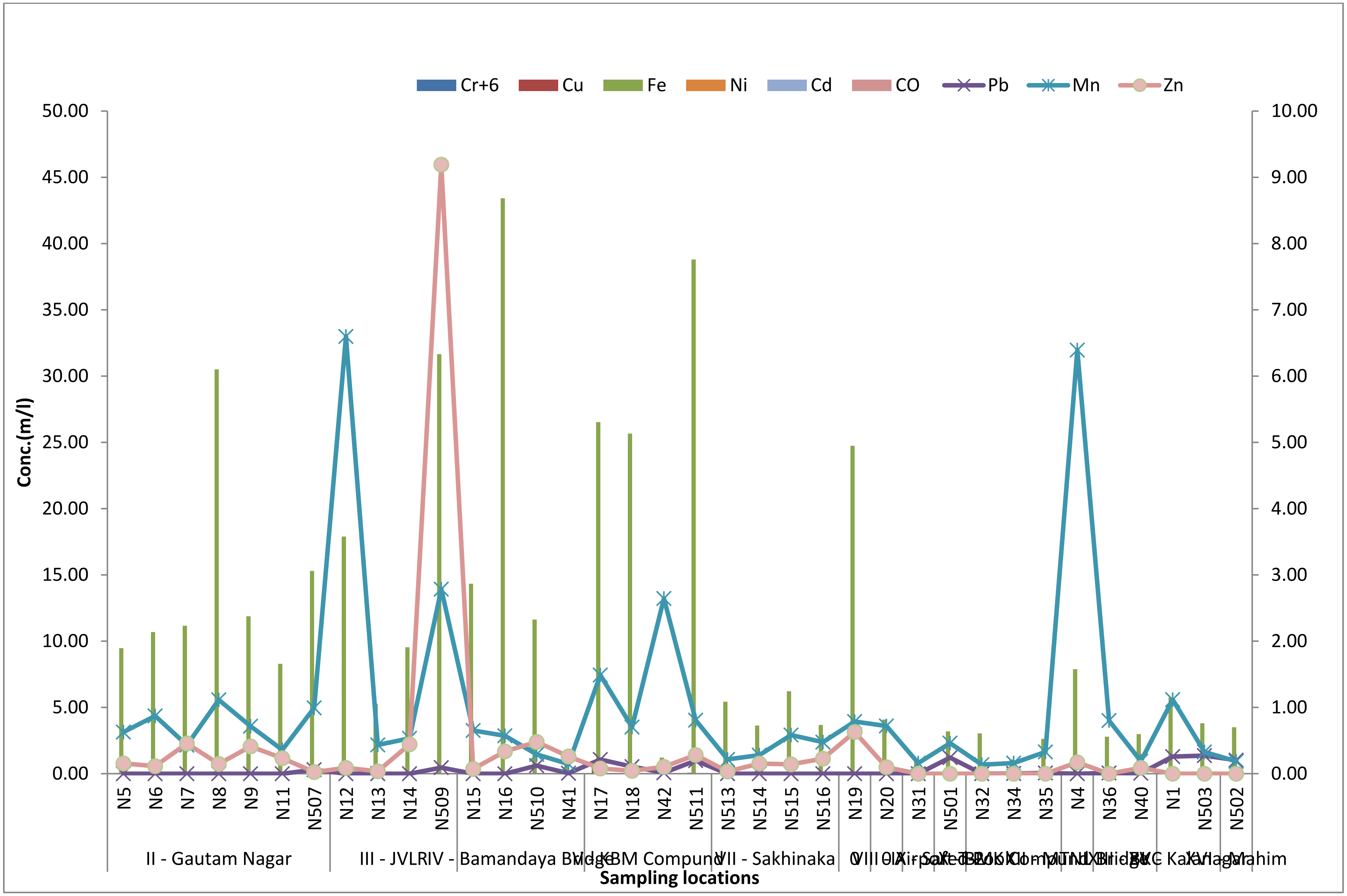


Figure 6.8 Special Parameters Representing Characters of Nallahs

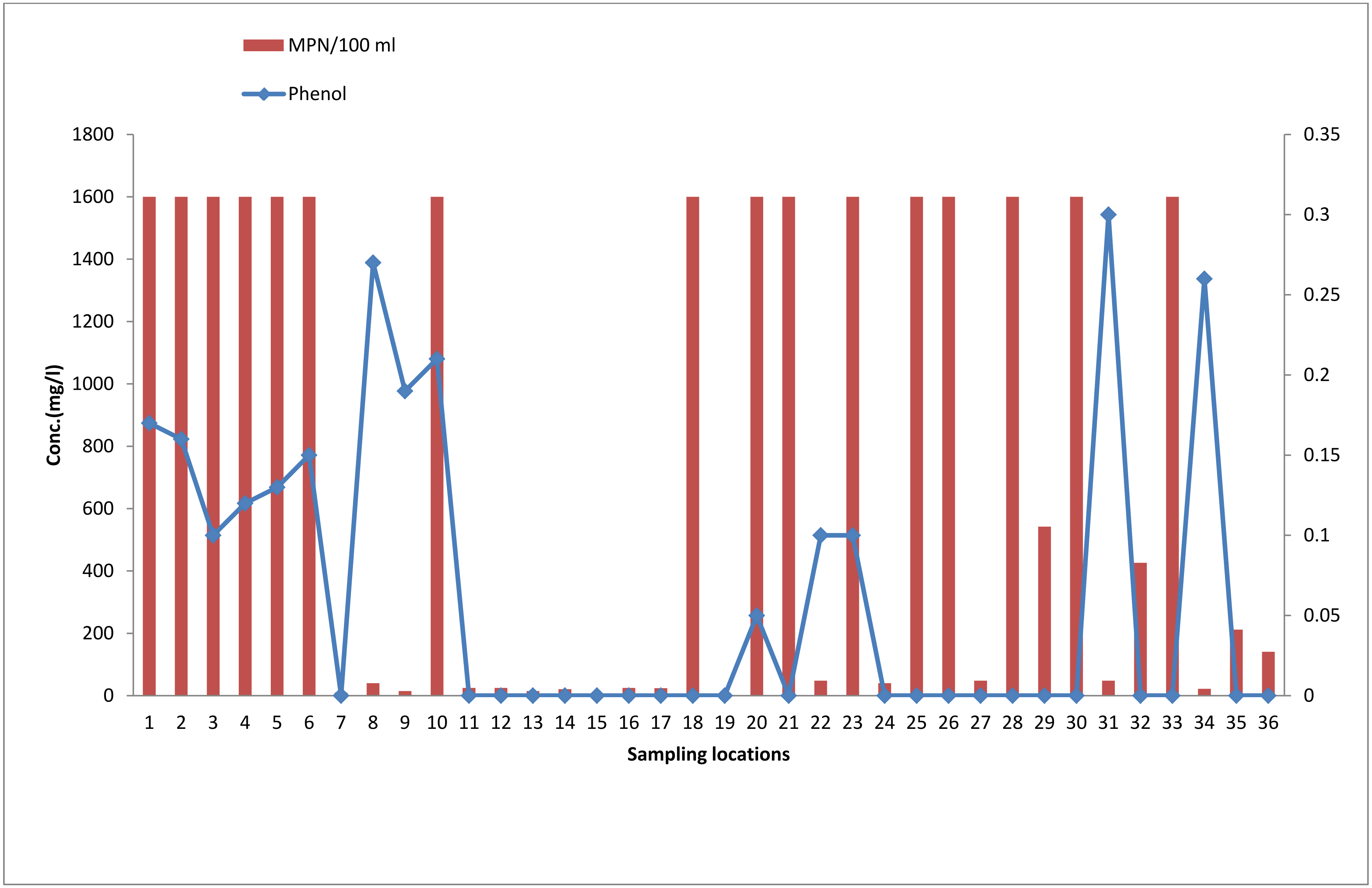


Table 6.8 Statistical Analysis of Special Parameters of Nallahs during Monsoon

Parameters	Minimum	Maximum	Average	SD	Std. (PS - b)
Phenols (mg/l)	BDL	0.4	0.1	0.1	1.0
MPN (Col/100ml)	10.0	1600.0	817.9	759.5	NA

Phenol concentrationsas shown in **Table 6.8**are almost similar to those found in river as expected since the major source of these phenols are probably domestic in nature. The average concentration is found to be 0.1mg/l whereas there are several nallahs showing BDL and maxima of 0.4mg/l.

6.3 Physico-chemical Characterization of Vakola Nallah

Vakola is one of the major nallahs that contributes to Mithi River and comprises of numerous small nallahs entering into it. Most of the banks along the approximate 3.5kms of Vakola are walled to a height of about 10 odd meters or more at most of the places and these numerous small networks of nallahs forming rivulets entering it are mostly underground and closed piped. Thereby flow determination of these though have been very difficult, 39 of the major accessible nallahs contributing ultimately to Vakola are selected for sample collection and analysis. Parameters similar to those for river and other major nallahs have been selected with the view to reproduce comparative trends of all of them as discussed in following sections.

6.3.1 Major Parameters Contributing & Representing Conductivity in Vakola Nallah

Vakola nallah falls within the ambit of tidal influence and is directly reflected in the values of parameters as presented in **Figure 6.9**. High values of conductivity equating almost similar trends in TDS concentrations reflect common source as they go hand in hand in almost all the locations showing such trends. Vakola is surely under the influence of tidal intrusion inland which extends surely beyond it and is prominently marked with peaks in the figure. Chlorides too vary in line with TDS and conductivity thereby making it even more evident that sea water is the source of such peaks. The nallahs are presented in numbers as described in Chapter II and thereby peaks are reflected irregularly rather than in one section of the nallah, though single digit series represent one of the banks while the other is presented via 3 digits numerical. Almost 10 out of the 39 nallahs show high values of all dependent variables i.e. conductivity, TDS, chlorides and hardness whereas alkalinity is independent and low in concentrations. Statistical analysis of same is depicted in **Table 6.9**.

Figure 6.9 Major Parameters Contributing and Representing Conductivity in Vakola Nallah

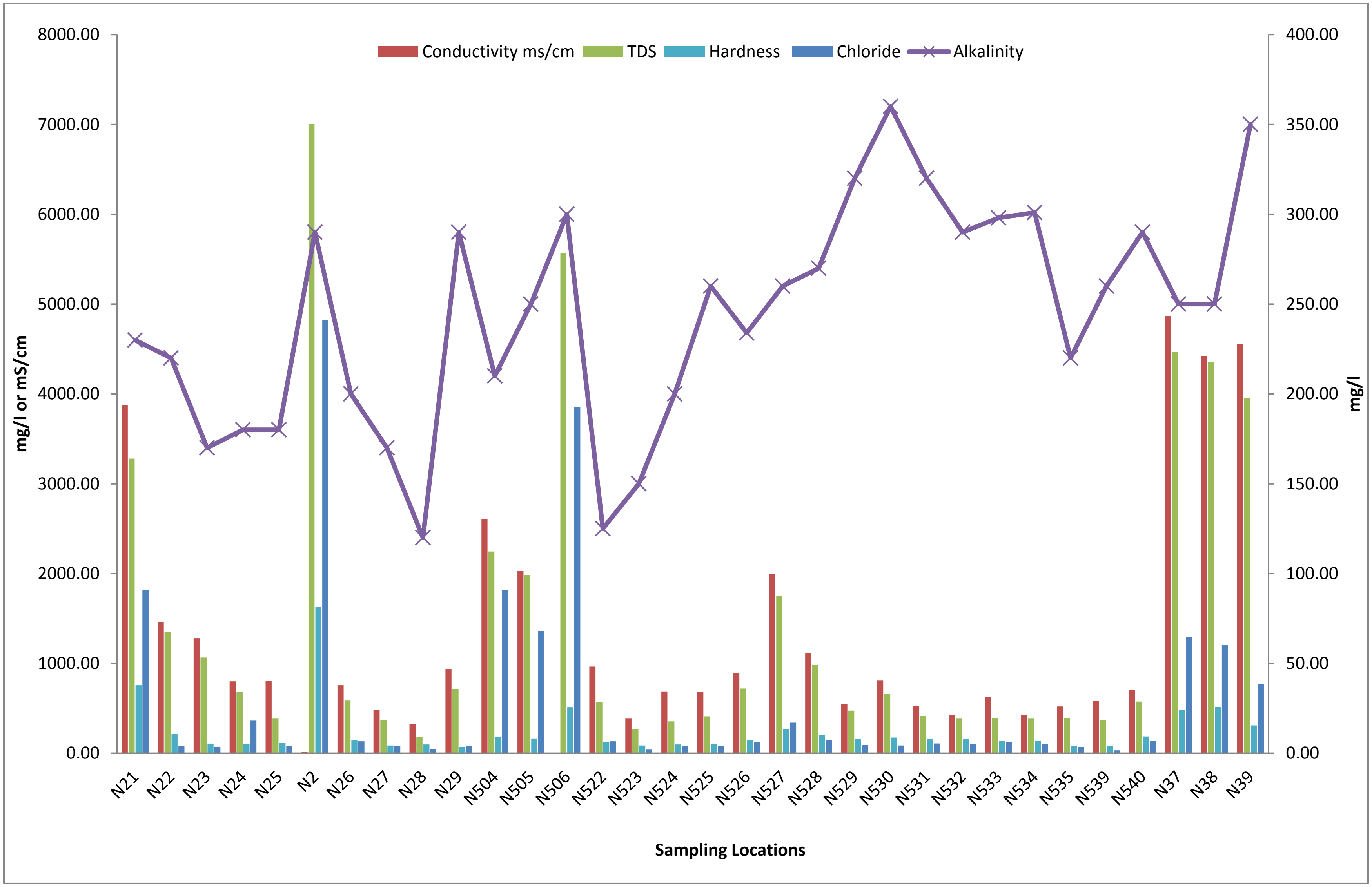


Table 6.9 Statistical Analysis of Major Parameters of Vakola Nallah Contributing TDS during Monsoon

Parameters	Minimum	Maximum	Average	SD	Std. (PS - b)
Conductivity (ms/cm)	2.9	4866.0	1285.3	1333.4	NA
TDS (mg/l)	180.0	7005.0	1478.7	1761.4	2100
Chloride (mg/l)	32.0	4821.0	614.1	1116.7	1000
Alkalinity (mg/l)	120.0	360.0	244.3	62.1	NA
Hardness (mg/l)	68.0	1628.0	243.4	297.2	NA

Average conductivity is found to be 1285.3mS/cm which seems to be directly correlated with average TDS concentration of 1478.7mg/l indeed reflecting direct contribution from chlorides with average concentration of 644.1mg/l & hardness of 243.4mg/l. Alkalinity in Vakola is found to be prominent in almost entire section and averaging about 244.3mg/l which is for the first time marginally in line with chlorides as compared to those in river and other nallahs. Both TDS and chlorides are found to be beyond the Public Sewer Standards of Schedule VI - General Discharge Standards.

6.3.2 Major Parameters Contributing & Representing Anions in Vakola Nallah

It is the sulphates that contribute to the hardness levels as have been the case in all the earlier discussion including the Mithi River itself wherein concentrations ranging from BDL in some of the nallahs are observed in Vakola too and maxima are aligned at 2893.9mg/l with average of 504.0mg/l as delineated in **Table 6.10**. Nutrient concentrations are more or less in tandem with those found in other nallahs with concentrations of PO_4 ranging from BDL at several locations to 182.7mg/l with average of 35.9mg/l whereas that of NO_3 ranging again from BDL to 1.0mg/l and averaging to 0.2mg/l. SO_4 concentrations are found to be almost half of that prescribed by the Public Sewer Discharge Standards of Schedule VI - General Discharge Standardsand those for nutrients being not prescribed do not pose cause of concern.

Table 6.10 Statistical Analysis of Anionic Parameters of Vakola Nallah during Monsoon

Parameters	Minimum	Maximum	Average	SD	Std. (PS - b)
SO_4(mg/l)	BDL	2893.9	504.0	772.1	1000
PO_4(mg/l)	BDL	182.7	32.2	35.9	NA
NO_3(mg/l)	BDL	1.0	0.1	0.2	NA

Details of individual nallahs contributing to Vakola in terms of major anions other than chlorides are presented in **Figure 6.10** for a more elaborate view.

6.3.3 Major Parameters Contributing & Representing Cations in Vakola Nallah

It is interesting to note that most of the nallahs feeding into Vakola show trends of cations too very similar to those of the nallahs entering Mithi River and thereby also revealing the probability that sources to such nallahs are mostly similar in nature and extent with minimum metal concentrations & several of them being BDL such as Cr+6, Cu, Ni, Cd and Co which further validates the proposition that these nallahs have minimal industrial source contribution as represented in **Table 6.11**. Other metals that do have presence are minimal in concentrations with average values of 2.9mg/l for Fe, 0.3mg/l for Mn, 0.03mg/l for Pb and 0.8mg/l for Zn and as in all other cases Fe is the maximum available metal in rivulets of Vakola nallahs too as presented in **Figure 6.11**.Comparing to Public Sewer Discharge Standards, for prescribed metals they are well within the limits and thereby do not pose any critical cause of concern.

Table 6.11 Statistical Analysis of Cationic Parameters of Vakola Nallah during Monsoon

Parameters	Minimum	Maximum	Average	SD	Std. (PS- b)
Cr^{+6}(mg/l)	BDL	BDL	BDL	BDL	2.0
Cu (mg/l)	BDL	0.1	BDL	BDL	3.0
Fe (mg/l)	0.5	7.9	2.9	2.0	NA
Pb (mg/l)	BDL	0.3	0.03	0.1	1.0
Mn (mg/l)	BDL	1.1	0.3	0.3	NA
Ni (mg/l)	BDL	BDL	BDL	BDL	3.0
Cd (mg/l)	BDL	BDL	BDL	BDL	1.0
CO (mg/l)	BDL	BDL	BDL	BDL	NA
Zn (mg/l)	BDL	0.8	0.1	0.2	15.0

6.3.4 Special Parameters Representing Characters of Vakola Nallah

Statistical analysis of rivulets contributing to Vakola nallah are presented in **Table 6.12** which shows very high MPN counts only in one of the samples whereas averaging about 12408Col/100ml though not in all of the nallahs obviously due to the domestic wastewater inputs. Phenols show average concentration of 0.01 much below the prescribed standards. Trends in rivulets of Vakola are given in **Figure 6.12**.

Table 6.12 Statistical Analysis of Special Parameters of Vakola Nallah during Monsoon

Parameters	Minimum	Maximum	Average	SD	Std. (PS - b)
Phenols (mg/l)	BDL	0.1	BDL	BDL	1.0
MPN (Col/100ml)	345.0	71600.0	3631.2	12408.8	10 (IS10500)

Figure 6.10 Parameters Contributing and Representing Anions in Vakola Nallah

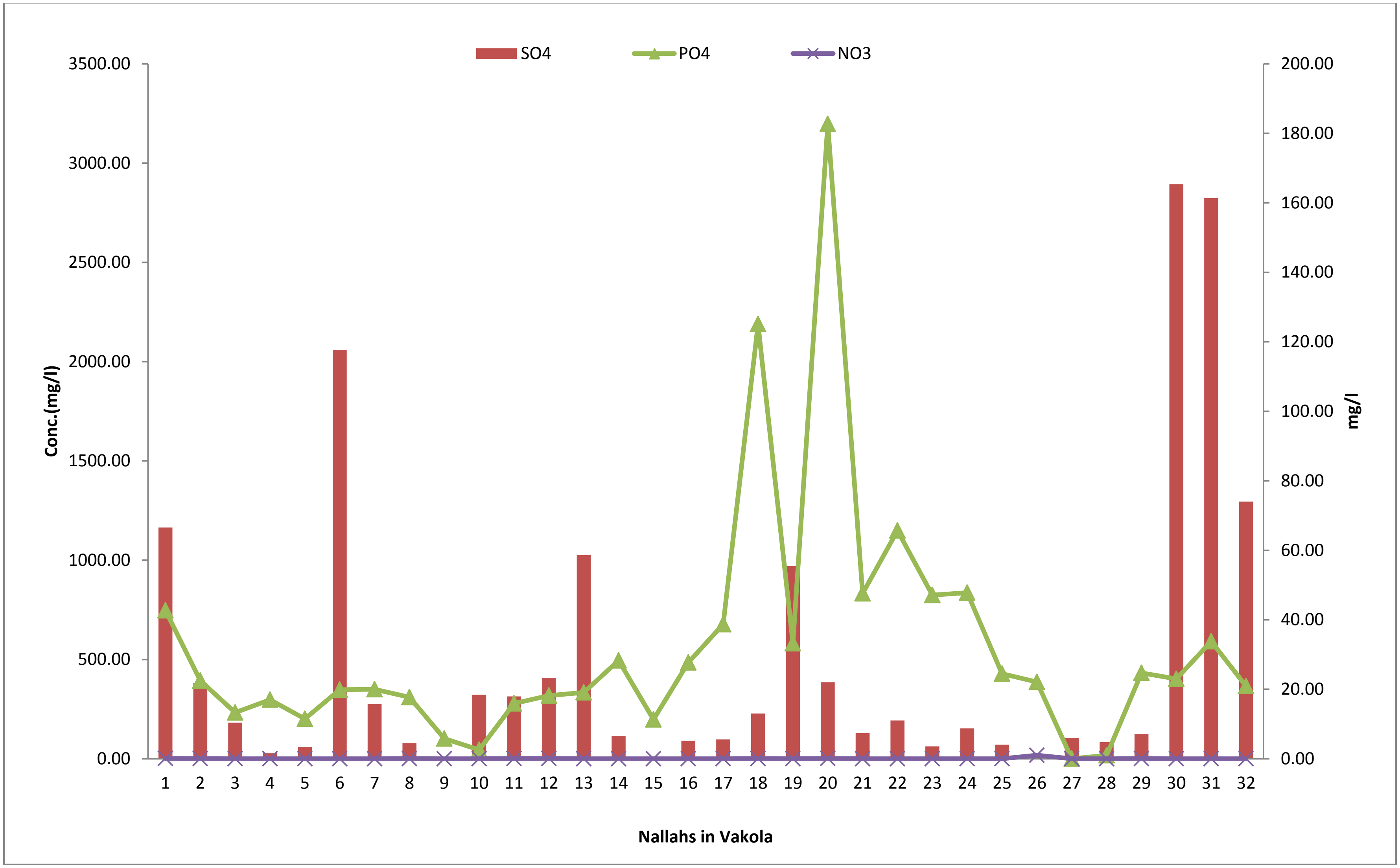


Figure 6.11 Parameters Contributing and Representing Cations in Vakola Nallah

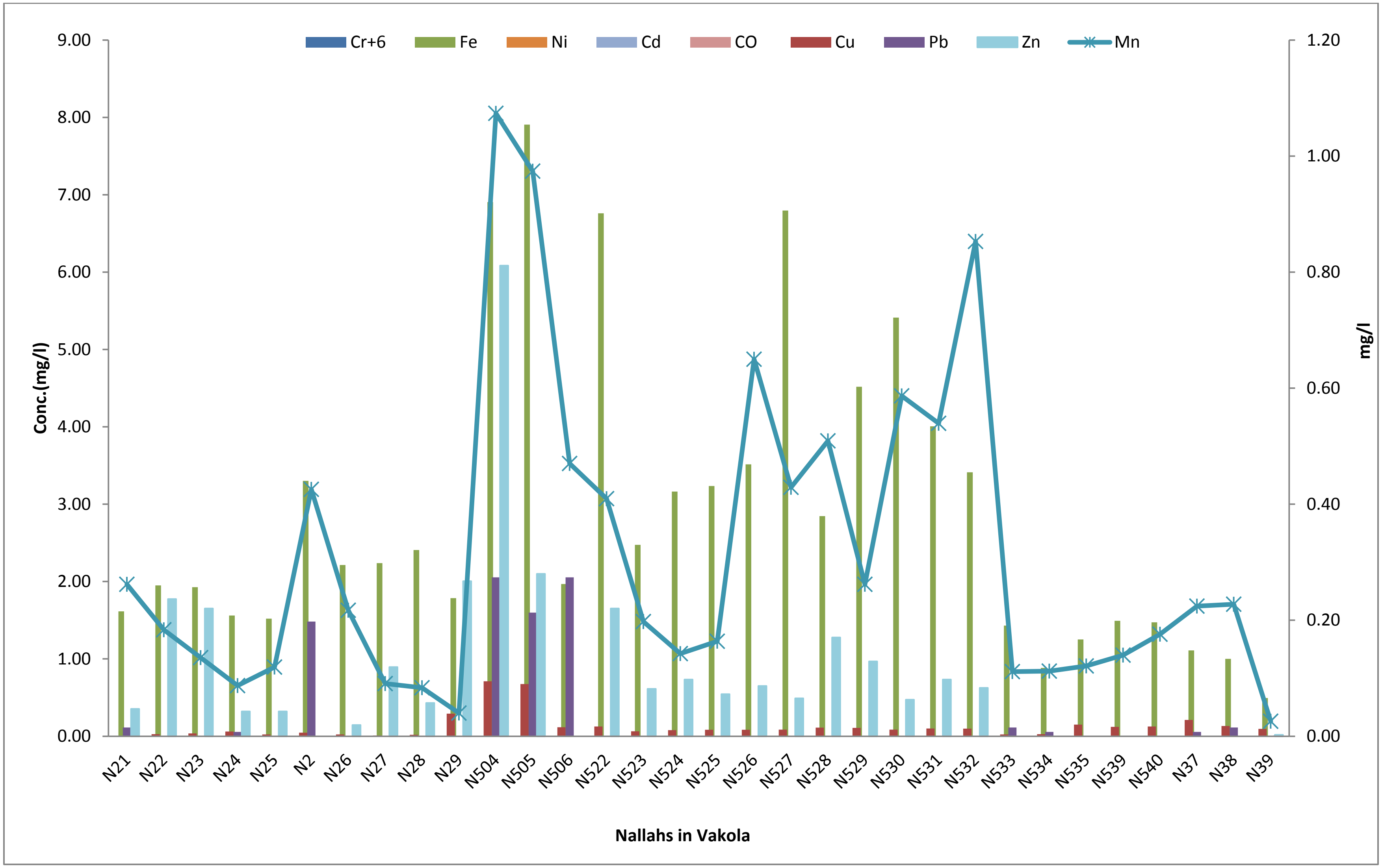
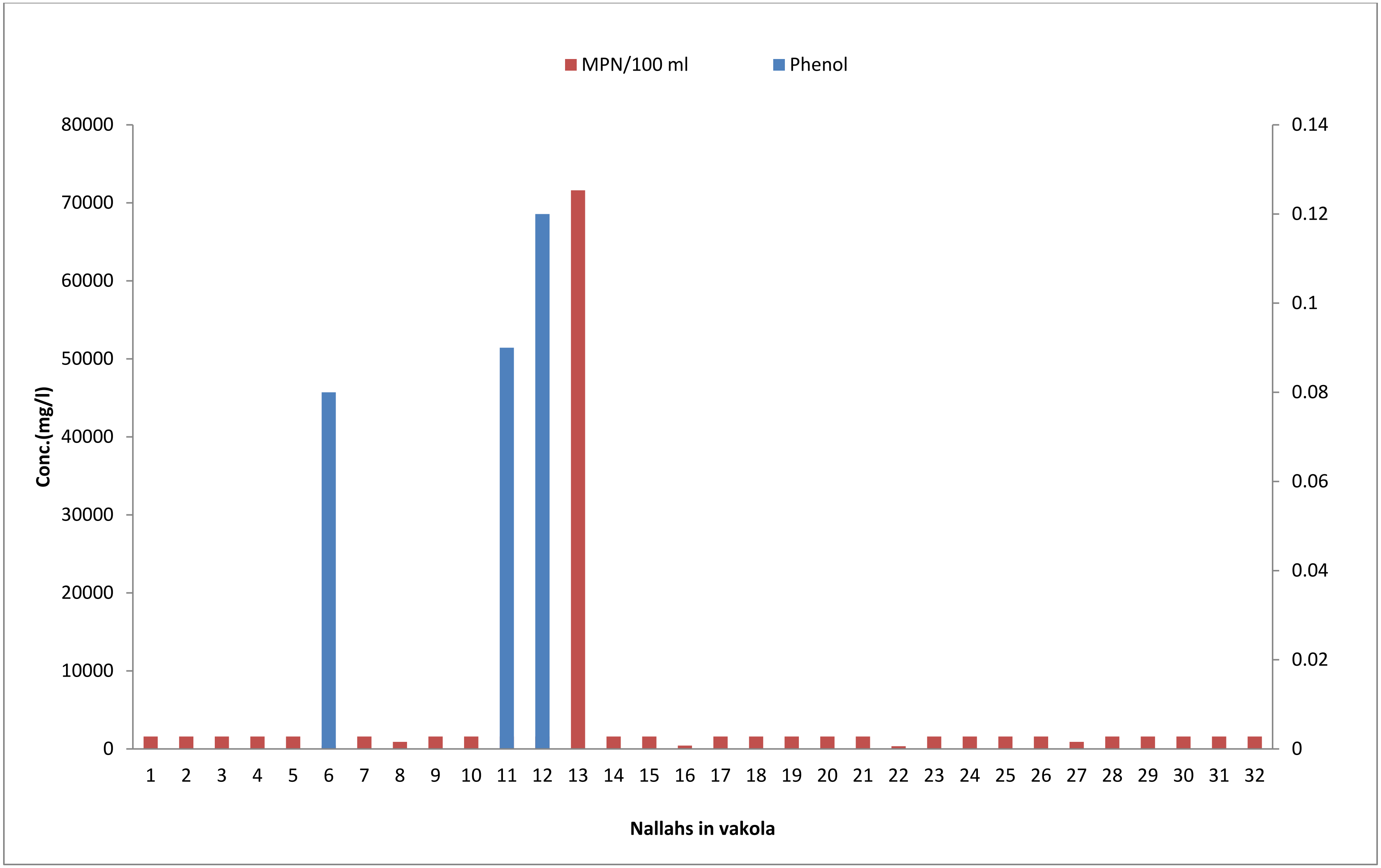


Figure 6.12 Special Parameters Representing Characters of Vakola Nallah



6.4 Industrial Source Wastewater Characterization

As outlined regarding the category of industries and their domain of functioning in previous **Chapter V** on Organics, the samples also included sewage from such industries especially Large Scale having high hydraulic flows wherever possible especially in MIDC area. Most of these industries were small scale and were ill equipped with effluent treatment facilities. However, the overall hydraulic flow of effluents from these surveyed industries accounted for not more than 100CMD. Nevertheless, since the inventorization and ground table survey of all those industries accounting for effluent discharges into Mithi is impossible, only representative sampling and surveys were conducted in 79 of them, the results of which are discussed in following sections.

6.4.1 Major Parameters Contributing & Representing Conductivity in Industries

Extremely concentrated flows of high TDS, pH bearing alkalinity and hardness ultimately causing high conductivity have been represented by few industries such as Cleaners that also dye and bleach in KBM Compound, Sihenshel Factory in Marol, Bottle & Drum Washing units such as Firoz Enterprises & others in Prem Nagar, etc. as evident from extremely high SD values that are almost 3 to 5 times that of averages as found to be 21255mS/cm for conductivity, 28115mg/l for TDS, 7846mg/l for chlorides, 30285mg/l for alkalinity and 11002mg/l for hardness and are presented in **Table 6.13**.

Table 6.13 Statistical Analysis of Major Parameters of Industries Contributing Conductivity

Parameters	Minimum	Maximum	Average	SD	Std. (Consented)
Conductivity (mS/cm)	0.0	136156.0	7390.9	21254.9	NA
TDS (mg/l)	95.0	148195.0	9457.5	28114.7	2100
Chloride (mg/l)	27.0	52182.0	2002.8	7846.4	NA
Alkalinity (mg/l)	0.0	208810.0	6122.2	30284.6	NA
Hardness (mg/l)	0.0	77600.0	2097.6	11001.9	1000

Parameters for which general standards are prescribed are found to be extremely higher than the limits and thereby may pose a serious cause of concern which needs immediate action. A detailed area wise listing of concentration / values of parameters for source samples is enclosed in **Annexure VI – I**. None of the SSI which were mostly unorganized and operating without provision of ETP/STP and those which have made such minimal provisions were found to be non-operational thereby leading to such extreme characteristics of effluents.

6.4.2 Major Parameters Contributing & Representing Anionic Parameters in Industries

In terms of sulphates the concentrations are found to be comparatively high averaging 3196.5mg/l though only 2 of the industrial units i.e. Sihenshel Factory with 48369mg/l in Marol and Firoz Enterprises with 29990mg/l in Prem Nagar of BKC are responsible for most of the high sulphate average values. All others show concentrations below 1000mg/l. Phosphates too are found to be highest in Sihenshel Factory though the averages are aligned at 34.9mg/l. Average concentration of Nitrates is found to be 7mg/l. It is evident that only 2 or 3 responsible industries with extremely concentrated outlets and minimal hydraulic flows as seen from extremely high SD values stated in **Table 6.14** results in such extreme behavior of anions and shall be considered in isolation since the low hydraulic flow gets highly diluted in the overall 4700MLD wastewater in Mithi River which are mostly fed by nallahs from adjoining area and shall not be confused with the behavior and concentration of same in the river which mainly is resembles tidal influence as discussed in **Chapter VIII** of this report.

Table 6.14 Statistical Analysis of Anionic Parameters of Industries

Parameters	Minimum	Maximum	Average	SD	Std. (Consented)
SO_4(mg/l)	0.0	48369.0	3196.5	8704.6	NA
PO_4(mg/l)	0.0	224.0	13.7	34.9	NA
NO_3(mg/l)	0.0	141.0	7.0	25.1	NA

6.4.3 Major Parameters Contributing & Representing Cationic Parameters in Industries

Though the consent conditions stipulated may vary from case to case, a generic concentration standard as applicable for Inland Water Discharges are used to compare the industrial source water. Ideally Load Based Standards are more applicable but being unorganized sector and limited data sharing by these industries, the authors are left with no choice but to use the best available information for such comparison. Interestingly as it is expected to be the case, Cr^{+6}& Co are absent even in those industrial samples analyzed from industries whereas Pb is found to be above the prescribed limits of Inland Surface Water Criteria. Metal concentration presented in **Table 6.15** shows average values of 0.5mg/l for Cu, 5.4mg/l for Fe, 0.5mg/l for Mn, 0.6 for Ni, 0.01 for Cd and 0.5mg/l for Zn. All these metals are found to be lower than the selected standards for comparison though sporadic instances of such metal discharges cannot be ruled out as seen by their respective maxima which thereby also confirm the main source of these metals into Mithi to be centered amongst industries especially surface cleaning, plating and washing / cleaning.

Table 6.15 Statistical Analysis of Cationic Parameters of Industries

Parameters	Minimum	Maximum	Average	SD	Std. (Consented)
Cr^{+6}(mg/l)	BDL	BDL	BDL	BDL	0.1
Cu (mg/l)	BDL	6.9	0.5	1.4	3.0
Fe (mg/l)	1.3	14.9	5.4	4.1	NA
Pb (mg/l)	BDL	20.5	0.6	3.4	0.1
Mn (mg/l)	BDL	7.1	0.5	1.3	NA
Ni (mg/l)	BDL	12.9	0.6	2.2	3.0
Cd (mg/l)	BDL	0.2	0.01	BDL	2.0
CO (mg/l)	BDL	0.1	BDL	BDL	NA
Zn (mg/l)	BDL	3.2	0.5	0.9	5.0

6.4.4 Major Parameters Contributing & Representing Special Parameters in Industries

It is obviously validated form **Table 6.16** that MPN found in nallahs and Mithi river is not sourced from industrial areas especially the effluents and those locations where STP water is collected have effective disinfection systems in place resulting in such low MPN numbers ranging from just 2.0 to 900 with average of about 142Col/100ml that too only found in very limited units as further corroborated by high SD values. Phenols too are mostly consistently found sourced from STP and related domestic sewage samples with average concentration of 0.1mg/l confirming the say that most of it originates from domestic wastewater.

Table 6.16 Statistical Analysis of Special Parameters of Mithi River during Monsoon

Parameters	Minimum	Maximum	Average	SD	Std. (ISW - a)
Phenols (mg/l)	BDL	1.3	0.1	0.2	1.0
MPN (Col/100ml)	2.0	900.0	141.6	241.7	10 (IS10500)

6.5 Comparative Account of ParametersAcross River and Nallahs

It would be an interesting way to analyze parameters in comparison with each other across various nallahs and that of river and thereby this special section is included in this chapter. Though the overall discussion previously done suggests that most of the nallahs are fed with domestic water, there are very few such nallahs that find its source from direct industrial discharges. Nevertheless, those which find such sources are very few and several others even with the industrial source as a contributor carry domestic mixed effluents and discharge ultimately to either Vakola or Mithi indeed. **Table 6.17** shows average concentrations of major parameters that potentially are thought to be polluting ones.

Taking ahead the discussion of **Chapter V** regarding use of unconventional concept of ratio of River : Nallah : Vakola Nallah : industry to reflect proximities of parameters, **Table 6.17** depicts those that represent and/or contribute to conductivity sources across samples. Interestingly none of the ratio shows direct proximity to river TDS & chlorides and thereby other such source such as tidal influence has been considered as more appropriate contributor. However, alkalinity finds its analytically proximate partner in both nallahs that directly enter Mithi as well as those contributing to Vakola ultimately leading into Mithi River. Hardness on other hand similar to chlorides and TDS shows other such source in river which probably can be attributed only to tidal influence in this case.

Table 6.17 Comparative Account of Parameters Contributing and Representing Conductivity

Parameters	River	Nallahs into Mithi	Nallah into Vakola	Industries
TDS (mg/l)	5303.4	2479.1	1478.7	9457.5
TDSRatio of River:Nallah:Vakola:Industry			**1.00 : 2.14 : 0.28: 0.56**	
Chloride (mg/l)	2880.0	748.4	614.1	2002.8
ChlorideRatio of River:Nallah:Vakola:Industry			**1.00 : 3.85 : 0.21: 1.44**	
Alkalinity (mg/l)	230.7	249.6	244.3	6122.2
AlkalinityRatio of River:Nallah:Vakola:Industry			**1.00 : 0.92 : 1.06 : 0.04**	
Hardness (mg/l)	845.5	422.9	243.4	2097.6
HardnessRatio of River:Nallah:Vakola:Industry			**1.00 : 2.00 : 0.29 : 0.40**	

For anions, it seems that all the proximate source contribution comes from nallahs with almost ratios ranging from 0.75 for PO_4 to 1.12 & 1.19 for NO_3 and SO_4 in nallahs leading into Mithi River though there is still some scope for inclusion of sources other than these direct ones as have been discussed earlier especially to represent sulphates from sea water intrusion. Industrial sources & nallahs leading to Vakola's contribution seems to be minimal in case of anions and are seem to be not even distantly correlated as seen from **Table 6.18**.

Table 6.18 Comparative Account of Anions

Parameters	River	Nallahs into Mithi	Nallah into Vakola	Industries
SO_4 (mg/l)	917.7	771.4	504.0	3196.5
SO_4 Ratio of River:Nallah:Vakola:Industry			**1.00 : 1.19 : 0.55 : 0.29**	
PO_4 (mg/l)	12.1	16.2	32.2	13.7
PO_4Ratio of River:Nallah:Vakola:Industry			**1.00 : 0.75 : 2.66 : 0.88**	
NO_3 (mg/l)	0.19	0.17	0.06	7.0
NO_3Ratio of River:Nallah:Vakola:Industry			**1.00 : 1.12: 0.32 : 0.03**	

Since the concentration of metals is already pretty low and as discussed in the earlier sections of this chapter the sources of metals are mainly from industries, it would not be appropriate to apply the ratios method since metals are of recalcitrant nature and thereby may find its way to persist through the sections from source to the end point of Mithi. Thereby in this case more the concentration at source, more is the correlation established in terms of contribution. As presented in **Table 6.19** almost all the metals show higher concentration in industrial samples than those compared to river, nallahs directly discharging to Mithi and those of Vakola except for Fe which may have natural origins or are generated during transfer due to leaching.

Table 6.19 Comparative Account of Cations

Parameters	River	Nallahs into Mithi	Nallah into Vakola	Industries
Cr^{+6} (mg/l)	BDL	BDL	BDL	0.01
Cu (mg/l)	0.05	0.06	0.02	1.40
Fe (mg/l)	7.60	10.64	2.89	4.14
Pb (mg/l)	0.13	0.06	0.03	3.36
Mn (mg/l)	0.59	0.98	0.31	1.28
Ni (mg/l)	0.06	BDL	BDL	2.19
Cd (mg/l)	BDL	BDL	BDL	0.04
CO (mg/l)	BDL	BDL	BDL	0.01
Zn(mg/l)	7.53	0.44	0.10	0.91

Similar to the cations, phenols & MPN do not show proximity to their counterparts in any possible way though the convention regarding same would be to have perfect proximities between river and nallahs carrying raw sewage. However, the point has been already discussed earlier describing open defecation finding its route to river water and thereby sources other than nallahs contribute to MPN as seen from **Table 6.20**. Similarly phenols too do not find any proximate source contributing to river though higher average concentration in industries may be thought as one of the sources in terms of persistent nature of phenols though sewage water too seems to be more proximate than industrial sources but since the concentrations are extremely low it may not be a cause of concern.

Table 6.20 Comparative Account of Special Characteristics

Parameters	River	Nallahs into Mithi	Nallah into Vakola	Industries
Phenol (mg/l)	0.04	0.08	0.01	0.1
Phenol Ratio of River : Nallah : Vakola : Industry			**1.00 : 2.00 : 0.25 : 2.50**	
MPN (Col/100 ml)	8027.6	817.9	3631.2	141.6
MPN Ratio of River : Nallah : Vakola : Industry			**1.00 : 0.10 :0.45 : 0.01**	

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Chapter VII

Criticality Index for Mithi River Stretches

7.0 Background

Physico-chemical and biological analysis for about 270 samples of river, nallahs and industrial / domestic sources were carried out during the entire study of 3 seasons with maximum insight to thorough investigation during per-monsoon period of May 2014. The results of the same are outlined and discussed in detailed in various Chapters of this report. Nevertheless, the authors of this report have resorted to interpreting analysis data in simpler form for making the decision making process easier and for more effective communication of such enormous data in numerical form to be used by even laymen and to further assess the extent of pollution and prioritize conservation management plan for each individual stretches of Mithi based on criticality of that particular region. An attempt has been made to develop Mithi specific criticality indices for each stretch to represent relative pollution potential within the 15km river along with providing significant environmental determinants of every stretch that are probably responsible for contribution to the varying loads.

These criticality indices are representations of parameters responsible for pollution in each of the stretch based on applicable / available standards of discharge, background information and concentrations in similar studies of surface water bodies and toxicity of parameters. Though not all the parameters have been considered in this particular study for the ease of representation & computation, the criticality indices are categorized into 2 subsets viz. Organics that include BOD, COD, Total suspended solids and oil & grease and Cations comprising of all heavy metals. Weights are assigned to each parameter depending on its environmental significance in terms of pollution potential, toxicity, background concentration, Desirable / Prescribed Standards wherever possible and other such review characteristics using Analytical Hierarchical Process. Scaling of the monitored value of particular parameter is then distributed within the appropriate weight resulting in score of individual parameter. These are ultimately used to derive Indices that represent sum total of overall rating of the stretch considering each analysis parameter and finally presented as color codes set up to indicate the pollution extent in each stretch.

Ultimately this whole complex exercise is concluded in form of a simple & visually self-explanatory Map of River indicating the color code based relative criticality in the virtual 1km classification domain used throughout this chapter for representation of Mithi River thereby anticipated to provide insight of critical patches of river and parameters responsible to prioritize management needs of a particular stretch and significant pollutant / source in an elaborate way.

7.1 Assumptions and Baselines

In order to develop the criticality indices, the most important basis taken into account was Desirable Standards as applicable. Criticality is simply dependent on the extent to which particular parameter is exceeding from its desired concentrations. For the criticality indices of river, Inland Surface Water Discharge Standards (a) were adopted from Schedule VI of EPA 1986. For nallahs, General Discharge Standards for Public Sewers (b) have been referred. **Table 7.1** indicates the concentration limits for river while **Table 7.2** shows the standards referred for developing indices for nallahs. Though the General Discharge Standards for COD for Inland Surface Water discharges is 250mg/l, the same has been modified to 100mg/l considering the already existing load of organics and probable load in future that could lead to causes of concern. All other parameters are used as it is prescribed in Standards.

Table 7.1 Standard Limits for river

Parameter	Standard Limits (mg/l)
Organics	
BOD	30
COD	100
Organic Load	N.A.
Oil and Grease	10
Phenols	1
TSS	100
Cations	
Chromium(Cr^{+6})	0.1
Copper(Cu)	3.0
Iron(Fe)	3.0
Lead(Pb)	0.1
Manganese(Mn)	2.0
Nickel(Ni)	3.0
Cadmium(Cd)	2.0
Zinc(Zn)	5.0

Table 7.2 Standard Limits for Nallahs

Parameter	Standard Limits (mg/l)
Organics	
BOD	350
COD	250
Oil and Grease	20
Phenols	10
TSS	600
Cations	
Chromium(Cr+6)	2.0

Parameter	Standard Limits (mg/l)
Copper(Cu)	3.0
Iron(Fe)	3.0
Lead(Pb)	1.0
Manganese(Mn)	2.0
Nickel(Ni)	3.0
Cadmium(Cd)	1.0
Zinc(Zn)	15.0

Along with the physico-chemical parameters, flow of the river also plays a vital role in characterizing the criticality of Mithi. Amount of organic load observed in particular stretch is majorly dependent on the flow of river water. It is expected that more the flow, greater the dilution which in turn shall lead to lower load of the pollutant and vice-versa. Thereby in addition to the physico-chemical parameters, criticality of Mithi is also assessed considering the COD load in each of the stretch, COD being the representative of organic load present in the river water. Devoid of any specific standards for COD load, while assessing the criticality, the maximum observed COD load along all the stretches has been considered as the worst condition.

7.1.1 Weights Assigned to Parameters

Based on the environmental significance, toxicity, persistent nature of parameter and extent of treatment required, each of the concerned parameter are assigned logical weights so as to develop the grading scale. Weight of each parameter is only done to prioritize their significance in defining their environmental value relative to each other. *In simple terms, lower the concentration of pollutant, lower weight and better the status & vice versa.*

Thereby, in order to evaluate the criticality of the river stretches, parameters distributed in two sections were assigned weights out of a total value of 100. Organics being one of the major concerns as established by monitored and analyzed data from previous as well as latest studies were significantly prioritized by assigning 85 weights whereas cations in form of metals were assigned lower i.e. 15 weights due to their limited presence in background but considering their toxicological importance after thorough sensitivity analysis and neutralization of anticipated bias.

Furthermore, each of the samples collected in river as well as nallah are considered as individual case & indices are developed for them which ultimately are averaged for particular class of Organics and cations and computed for sum total to be converted to color coded outputs of final criticality index.

According the Hierarchical Process, those parameters forming organics are subsequently again assigned subset weights based on their intra- relative environmental significance wherein COD is thought to be the most significant representative of pollution and thereby most weighted followed by BOD, Oil and Grease & finally TSS ,Organic load and phenols. In order to assess the dilution in the concentration of the parameters due to the varying flow, Total Organic Load has been incorporated as a parameter for criticality. For indicating the organic load, COD load has been calculated as the product of COD concentration and flow of that particular stretch. Total of 5 marks has been assigned to Organic Load. In case of cations, weightage has been distributed according to the concentration limits prescribed in the Schedule VI of EPA 1986.

There could be debate on assignment of weights which the authors are fully aware and thereby this chapter needs to be only referred as a framework for such studies and need not use absolute values of any weights or others referred. However, being also aware and experienced the authors have tried to use enough background information to arrive at use of this method through deliberations with experts from this field.

In terms of metals and in light of river water not used for consumption and / or contact purposes, sensitivity of acceptable standard limits and toxicological published data of significance of heavy metals were adopted referring to Chromium, Lead, Copper, Iron and Nickel as more prioritized than their other counterparts. **Table 7.3** indicates the rating based on AHP adopted for computation of subset significance.

Table 7.3 Weights Assigned in Rating of Parameters using AHP

Organics	**BOD**	**COD**	**Organic Load**	**O&G**	**Phenols**	**TSS**			**Total Weight**
Individual Weights	25	30	5	15	5	5			**85**
Cations	**Cr^{+6}**	**Cu**	**Fe**	**Pb**	**Mn**	**Ni**	**Cd**	**Zn**	**15**
Individual Weights	3	2	2	3	1	2	1	1	

7.1.2 Color coding

Further to assigning of individual weights to make up the subset scores amounting to a total index value of 100, a color code to represent extent of pollution in particular stretch of Mithi is developed using array of weighted averages of individual parameter converted into Final Score and rated out of 100. The color coding is a self-explanatory way to understand pollution potential / pollution load or precise existing environmental status relative of stretches. This color code is assigned by computing sum total of individual scores obtained for subsets of both organics and cations in a particular stretch / nallah. **Table 7.4** represents final score ranges& corresponding color coding used for defining the criticality of the stretch.

Table 7.4 Color coding for criticality of the river stretches

Marking	Out of 100	Color	Interpretation
Good	0-20	Green	When all parameters are below 30% of the standards
Average	21-40	Blue	when BOD &COD between 30-60% of standards and all others within standards
Bad	41-60	Orange	BOD & COD are 60-90% of the standards and few others may be beyond standards
Worst	61-80	Pink	All beyond standards but below 1.2 times OR both BOD and COD are beyond 1.2 times and few others are just reaching the standards
Critical	81-100	Red	All the parameters are beyond 1.2 times standards

Red color indicates the critical pollution status of the stretch / nallah which has to be given major priority in order to mitigate and control the pollution while green represents the least polluted stretch. Blue, Orange and pink colors are representing the gradual degradation in the river water and increase in the pollution load respectively. In simple terms, lower the final rating lower the pollution and greener the colour of nallah/stretch. The colour also presents categorization of pollution into 5 different aspects ranging from Good to Critical.

7.2 Stretch-wise Criticality of Mithi

Assigning the weights, scoring & rating of individual nallah & river stretch was done, ultimately leading to compilation of criticality indices for each of them accordingly and the corresponding color coding is incorporated in the Google Images to visually represent the existing pollution status.

7.2.1 Stretch I - Vihar Lake to Filterpada

As described in earlier chapters, only one sample of river was able to be collected in this stretch as the flow was miniscule. For the collected sample, criticality indices calculated value of indices is found to be 69.5 out of 100 which suggests that the Stretch I falls in the Worst category appearing Pink coloured as represented in the **Figure 7.1.**

Figure 7.1 Criticality of Stretch I Vihar Lake to Filterpada

7.2.2 Stretch II Filterpada to Gautam Nagar

In the Stretch II, criticality indices were calculated for the 4 river samples with score of 61 upstream and 80.9 downstream of the river. Accordingly stretch is appearing Light Pink which gets converted in the lighter shade of Red/Dark Pink from upstream to downstream as shown in **Figure 7.2.** Total of seven nallahs has been sampled in this stretch. Corresponding color coding of those nallahs is shown in **Figure 7.2**.

Out of 7 nallahs, two nallahs have been indicated by Orange color and two are by Pink which need immediate intervention. Three of these nallahs are indicated as Blue colored representing average levels of pollution with one being extremely Light Blue coloured.

Figure 7.2 Criticality of Stretch II – Filterpada to Gautam Nagar

S. NO	X Lattitude	Y Longitude	COD	BOD	Flow(mld)
R 8	72 52'22.3"E	19 04'16.4"N	106.0	45.0	1.5
R 506	72 89'64.1"E	19 13'27.1"N	63.0	30.3	2.4
N 5	72 52'17.7"E	19 04'14.2"N	253.0	38.6	Un Approachable
N 6	72 52'17.7"E	19 04'14.2"N	190.0	61.1	Un Approachable
N 7	72 52'17.7"E	19 04'14.2"N	342.0	112.0	0.0
N 8	72 52'17.7"E	19 04'14.2"N	132.0	37.3	0.0
N 9	72 52'17.7"E	19 04'14.2"N	635.0	229.8	0.0
N 11	72 52'17.7"E	19 04'14.2"N	745.0	247.5	0.0
N 507	73 29'64.9"E	19 13'27.1"N	368.0	151.8	0.0
R 19	72 89'64.1"E	19 13'27.1"N	62.0	18.6	
R 507	72 89'64.1"E	19 13'27.1"N	115.0	35.8	4.7

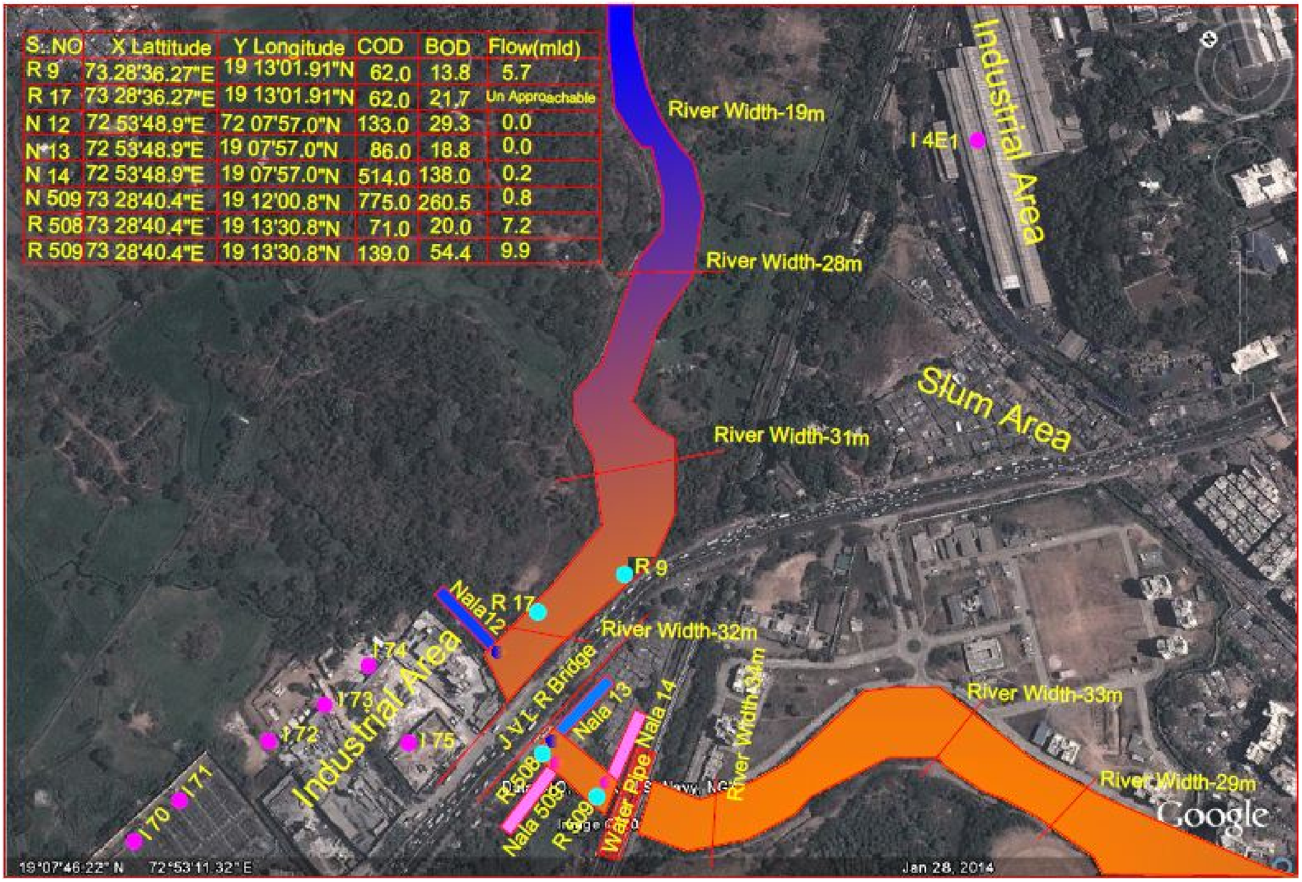
Pollution levels downstream of the stretch, seems to be slightly increased as compared to the upstream location.

7.2.3 Stretch III Gautam Nagar to JVLR Bridge

Figure 7.3 depicts the color coding of the Stretch III depending on the criticality indices developed suggesting pollution levels gradually changing from Average to Bad category.

Out of those four nallahs, two are represented as Pink colored being Worst polluted indicating severely polluted wastewater discharges might be probably carrying industrial wastewater mixed with domestic. Other one at the downstream of bridge is Blue colored suggesting Average pollution load. Upstream of JVLR Bridge, one of the nallahs is seen as Blue colored revealing that it is possibly carrying domestic wastewater representing characters well within the standards.

Figure 7.3 Criticality of Stretch III – Gautam Nagar to JVLR Bridge

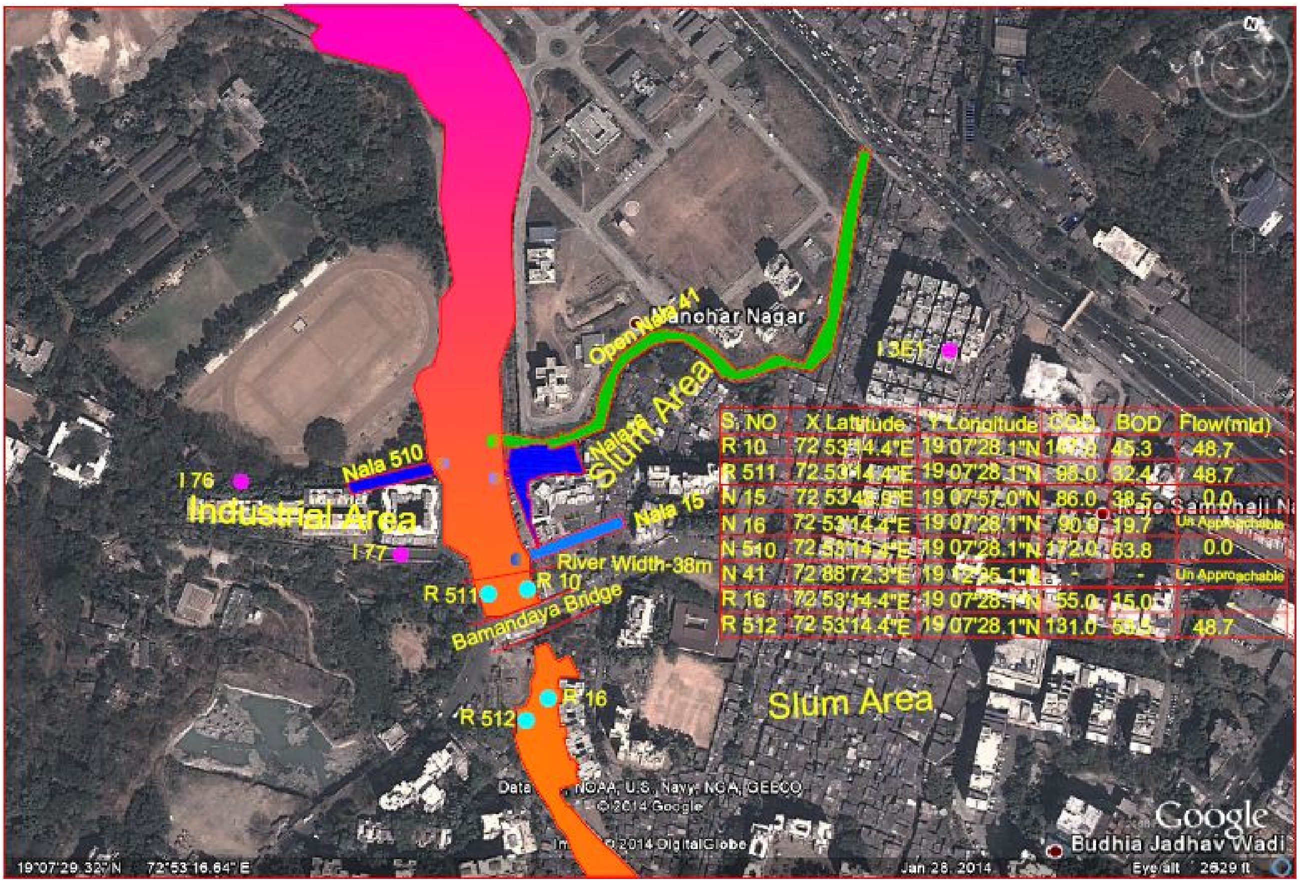


7.2.4 Stretch IV - JVLR to Bamandaya Pada

From downstream of JVLR, pollution levels seem to be gradually decreasing towards the downstream of Stretch IV i.e. at Bamandaya Pada Bridge represented in Dark Pink at upstream gradually turning into Orange downstream probably due to excessively diluted streams of domestic inputs as presented in **Figure 7.4**.

In this stretch, out of the four nallahs entering river, 2 are indicated by Blue color with moderate pollution levels whereas 1 is Light Blue coloured indicating less pollution load. One open nallah entering river from right bank probably carrying sewage from the nearby residential area is found relatively less polluted than others in this stretch being “Good” in terms of index.

Figure 7.4 Criticality of Stretch IV – JVLR to Bamandaya Pada



7.2.5 Stretch V –Bamandaya Pada to KBM Compound

Stretch V seems to be relatively more polluted as represented by consistent Pink shade throughout the stretch. **Figure 7.5** indicates four nallahs entering river one being Orange and other three Blue colored. Out of the three Blue coloured nallahs one at the left bank is represented in Dark Blue colour revealing that it carries relatively higher pollution load compared to other two although all of them have characters in the range of 30-60% of the standards. Blue color resembles that the wastewater carried by nallah is moderately polluted and has concentration of parameter within the standard limits for nallahs whereas Orange colored nallah indicates badly polluted wastewater probably carrying part of industrial waste needing immediate intervention.

Figure 7.5 Criticality of Stretch V – Bamandaya Pada to KBM Compound

7.2.6 Stretch VI - KBM Compound to Marol

Stretch VI beginning from downstream of KBM Compound and extending upto Marol is indicated with Dark Blue colour at upstream and Orange color shade at the downstream revealing that the pollution levels in this stretch are increasing as the nallah entering into the river.

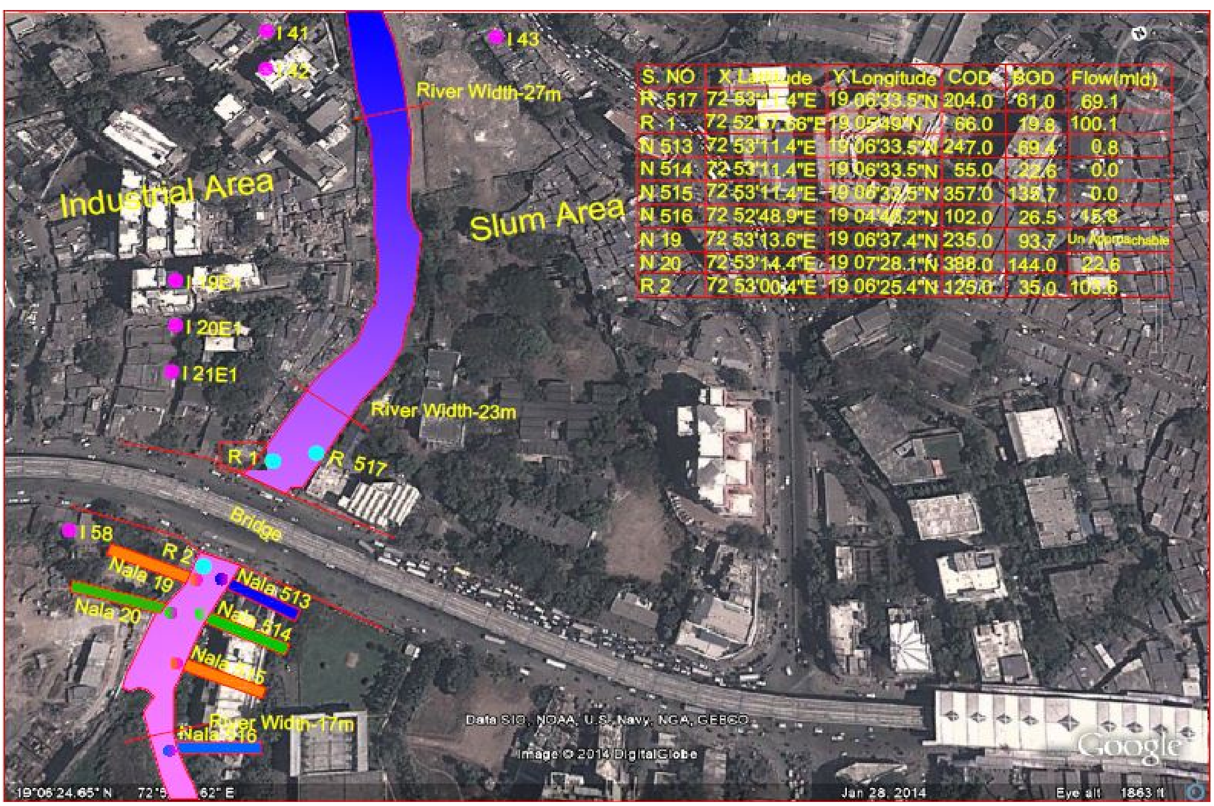
As seen from **Figure 7.6** the nallah entering right bank of the river probably includes partial discharges from industrial zones mixed with domestic wastewater as shown in Orange color is also confirmed from the survey details of this area.

7.2.7 Stretch VII - Marol to Sakhinaka

The Stretch VII of Mithi as shown in **Figure 7.7** suggests gradual increase in pollution from upstream to downstream. At the upstream of the stretch represented by Blue color reveals existence of lower levels of pollution which probably is because of the extensive load of diluted sewage entering from various sections of the upstream nallahs thereby leading to concentrations of parameters ranging around half of the standards prescribed in the **Table 7.1.**

Figure 7.6 Criticality of Stretch VI – KBM Compound to Marol

Figure 7.7 Criticality of Stretch VII – Marol to Sakhinaka



At the downstream, the color is changed to Pink which indicates the increasing pollution load in the stretch through nallahs joining river. Out of the 6 nallahs entering, two are indicated by Green color suggesting least polluted effluent being carried by them & probably comprising of lower concentrations of almost all the parameters. Two nallahs are seen as Orange colored suggests industrial sources mixed wastewater polluted enough to further add to the pollution load in river whereas remaining 2 seen as Blue colored probably carry sewage from the nearby slum areas and has relatively low concentrations of organics and cations as compared to Orange coloured nallahs in this stretch.

7.2.8 Stretch VIII - Sakhinaka to Domestic Airport

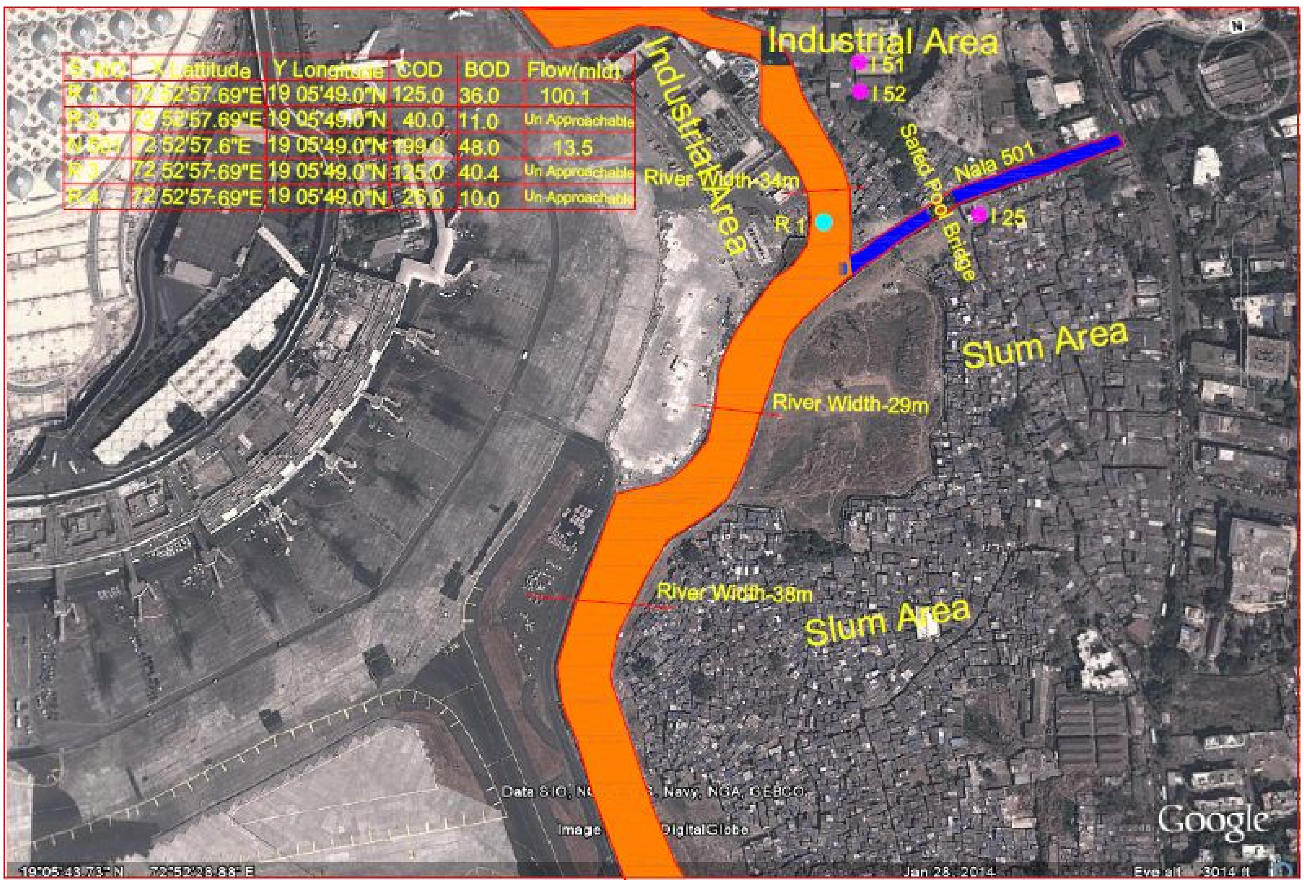
As presented in Stretch VIII, pollution levels are Bad at upstream as represented with Orange color. However, as the river flows towards downstream, it gets converted in Pink indicating addition of pollution load in the river to the point of making it Worst, the precise sources of same could not be identified. One nallah entering the river from its left bank carrying treated sewage from sewage treatment facility of Airport as seen in Dark Green color indicating that the pollution load is minimal as presented in **Figure 7.8**.

Figure 7.8 Criticality of the Stretch VIII – Sakhinaka to Domestic Airport

7.2.9 Stretch IX - Domestic Airport to Safed Pool

Stretch IX starts at the Airport and extends upto the downstream of Safed Pool Bridge. In this stretch, open nallah of Safed Pool is adding considerable hydraulic load as represented in the **Figure 7.9.** The entire stretch is indicated by Orange color suggesting that the concentrations of the organics and cations are almost nearing the stipulated limits used for computing criticality. Although the nallah adding into the river, located on the right bank shows Average pollution levels indicated in Dark Blue colour, which is directly responsible for diluting the prevailing Worst condition carried forward from earlier stretch and converted to Bad state.

Figure 7.9 Criticality in Stretch IX – Domestic Airport to Safed Pool



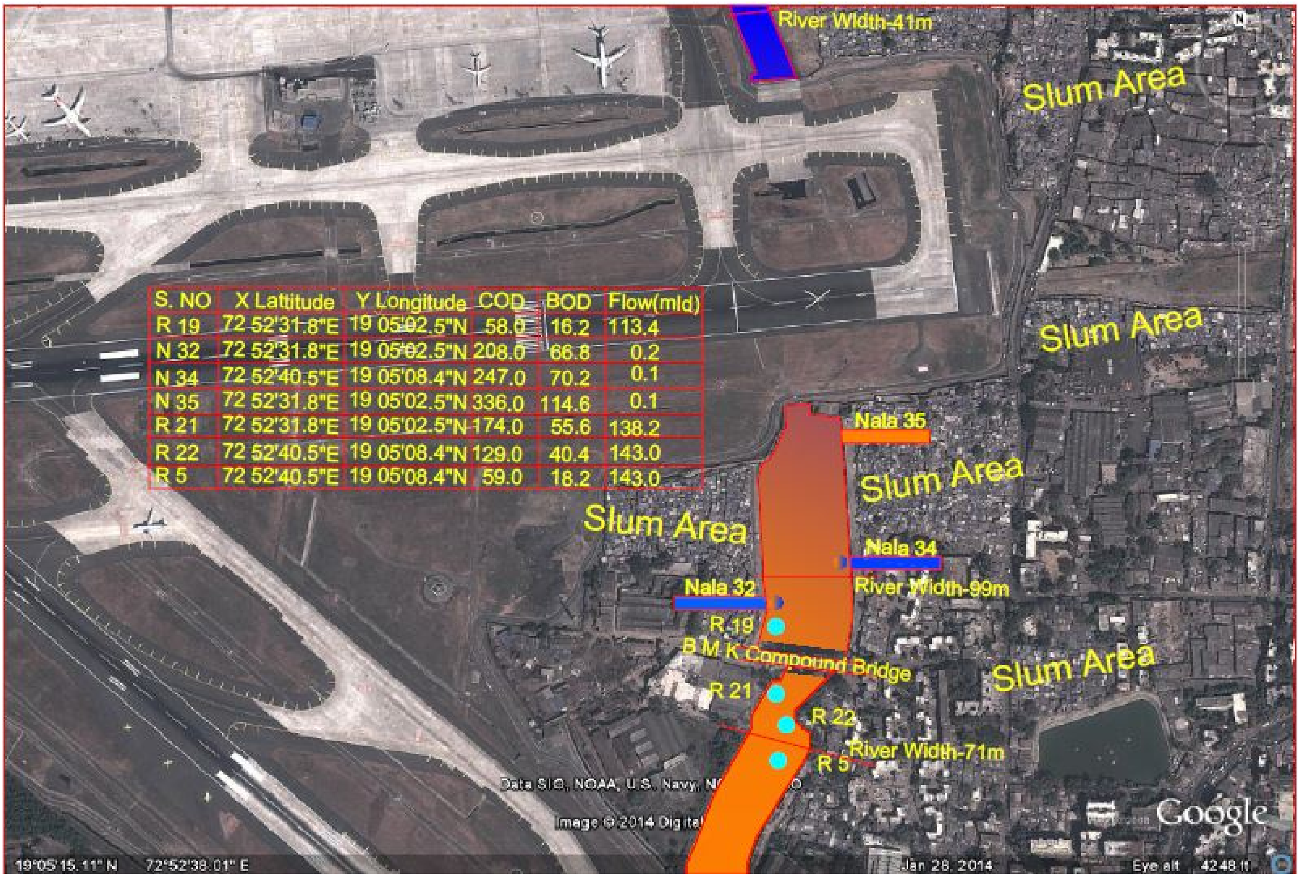
7.2.10 Stretch X - Safed Pool to BMK Compound

The Stretch X initiates at the downstream of the Safed Pool and ends at the BMK Compound. **Figure 7.10** depicts the criticality of the stretch with adopted color coding system & as discussed in the previous Stretch, the Bad condition of river downstream of Stretch IX indicated in Orange colour changes to Average indicated in Blue colour upstream of Stretch X. However, as the river reaches BMK compound, possibly there is certain addition of pollution load as indicated by change to

Orange colour which however in terms of practically collected samples do not explain shifting of condition of river.

Out of three nallahs sampled, 2 seen as Blue colored suggests Average pollution loads indicating characteristics of some parameters marginally close to Prescribed Standards whereas the remaining nallah is seen in Orange color that suggests relatively more pollution load.

Figure 7.10 Criticality in Stretch X – Safed Pool to BMK Compound

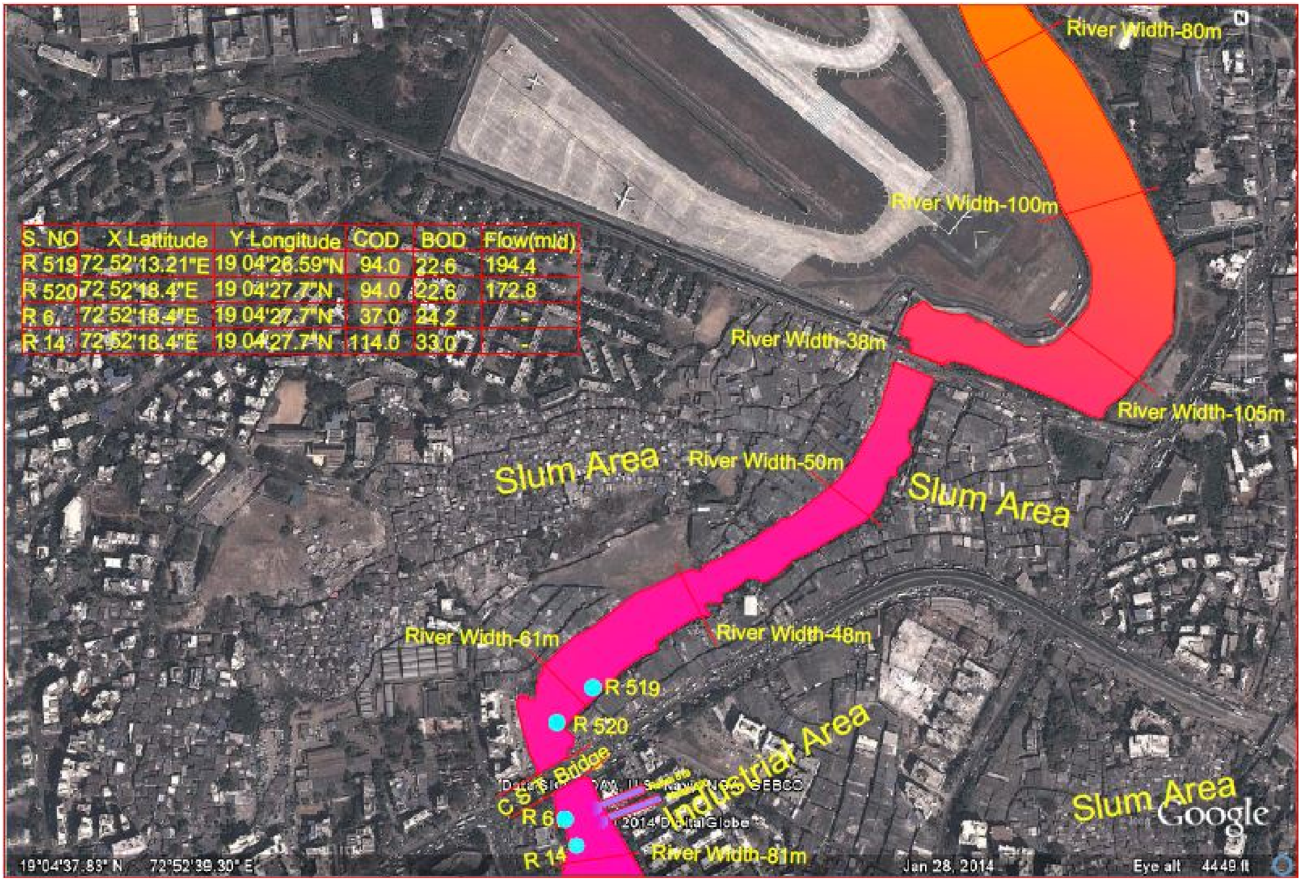


S. NO	X Lattitude	Y Longitude	COD	BOD	Flow(mld)
R 19	72 52'31.8"E	19 05'02.5"N	58.0	16.2	113.4
N 32	72 52'31.8"E	19 05'02.5"N	208.0	66.8	0.2
N 34	72 52'40.5"E	19 05'08.4"N	247.0	70.2	0.1
N 35	72 52'31.8"E	19 05'02.5"N	336.0	114.6	0.1
R 21	72 52'31.8"E	19 05'02.5"N	174.0	55.6	138.2
R 22	72 52'40.5"E	19 05'08.4"N	129.0	40.4	143.0
R 5	72 52'40.5"E	19 05'08.4"N	59.0	18.2	143.0

7.2.11 Stretch XI - BMK Compound to CST Bridge

In the Stretch XI of the river, the pollution levels increases from upstream to downstream as shown in **Figure 7.11**. The Orange color at upstream translates into Pink color at downstream of the stretch probably indicating high organics load contributed by the nallahs that could not be accounted for during the sampling. However, possibly there were discharges into the river through underground piped sources that may include portions of industrial wastewater mixed with domestic ones.

Figure 7.11 Criticality of Stretch XI – BMK Compound to CST Bridge



7.2.12 Stretch XII - CST to MTNL Bridge

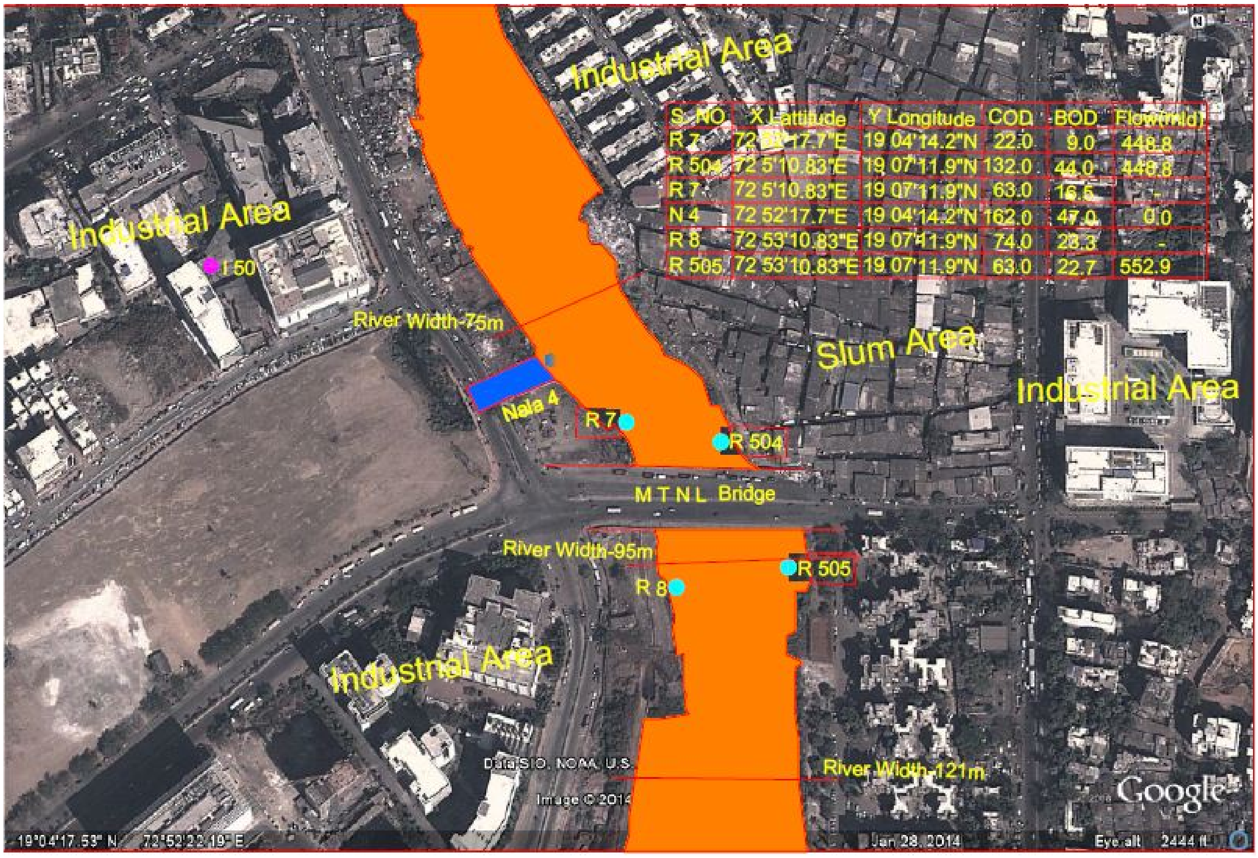
From the **Figure 7.12** it can be observed that the concentrations of concerned parameters are just reaching the prescribed standards as indicated by Orange colour consistent throughout the stretch. N4 nallah entering the river from left bank is indicated in Blue colour suggesting moderate pollution potential discharge well within the standard limits.

7.2.13 Stretch XIII - MTNL Bridge to Bandra-Kurla Complex (BKC)

Stretch XIII begins from downstream of MTNL Bridge and ends at BKC as shown in **Figure 7.13** with moderate pollution load indicated by Dark Blue color in entire stretch. As the tidal influence is prominent in this stretch, flushing as well as dilution probably positively impacts the concentration of organics as well as cations resulting into the Average criticality indices.

Even when the 3.5km Vakola Nallah with enormous hydraulics are adding to the river in this stretch, the tidal impact both here and in Vakola seems to lower down the concentrations of desired parameters to such a level that entire stretch appears to have very moderate pollution. Other than Vakola, two major nallahs are identified joining the river from left bank which are indicated by Green color. These nallahs probably carry sewage from the nearby areas that it shows lowest pollution levels.

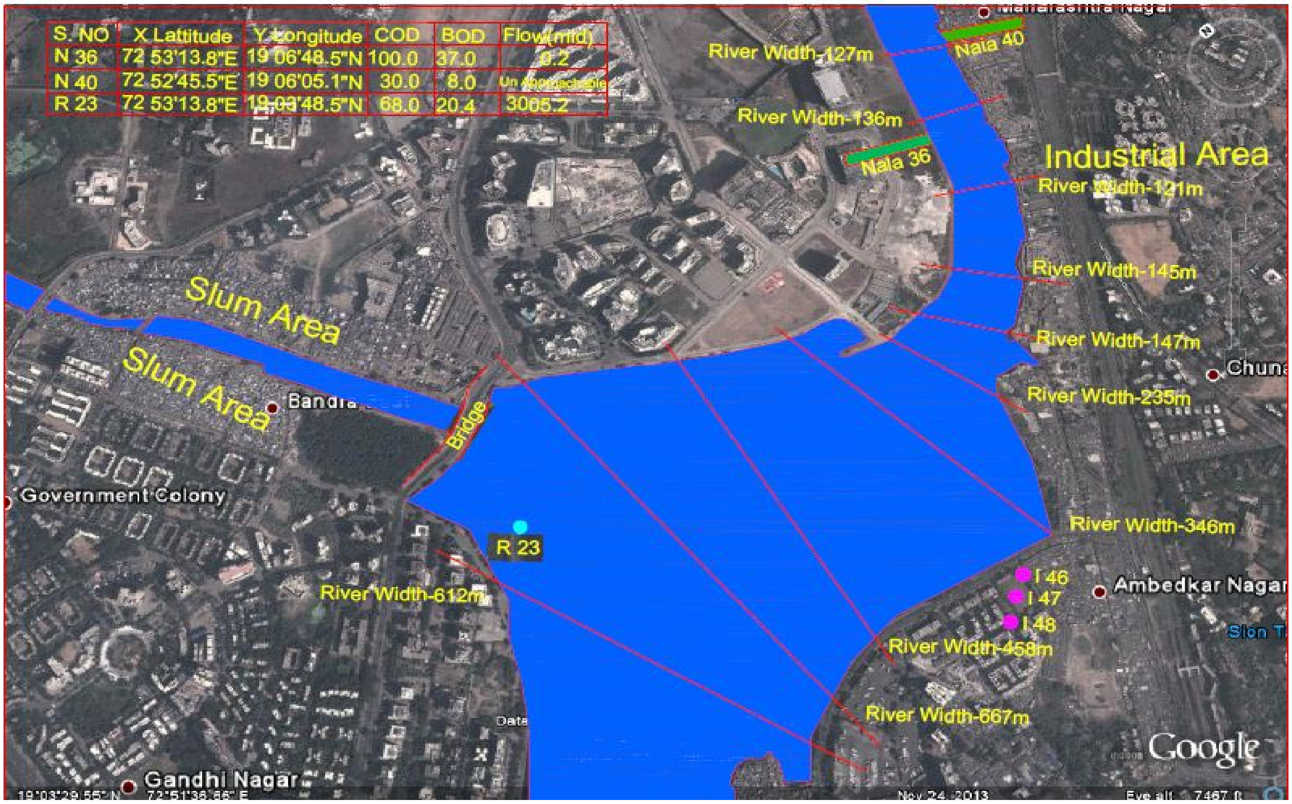
Figure 7.12 Criticality of Stretch XII – CST to MTNL Bridge



7.2.14 Stretch XIV –Vakola Nallah

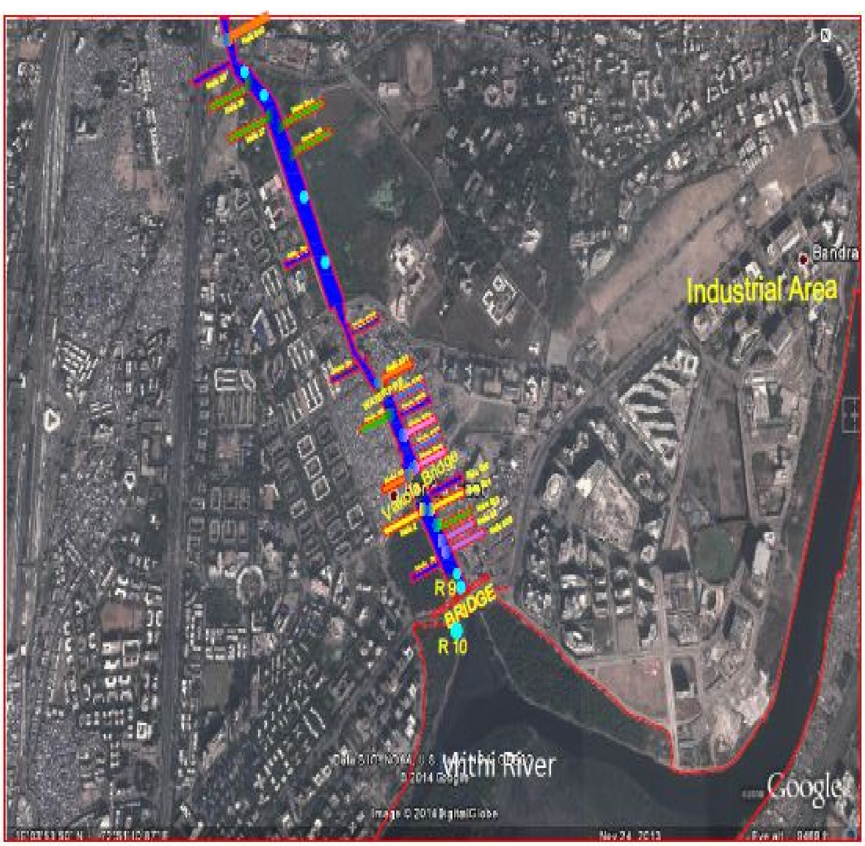
Vakola Nallah has been separately analyzed for its status of pollution and relative criticality. As shown in **Figure 7.14**, out of the numerous nallahs that enter into the Vakola. Out of the 32 selected ones,14nallahs represents Green color revealing minimal pollution load whereas 9 indicated by Blue reveals concentrations of certain parameters to be almost half of the standards. 6 of the nallahs seen as Orange colored suggests pollution load carried in Bad range i.e. concentration of the parameters aligned to the standards whereas remaining 2 as indicated by Pink color indicate high levels of pollution and probably industrial source discharges. Ultimately, Vakola is witnessed by a variety of load bearing nallahs ranging from practically free from pollution ones to extremely polluted drains. Vakola is indicated by Dark Blue color which remains unchanged upto the downstream which is due to the varied pollution load added into it in its path.

Figure 7.13 Criticality of Stretch XIII – MTNL Bridge to BKC



S. NO	X Lattitude	Y Longitude	COD	BOD	Flow(mld)
N 36	72 53'13.8"E	19 06'48.5"N	100.0	37.0	0.2
N 40	72 52'45.5"E	19 06'05.1"N	30.0	8.0	Un Approachable
R 23	72 53'13.8"E	19 03'48.5"N	68.0	20.4	3005.2

Figure 7.14 Criticality of Stretch XIV – Vakola Nallah



S. NO	X Lattitude	Y Longitude	COD	BOD	Flow(mld)
N 21	72 51'17.5"E	19 03'48.2"N	106.0	31.8	-
N 22	72 51'17.5"E	19 03'48.2"N	137.0	37.1	-
N 23	72 51'17.5"E	19 03'48.2"N	251.0	92.5	-
N 24	72 51'17.5"E	19 03'48.2"N	319.0	98.9	-
N 25	72 51'17.5"E	19 03'48.2"N	114.0	35.4	-
N 2	72 51'23.9"E	19 03'36.7"N	147.0	37.5	5.6
N 26	72 51'18.9"E	19 04'01.0"N	99.0	29.9	69.1
N 27	72 51'18.9"E	19 04'01.0"N	201.0	72.0	Un Approachable
N 28	72 51'18.9"E	19 04'01.0"N	137.0	54.5	
N 29	72 51'18.9"E	19 04'01.0"N	36.0	10.8	
N 504	72 50'18.7"E	19 02'53.9"N	77.0	23.0	86.4
N 505	72 50'18.7"E	19 02'53.9"N	103.0	28.8	86.4
N 506	72 50'18.7"E	19 02'53.9"N	70.0	20.9	1.5
N 522	72 51'23.6"E	19 03'35.5"N	855.0	325.0	Un Approachable
N 523	72 51'23.6"E	19 03'35.5"N	11.0	4.0	
N 524	72 51'23.6"E	19 03'35.5"N	281.0	94.0	
N 525	72 51'23.6"E	19 03'35.5"N	159.0	54.0	0.0
N 526	72 51'23.6"E	19 03'35.5"N	935.0	438.0	-
N 527	72 51'17.5"E	19 03'48.2"N	110.0	48.0	96.0
N 528	72 51'17.5"E	19 03'48.2"N	673.0	246.0	0.1
N 529	72 51'17.5"E	19 03'48.2"N	167.0	56.0	0.1
N 530	72 51'17.5"E	19 03'48.2"N	175.0	73.0	0.0
N 531	72 51'17.5"E	19 03'48.2"N	281.0	96.0	0.0
N 532	72 51'17.5"E	19 03'48.2"N	152.0	66.0	-
N 533	72 51'17.5"E	19 03'48.2"N	247.0	98.0	65.2
N 534	72 51'17.5"E	19 03'48.2"N	65.0	23.0	0.0
N 535	72 50'53.7"E	19 04'50.0"N	95.0	32.0	86.4
N 539	72 50'58.0"E	19 04'50.8"N	27.0	8.0	70.0
N 540	72 51'19.4"E	19 03'37.1"N	336.0	124.0	-
N 37	72 52'02.1"E	19 03'09.3"N	81.0	28.8	162.0
N 38	72 53'13.8"E	19 03'48.5"N	89.0	30.4	185.1
N 39	72 53'13.8"E	19 03'48.5"N	-	-	185.1

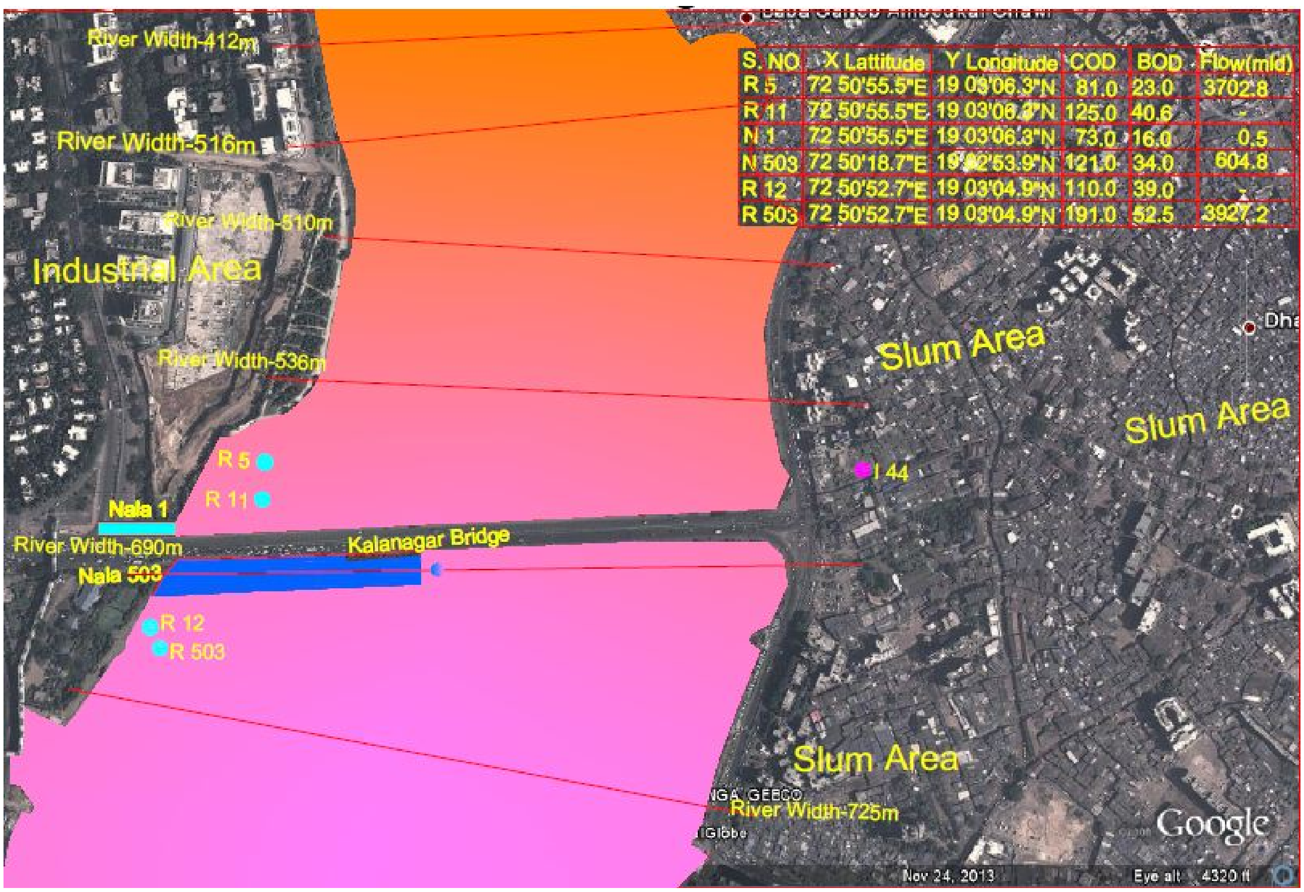
7.2.15 Stretch XV - BKC to Kalanagar

Two nallahs entering river from left bank indicated by Blue color respectively suggests moderate load of sewage being discharged in this stretch of the river though the river in itself seems to be pretty Bad as per indices represented by Orange to Pink color transformation as presented in **Figure 7.15** suggesting increase in load at downstream of the stretch.

7.2.16 Stretch XVI - Kalanagar to Mahim

The Pink colour at upstream gets changed into Orange in this Stretch XVI as shown in **Figure 7.16** revealing pollution levels exceeding prescribed standards at the upstream which seems to get diluted at the downstream because of the tidal influence. Only 1 nallah indicated by Dark Green colour index enters river downstream with minimal pollution and the overall moderate pollution in this stretch can also be accounted to tidal influence being the last part of river converging into Sea.

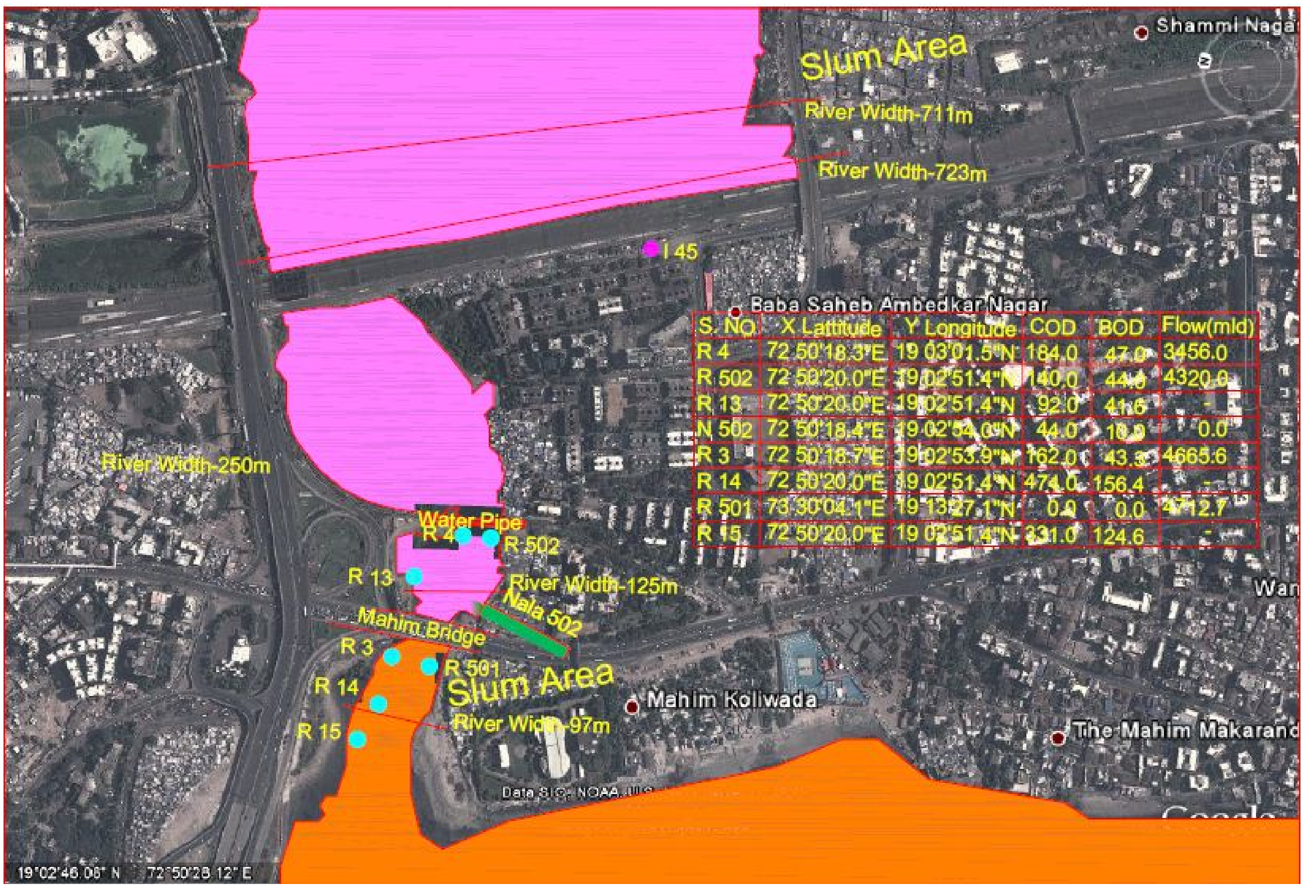
Figure 7.15 Criticality in stretch XV – BKC to Kalanagar



In conclusion, it can be interpreted that none of the stretches across the river falls within the index of Critical nature to be represented by Red colour. Few of the stretches i.e. point of origin from Vihar Lake to Filterpada with direct source of sewage and open defecation whereas Gautam Nagar, KBM Compound, downstream of Sakinaka and CST probably contributing some part of industrial sourced wastewater mixed with domestic. Thirdly, downstream of Airport and Kalanagar whereas upstream of Bamandaya Pada and Mahim also falls within the purview of Worst category represented by Pink colour and characterized by almost all organic parameters above the standards used for this study.

Criticality levels characterized by organic parameters marginally below the standards with few others probably beyond their respective limits represented as Bad nature – Orange coloured are observed along downstream of JVLR Bamandaya Pada, Marol, BMK Compound and Mahim whereas upstream of Airport, CST, Kalanagar and entire stretch of Safed Pool and MTNL mainly sourcing wastewater from domestic discharges.

Figure 7.16 Criticality in stretch XVI – Kalanagar to Mahim



There are no such indications of extremely low concentrations of parameters determining Good characteristics of river however in terms of Average quality as represented by Blue colour along the criticality index, upstream of JVLR, Marol, Sakhinaka, BMK Compound, entire of BKC and Vakola shows pollutant concentrations almost half of the prescribed limits used to compute the same and mostly incorporating diluted domestic wastewater discharge. **Table 7.5** summarizes the color coding obtained at upstream and downstream of the stretches along Mithi River.

Table 7.5 Summary of Criticality along Mithi River

Stretch of Mithi River	Color at Upstream	Color at Downstream
I Vihar Lake to Filterpada	Pink	Pink
II Filterpada to Gautam Nagar	Light Pink	Dark Pink
III Gautam Nagar to JVLR Bridge	Dark Blue	Orange
IV JVLR Bridge to Bamandaya Pada	Pink	Orange
V Bamandaya Pada to KBM Compound	Pink	Pink
VI KBM Compound to Marol	Dark Blue	Orange
VII Marol to Sakhinaka	Dark Blue	Pink
VIII Sakhinaka to Domestic Airport	Orange	Pink
IX Domestic Airport to Safed Pool	Orange	Orange
X Safed Pool to BMK Compound	Blue	Orange
XI BMK Compound to CST Bridge	Orange	Pink
XII CST Bridge to MTNL Bridge	Orange	Orange
XIII MTNL Bridge to Bandra-Kurla Complex	Dark Blue	Dark Blue
XIV Vakola Nallah	Dark Blue	Dark Blue
XV Bandra-Kurla Complex to Kalanagar	Orange	Pink
XVI Kalanagar to Mahim	Pink	Orange

The main purpose of this exercise was to make it convenient for decision makers to have an easy and simple interpretable means of understanding of criticality of Mithi so that immediate intervention can be planned and priority can be set for those sections of the river needing it the most. Thereby nallahs that are marked from Orange to Pink to Red as indicated in **Figure 7.17** & stretches of river represented by similar colour range needs to be the prime centre's of cause of concern pollution mitigation point of view.

On the other hand long term plans to control and maintain pollution levels in Blue coloured sections of river as well as those indicated similarly in nallahs need to be worked out. The framework can be easily updated annually to indicate success of management implementation just by viewing time scale maps of this kind putting in basic analysis data in future.

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Source Receptor Modeling

8.0 Background

In the effluent Characterization studies, many variables are measured to typify the system. However, it is an interesting fact that all of the variables are not independent of each other and hence there is a need to develop mathematical techniques that permit the study of these simultaneous variations of multiple variables. One such analysis i.e. the correlation is based on identifying the relationships between pairs of variables.

Correlation analysis forms one such method but does not provide a clear view of multiple interactions in the data. Thus, eigenvector analysis was used to convert the correlation data into multivariate information. Factor Analysis is the name given to one of the variety of forms of eigenvector analysis [Gupta A., et. al., 1997].

The varied application methods have resulted in different terminologies such as factor Analysis, Principal Component Analysis, Principal Component Factor Analysis, Empirical Orthogonal Function Analysis, etc. depending upon the way the data are scaled before analysis or how the resulting vectors are treated after the eigenvector analysis is completed.

The major problem in environmental pollutant characterization is the resolution of environmental mixtures to their source contributions. For example, a sample of air borne particulate matter collected at a site is made up of particles of soil, motor vehicle exhaust, secondary sulphate particles, and primary emissions from industrial point source, etc. It then forms a point of interest to determine the contribution from each source to the total mass collected. It is then assumed that the measured ambient concentration of some species Xi, where I = 1…m, is a linear sum of elemental concentrations from P independent source of particles. Each K^{th} source emits particles that have a profile of elemental concentrations, a_{ik} and a mass contribution per unit volume of the K^{th} source is f_k. When the compositions are measured for 'n' number of samples, the equation is obtained.

$$X_{ij} = \sum_{K=1}^{P} a_{ik} f_{kj}$$

This technique has been used by a number of researchers for the identification of various sources.

Principal Component Analysis (PCA) is an important chemometric tool [Jolliffe I. T., 1996; Jackson J.E., 1991] that can be used to establish combinations of variables, capable of describing the principal data tendencies observed. This technique has been successfully used to study coastal water contamination [Reisenholer E., 1996]receptor modeling of air [Bellheimer D., 2001; Pinto J.P., 1998] as well as for characterization and determination of sources of contamination and eutrophication in lake waters [Reisenhofer E., 1995].

In Environmental Impact Assessment, FA had played a very important role very recently. An approach of objective weighting by using a procedure of PCFA, which suits specifically those parameters measured directly by physical scales, has been proposed by Ying and Liu in 1995 [Ying L. G., 1995]. PCA has been applied to evaluate the effect of pollution on the ecosystems. In a study to identify the possible effects of thermal pollution on the macro benthic communities and to compare them with the main influencing factors PCA was found to be the most powerful technique in evidencing the effect.

Factor analysis has also been applied by a number of researchers to interpret water quality data. It has been used to classify the stretch of a river into pollution zones. It has been also used to find out the dominating variables at different locations and to evaluate the sampling network and frequency. As in air quality application, it helps in identifying the nature of the sources in a broad sense with respect to mineralisation in and around a location. Mehloch first applied this technique to interpret the water quality data in 1974 [Mehloch J. L., 1974].

As far as the study area is concerned, a need for the application of the Receptor model was felt taking into consideration the following reasons:

- Lack of precise information on water supply and sewage/effluent generated from the sources entering Mithi river
- Numerous intermediate, unknown & untreated discharges leading to extensive anticipated pollution load as confirmed from the characterization studies of nallah/industrial and domestic sources
- There may be many synergistic and antagonistic effects among variables since the effluent is a mixed type
- The effluent /sewage characterization includes multiple variables and complex co-existence of all parameters, which originate from altogether different sources
- It was assumed that these parameters that come from different sources and characterize the effluents are nothing but the variables, which may or may not be independent of one another

- Limitations of use of conventional physical ground truthing and other methods to evaluate industrial v/s domestic wastewater contribution to Mithi river

8.1 Factor Analysis Model

The mathematical model for factor analysis is similar to multiple regression analysis. Each variable is expressed as combinations of factors that are not actually observed.

The model for i^{th} standardized variable is:

$$X_i = A_{i1}F_1 + A_{i2}F_2 + \ldots\ldots + A_{ik}F_k + U_i$$

Where:

F_i's = common factors (all variables are expressed as functions of them) &
U_i = unique factor (uncorrelated)

These factors are common factors because all the variables are expressed as functions of them. The unique factors are assumed to be uncorrelated with each other and with the common factors.

The factors are labels for group of variables i.e. they are linear combinations of variables that characterize these concepts. The factors are inferred from observed variables and can be estimated as linear combinations of them. For example, the factor F_j can be expressed as:

$$F_i = \Sigma W_{ji} \qquad X_i = W_{ji}\, X_i + W_{j2}\, X_2 + \ldots + W_{jp}X_p$$

Where:

W_i's = factor score coefficients and
P = number of variables

It is quite possible that all the variables might contribute to the factor F_j, but then by convention it seems that only a few subsets of variables characterize F_j, as indicated by their large coefficients.

8.1.1 Experimental

The characterization of the river water from the study area was carried out by measuring 24 different parameters including 9 metals as discussed in the previous chapters. To identify the sources of such varied characteristics, it was felt essential to utilize only some selected parameters for receptor modeling since all the parameters may lead to erroneous results.

Receptor modeling was performed using SPSS 11.0, software termed as Statistical Package for Social Sciences version 11.0.

Factor Analysis has been used to determine the sources of particular pollutant in the 2 different regimes i.e. river & nallah each of which is further factored with special reference to the typical characteristic parameters such as physical along with BOD, COD, oil, grease, nitrates and MPN and heavy metals separately. The results of the analysis have been overlaid with the surveyed data for discharges as well as categorized analysis data from industrial & domestic sources whereby an attempt is made to establish correlation and authenticity of the Receptor model.

The authors feel that is would be of utmost importance to elucidate steps that are involved in Factor Analysis and enlist all such necessary inputs that are used in this study for transparency and QA/QC checks for all readers as discussed in following sections.

8.1.1.1 Steps Involved in Factor Analysis [FA]

To put it simply, factor analysis basically involves data reduction in the form of matrices involving the use of Eigen values and Eigenvectors. Thus, before discussing the steps involved in FA, it is essential to understand these concepts, which is outlined here.

The eigenvalue problem is a problem of considerable theoretical interest and wide-ranging application. For example, this problem is crucial in solving systems of differential equations, analyzing population growth models, and calculating powers of matrices (in order to define the exponential matrix). Other areas such as physics, sociology, biology, economics and statistics have focused considerable attention on "eigenvalues" and "eigenvectors"-their applications and their computations. Before we give the formal definition, let us introduce these concepts on an example.

For Example, Consider the matrix

$$A = \begin{pmatrix} 1 & 2 & 1 \\ 6 & -1 & 0 \\ -1 & -2 & -1 \end{pmatrix}.$$

Consider the three column matrices

$$C_1 = \begin{pmatrix} 1 \\ 6 \\ -13 \end{pmatrix},\ C_2 = \begin{pmatrix} -1 \\ 2 \\ 1 \end{pmatrix},\ \text{and}\ C_3 = \begin{pmatrix} 2 \\ 3 \\ -2 \end{pmatrix}.$$

We have

$$AC_1 = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, \; AC_2 = \begin{pmatrix} 4 \\ -8 \\ -4 \end{pmatrix}, \text{ and } AC_3 = \begin{pmatrix} 6 \\ 9 \\ -6 \end{pmatrix}.$$

In other words, we have

$$AC_1 = 0C_1, \; AC_2 = -4C_2, \; \text{ and } \; AC_3 = 3C_3.$$

Next consider the matrix *P* for which the columns are C_1, C_2, and C_3, i.e.,

$$P = \begin{pmatrix} 1 & -1 & 2 \\ 6 & 2 & 3 \\ -13 & 1 & -2 \end{pmatrix}.$$

We have *det*(*P*) = 84. So this matrix is invertible. Easy calculations give

$$P^{-1} = \frac{1}{84}\begin{pmatrix} -7 & 0 & -7 \\ -27 & 24 & 9 \\ 32 & 12 & 8 \end{pmatrix}.$$

Next we evaluate the matrix $P^{-1}AP$. We leave the details to the reader to check that we have

$$\frac{1}{84}\begin{pmatrix} -7 & 0 & -7 \\ -27 & 24 & 9 \\ 32 & 12 & 8 \end{pmatrix}\begin{pmatrix} 1 & 2 & 1 \\ 6 & -1 & 0 \\ -1 & -2 & -1 \end{pmatrix}\begin{pmatrix} 1 & -1 & 2 \\ 6 & 2 & 3 \\ -13 & 1 & -2 \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & -4 & 0 \\ 0 & 0 & 3 \end{pmatrix}.$$

In other words, we have

$$P^{-1}AP = \begin{pmatrix} 0 & 0 & 0 \\ 0 & -4 & 0 \\ 0 & 0 & 3 \end{pmatrix}.$$

Using the matrix multiplication, we obtain

$$A = P\begin{pmatrix} 0 & 0 & 0 \\ 0 & -4 & 0 \\ 0 & 0 & 3 \end{pmatrix}P^{-1}$$

which implies that *A* is similar to a diagonal matrix. In particular, we have

$$A^n = P\begin{pmatrix} 0 & 0 & 0 \\ 0 & (-4)^n & 0 \\ 0 & 0 & 3^n \end{pmatrix}P^{-1}$$

for n= 1,2,…. It is worth noting that finding A^{75} directly from the original form of A is practically impossible.

This example is so rich of conclusions that many questions impose themselves in a natural way. For example, given a square matrix *A*, how do we find column matrices, which have similar behaviors as the above ones? In other words, how do we find these column matrices, which will help find the invertible matrix *P* such that $P^{-1}AP$ is a diagonal matrix?

From now on, we will call column matrices **vectors**. So the above column matrices C_1, C_2, and C_3 are now vectors. We have the following definition.

By the Definition, Let A be a square matrix. A non-zero vector C is called an **eigenvector** of A if and only if there exists a number (real or complex) λ such that

$$AC = \lambda C.$$

If such a number λ exists, it is called an **eigenvalue** of A. The vector C is called eigenvector associated to the Eigenvalue λ. The eigenvector C must be non-zero since we have

$$A\mathcal{O} = \mathcal{O} = \lambda\mathcal{O}$$

For any number λ.

For Example, Consider the matrix

$$A = \begin{pmatrix} 1 & 2 & 1 \\ 6 & -1 & 0 \\ -1 & -2 & -1 \end{pmatrix}.$$

We have seen that

$$AC_1 = 0C_1,\ AC_2 = -4C_2,\ \text{and}\ AC_3 = 3C_3$$

Where

$$C_1 = \begin{pmatrix} 1 \\ 6 \\ -13 \end{pmatrix},\ C_2 = \begin{pmatrix} -1 \\ 2 \\ 1 \end{pmatrix},\ \text{and}\ C_3 = \begin{pmatrix} 2 \\ 3 \\ -2 \end{pmatrix}.$$

So C_1 is an eigenvector of A associated to the eigenvalue 0. C_2 is an eigenvector of A associated to the eigenvalue -4 while C_3 is an eigenvector of A associated to the eigenvalue 3.

8.1.1.1.1 Computation of Eigenvalues

Consider the matrix

$$A = \begin{pmatrix} a & b \\ c & d \end{pmatrix}$$

And assume that λ is an eigenvalue of A. Then there must exist a non-zero vector

$$Y_0 = \begin{pmatrix} x_0 \\ y_0 \end{pmatrix}$$

Such that $AY_0 = \lambda Y_0$. This equation may be rewritten as the algebraic system

$$\begin{cases} a\,x_0 + b\,y_0 &= \lambda\,x_0 \\ c\,x_0 + d\,y_0 &= \lambda\,y_0 \end{cases}$$

which is equivalent to the system

$$\begin{cases} (a-\lambda)\,x_0 & + & b\,y_0 & = & 0 \\ c\,x_0 & + & (d-\lambda)\,y_0 & = & 0 \end{cases}$$

Since both χ_0 and y_0 cannot be equal to zero at the same time, we must have the determinant of the system equal to zero. That is,

$$det \begin{pmatrix} (a-\lambda) & b \\ c & (d-\lambda) \end{pmatrix} = (a-\lambda)(d-\lambda) - bc = 0,$$

Which reduces to the algebraic equation

$$\lambda^2 - (a+d)\lambda + ad - bc = 0.$$

The above equation is independent of the vector Y_0. This equation is called the **Characteristic Polynomial** of the system.

8.1.1.1.2 Computation of Eigenvectors

Assume λ is an eigenvalue of the matrix *A*. An eigenvector Y_0 associated to λ is given by the matricial equation

$$A\,Y_0 = \lambda\,Y_0.$$

Set $$Y_0 = \begin{pmatrix} x_0 \\ y_0 \end{pmatrix}.$$

Then, the above matricial equation reduces to the algebraic system

$$\begin{cases} a\,x_0 + b\,y_0 & = & \lambda\,x_0 \\ c\,x_0 + d\,y_0 & = & \lambda\,y_0 \end{cases}$$

which is equivalent to the system

$$\begin{cases} (a-\lambda)\,x_0 & + & b\,y_0 & = & 0 \\ c\,x_0 & + & (d-\lambda)\,y_0 & = & 0 \end{cases}$$

Since λ is known, this is now a system of two equations and two unknowns. It must be noted that if Y_0 is an eigenvector, then KY_0 is also an eigenvector.

The factor analysis is carried out in four steps.

1. The first step in the analysis of the data involves calculation of a function that indicates the degree of interrelationships, which exists within the data i.e. the product moment correlation coefficient

2. The second step involves determination of the number of factors necessary to represent the data and the method of calculating them. This step also ascertains the fitness of the chosen model with the data
3. The third step is Rotation that focuses on transforming the factors to make them more interpretable
4. At the fourth step, scores for each factor is computed for each sampling location in both the river & nallahs

8.1.1.2 Correlation Coefficient

Correlation coefficient between two variables x_i and x_j, over all n samples is:

$$R_{ij} = \frac{\sum_{k=1}^{n} (X_{ik} - X_i)(X_{jk} - X_j)}{\sqrt{\left\{\sum_{k=1}^{n} (X_{ik} - X_i)^2\right\}} \sqrt{\left\{\sum_{k=1}^{n} (X_{jk} - X_k)^2\right\}}}$$

The original variables can be transformed by subtracting the mean value and dividing by the standard deviation i.e.

$$Z_{ik} = \frac{X_{ik} - X_i}{\sigma_i}$$

Hence, correlation coefficient can be simplified to:

$$r_{ij} = \frac{\sum Z_{ik} Z_{jk}}{n}$$

The advantage of standardization is that each standardized variable has a mean value of zero and a standard deviation of one. Each variable carries one unit of system variance and the total variance for a set of measurements of **m** variables would be **m**.

Thus, the matrix of either the correlations or covariances, called the **dispersion matrix**, can be obtained from the original or transformed data matrices. The choice of dispersion function depends on the nature of the variables being measured. Another use of the correlation coefficient is that it can be interpreted in a statistical sense to test the null hypothesis as to whether a linear relationship exists between the pairs of variables being tested. It is important to note that the existence of a correlation coefficient that is different from zero does not prove that a cause and effect relationship exists. Also, it is important to note that the use of probabilities to determine if correlation coefficients are significant is very questionable for environmental data.

In the development of those probability relationships, explicit assumptions are made that the underlying distributions of the variables in the correlation analysis are normal. For most environmental variables, normal distributions are uncommon. Generally, the distributions are positively skewed and heavily tailed. Thus great care should be taken in making probability arguments regarding the significance of pair wise correlation -coefficients between variables measured in environmental samples.

It is then very important to examine the correlation matrix since the major aim of factor analysis is to help explain the correlations, the factor model must be related to each other for the model to be appropriate. If correlations between variables are small it is unlikely that they share common factors. Thus, certain tests are performed to evaluate the correlation matrix such as follows:

8.1.1.2.1 Bartlett's Test of Sphericity

This can be used to test the hypothesis that the correlation matrix is an identity matrix. The test requires that the data be a sample from a multivariate normal population. If the value of the test statistic for sphericity is large and the associated significance level is small, it appears unlikely that the population correlation matrix is identity

8.1.1.2.2 Kaiser – Meyer – Olkin Measure of Sampling Adequacy

It is an index for comparing the magnitudes of the observed correlation coefficients to the magnitudes of the partial correlation coefficients. It is computed as

$$KMO = \frac{\Sigma r_{ij}^2}{\Sigma r_{ij}^2 + \Sigma a_{ij}^2}$$

Where, the summation is for all values of i and j, i not equal to j; r_{ij} is the correlation coefficient between variables i and j; a_{ij} is the partial correlation coefficient between variables i and j. If the sum of the squared partial correlation coefficients between all pairs of variables is small when compared to the sum of the squared correlation coefficients, the KMO measure is close to 1. Small values of this measure indicate that a factor analysis of the variables may not be a good idea, since correlations between pairs of variables cannot be explained by the other variables. The measure in the 0.9's is characterized as marvelous, in the 0.8's as meritorious, in the O.7's as middling, in the 0.6 as mediocre, in the 0.5's as miserable and below 0.5 as unacceptable.

8.1.1.2.3 Measure of Sampling Adequacy

A measure of sampling adequacy can be computed for each individual variable in a similar manner. Instead of including all pairs of variables in the summations, only coefficients involving that variable are included. For the i^{th} variable, the measure of sampling adequacy is given by the equation

$$MSA_i = \frac{\Sigma\, r_{ij}^2}{\Sigma\, r_{ij}^2 + \Sigma\, a_{ij}^2}$$

The summation is for all values of j not equal to i. For a good factor analysis large values are needed.

8.1.1.3 Factor Extraction by Principal Component Analysis

This section outlines the factor extraction based on principal component analysis, which is most commonly used. Several different methods are used to obtain estimates of the factors which include Maximum likelihood algorithm, Principal axis factoring etc. The first principal component is the linear combination that accounts for the largest amount of variance in the sample. The second principal component accounts for the ~next largest amount of variance and is uncorrelated with the first. For example, consider the simplest case and try to understand principal component analysis when only two variables are present.

Let x_1 =10.530 x_2= 11.133 and
s_1 = 1.132 s_2 – 0.636
r_{12} = -0.6809

Where: x_1 and x_2 are the means of two variable and s_1 and s_2 are the standard deviations

We define a simple measure of simultaneous variability of all variables involved i.e., the sum of the variances, called the total variance.

$$s^2_{total} = s\,(X_1) + s^2\,(X_2) = 1.132^2 + 0.636^2 = 1.686$$

Variable X_1 has a proportion of 76.1% of the total variance. For the principal components F_l and F_2 one obtains the same sum of variances, that is

$$s^2\,(F_1) + s^2\,(F_2) = s\,(X_1) + s\,(X_2) = s^2 \text{ total'}$$

F_1 has a proportion of 89% of the total variance. This proportion depends crucially on the correlation between the variables under analysis, and approaches 100% if the, correlation lies near 1 in absolute value. As a general rule we say that the first principal component reproduces the data well if its proportion of the total variance is sufficiently large, e.g. larger than 80% or 90%.

Another important information about this type of analysis is that if there is perfect correlation (one) between the variables the first principal component will account for 100% of the total variance and determining the second principal component becomes unnecessary in this case. On the other hand if the correlation is absent (zero), it results in the original variables being the principal component.

8.1.1.4 Principal Components in Multidimensional Case

The relationships developed in the two dimensional case are valid for P > 2. If P > 2 the p principal components are linear combinations of the p variables.

$$
\begin{gathered}
F_1 = b_{12}X_1 + b_{j2}X_2 + ... + b_{1p}X_p \\
F_2 = b_{21}X_1 + b_{22}X_2 + ... + b_{2P}X_p \\
\dots \\
\dots \\
F_p = b_{p1}X_1 + b_{p2}X_2 + ... + b_{pp}X_p
\end{gathered}
$$

The transformation from the variables ~ to the principal components F_h can be viewed as rotation of the p-dimensional coordinate system in such a way that the new variables
$F_h$are mutually uncorrelated.

8.1.1.5 Number of Retained Factors

It is important to examine the percentage of total variance explained by each in order to decide how many factors are needed to represent the data. For simplicity in most of the cases all variables and factors are expressed in standardized form i.e. with a mean of 0 and a standard deviation of 1. Percentage of total variance and cumulative percentage attributable to each factor is calculated.

Several procedures have been proposed for determining the number of factors to use in a model. One criterion suggests that only factors that account for variances greater than 1 (eigenvalue greater than 1) should be included.

8.1.1.6 Rotation

Although the factor matrix obtained indicates the relationship between the factors and the individual variables, it is usually difficult to identify meaningful factors based on this matrix. Often the variables and factors do not appear correlated in any interpretable pattern. Most factors are correlated with many variables. The rotation phase of factor analysis attempts to transform the initial matrix into one that is easier to interpret.

8.1.1.7 Factor Scores

Factor score is another important output of factor analysis. Factor score f_{jk} for j^{th} factor for case k is computed by

$$f_{jk} = \sum_{i=1}^{p} W_{ji} X_{ik}$$

Where, $X_{ik}$is the standardized value of the i^{th} variable for case k and W_{JI} is the factor score coefficient for the j^{th}factor and the i^{th} variable. Mathematically, the relationship between the matrix of factor scores and the rotated factor matrix is as follows:

$$B=R^{-1} S$$

Where, B is the factor score coefficient matrix; R is the correlation matrix; and S is the rotated factor matrix.

Information on factor scores is useful if the factors could be well interpreted. Normally in analyzing water quality data, the first factor is found to be a representative of most of the important water quality parameters and is hence termed as the **general factor.** A computation of factor scores thus enables to compress the implications of several variables into a single number, very similar to Water Quality Index (WQI). A factor score is therefore referred as a FAWQ1.

Similarly, if factor II is found to be dominated by the organic pollution for example reflecting heavy factor loadings of TKN (Total Kjeldahl nitrogen), BOD. COD etc. then the factor scores computed for factor II would indicate the overall behavior of the state of organic pollution in the river.

Normally the factor scores should take values between ± 2 and seldom exceed ± 4. Values beyond the range of ± 2 imply noticeable state in the pattern of water quality.

8.2 Data Outputs & Discussions

Receptor modeling has been carried out with the aim to establish source contribution in Mithi River. Though the data interpretation is aligned by using references published elsewhere, it needs to be pointed out very clearly that there are numerous assumptions in such studies. Interpretation of data is mere statistical and imitation of the actual scenario. In any of the receptor studies only about 70 to 75% of variability of source contribution can be accounted for since these are random statistical analysis and interpretation.

It is assumed that the physic-chemical and organic parameters represent the primary categories of river water classification whereas metals represent the secondary category within the industrial sources and thereby FA of metals are used to further classify industrial sources within the extent of those extracted from primary variance.

8.2.1 Correlation Matrices

The correlation matrix presented in **Table 8.1** reports the correlations among the variables i.e. the physico-organic parameters whereas **Table 8.2** depicts metals analyzed. The values on the main diagonal are all 1.0, because each variable correlates perfectly with itself. Correlations above the main diagonal are a “mirror image” of those below. Since there are relatively few correlations near zero, factor analysis proves valid.

Table 8.1 & **Table 8.2** represents correlation matrix in river & nallah respectively explaining the dependency / relationship between two or more variables with each other. COD and BOD are correlated with each other to the extent of about 97% which is very well expected being representing direct dependency whereas Total Solids with TDS, SO_4& Hardness which probably means that most of the sulphates and hardness causing elements are present in precipitated form. Oil & Grease, PO_4 and NO_3 seems to be independent and do not correlate to any other parameters analyzed in this particular study under the purview of limited samples collected whereas alkalinity shows almost 81% correlation with Conductivity which is quite acceptable. The perfect proof of validity of receptor model used is shown by the correlation of hardness with conductivity to the extent of 65%, TDS almost 99%, chlorides about 97% & sulphates about 71% that is universally known to be very well correlated and contributing to each other whereas vice-versa correlation to similar or less of SO_4 with these mentioned above. Negative correlation values represent probability of antagonistic effect and/or independent nature or parameters across each other.

Table 8.1 Correlation Matrices for Physico-chemical &Organics in River

	pH	COD	BOD	TSS	O&G	Cond	TDS	Cl^-	Alk	Hard	SO_4	PO_4	NO_3	MPN
pH	1.000	-.149	-.179	.329	.002	.470	.622	.624	.511	.639	.478	-.406	-.086	.129
COD	-.149	1.000	.971	.253	-.110	.255	.163	.193	.116	.159	-.032	-.053	-.176	-.053
BOD	-.179	.971	1.000	.204	-.100	.247	.120	.159	.109	.121	-.068	-.080	-.153	-.073
TSS	.329	.253	.204	1.000	-.044	-.066	.632	.500	-.149	.589	.731	-.115	-.240	.175
O&G	.002	-.110	-.100	-.044	1.000	-.061	-.074	-.067	-.143	-.058	-.081	-.192	-.088	-.041
Cond	.470	.255	.247	-.066	-.061	1.000	.630	.766	.813	.652	.151	-.420	-.194	-.109
TDS	.622	.163	.120	.632	-.074	.630	1.000	.971	.408	.988	.753	-.359	-.310	-.015
Cl^-	.624	.193	.159	.500	-.067	.766	.971	1.000	.541	.972	.641	-.407	-.297	-.024
Alk	.511	.116	.109	-.149	-.143	.813	.408	.541	1.000	.450	.028	-.169	-.204	-.059
Hard	.639	.159	.121	.589	-.058	.652	.988	.972	.450	1.000	.715	-.360	-.305	.019
SO_4	.478	-.032	-.068	.731	-.081	.151	.753	.641	.028	.715	1.000	-.088	-.289	.117
PO_4	-.406	-.053	-.080	-.115	-.192	-.420	-.359	-.407	-.169	-.360	-.088	1.000	-.060	.197
NO_3	-.086	-.176	-.153	-.240	-.088	-.194	-.310	-.297	-.204	-.305	-.289	-.060	1.000	-.082
MPN	.129	-.053	-.073	.175	-.041	-.109	-.015	-.024	-.059	.019	.117	.197	-.082	1.000

Table 8.2 Correlation Matrices for Physico-chemical &Organics in Nallahs

	pH	COD	BOD	TSS	O&G	Cond	TDS	Cl^-	Alk	Hard	SO_4	PO_4	NO_3	MPN
pH	1.000	.009	-.064	.245	-.090	-.096	.227	.195	.006	.239	.075	-.114	.181	-.069
COD	.009	1.000	.977	.068	-.055	-.080	-.166	-.196	.063	-.144	-.129	.408	-.211	-.086
BOD	-.064	.977	1.000	.067	-.057	-.066	-.167	-.199	.046	-.148	-.129	.447	-.194	-.081
TSS	.245	.068	.067	1.000	-.085	-.060	.717	.639	.095	.717	.384	-.100	-.083	-.083
O&G	-.090	-.055	-.057	-.085	1.000	-.068	-.069	-.075	-.097	-.050	-.070	-.085	.076	-.055
Cond	-.096	-.080	-.066	-.060	-.068	1.000	.241	.169	.113	.245	.755	.021	-.111	-.070
TDS	.227	-.166	-.167	.717	-.069	.241	1.000	.950	.170	.977	.764	-.058	-.121	.065
Cl^-	.195	-.196	-.199	.639	-.075	.169	.950	1.000	.170	.941	.718	-.060	-.124	.201
Alk	.006	.063	.046	.095	-.097	.113	.170	.170	1.000	.112	.189	.255	-.116	.097
Hard	.239	-.144	-.148	.717	-.050	.245	.977	.941	.112	1.000	.779	-.067	-.102	.006
SO_4	.075	-.129	-.129	.384	-.070	.755	.764	.718	.189	.779	1.000	-.039	-.162	.018
PO_4	-.114	.408	.447	-.100	-.085	.021	-.058	-.060	.255	-.067	-.039	1.000	-.066	-.009
NO_3	.181	-.211	-.194	-.083	.076	-.111	-.121	-.124	-.116	-.102	-.162	-.066	1.000	-.048
MPN	-.069	-.086	-.081	-.083	-.055	-.070	.065	.201	.097	.006	.018	-.009	-.048	1.000

In nallahs however, the dependency of parameters is lesser reflected than in river for obvious reasons since nallahs are anticipated to carry wastewater from singular sources most of the times though not always. Thereby, nallahs show similar correlation of about 97% between COD & BOD whereas total solids are related to TDS and Hardness to the extent of about 71%. Similar to river, nallahs too show independent behavior of O&G, nutrients and MPN whereas the major difference is observed in case of conductivity wherein it is only related to sulphates in case of nallahs to about 75%. TDS & chlorides are related to hardness and sulphates as well as with each other most probably due to the tidal influence in Vakola nallah which forms almost 50% of the sample data used for modeling and cannot be neglected due to need of sampling adequacy.

8.2.2 KMO and Bartlett's Test

Both river and nallahs show that the sampling adequacy is more than 65% as presented in **Table 8.3** for river and **Table 8.4** for nallah and thereby is statistically valid.

Table 8.3 KMO & Bartlett's Test for River

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		.678
Bartlett's Test of Sphericity	Approx. Chi-Square	892.465
	df	91
	Sig.	.000

Table 8.4 KMO & Bartlett's Test for Nallah

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		.666
Bartlett's Test of Sphericity	Approx. Chi-Square	895.761
	Df	91
	Sig.	.000

These tests indicate the suitability of data for factor analysis. The Kaiser-Meyer-Olkin Measure of Sampling Adequacy is a statistic which indicates the proportion of variance in the variables which is common variance, i.e. which might be caused by underlying factors. High values (close to 1.0) generally indicate that a factor analysis may be useful with the data. If the value is less than .50, the results of the factor analysis probably won't be very useful. Since KMO values at all the sampling points is 0.50, factor analysis is useful with the data.

Bartlett's test of sphericity indicates whether the correlation matrix is an identity matrix, which would indicate that your variables are unrelated. The significance level gives the result of the test. Very small values (less than .05) indicate that there are probably significant relationships among variables. A value higher than about 0.10 or so may indicate that your data are not suitable for factor analysis.

Thus, the significance value obtained are all null, which indicate that there are significant relationships among the various parameters analyzed at all the sampling points and probably might have some common or related source contribution.

8.2.3 Communalities

Communalities indicate the amount of variance in each variable that is accounted for. Initial communalities are estimates of the variance in each variable accounted for by all components or factors. For principal components analysis, this is always equal to 1.0 (for correlation analyses) or the variance of the variable (for covariance analyses).

Extraction communalities are estimates of the variance in each variable accounted for by the factors (or components) in the factor solution. Small values indicate variables that do not fit well with the factor solution, and should possibly be dropped from the analysis. Values for communalities range from 0 (completely unrelated) to 1 (completely determined).

Table 8.5 Communalities for River & Nallah Samples

	Initial	Extraction for River	Extraction for Nallah
pH	1.000	.691	.619
COD	1.000	.957	.919
BOD	1.000	.957	.928
TSS	1.000	.895	.769
O&G	1.000	.863	.415
Cond	1.000	.935	.898
TDS	1.000	.961	.963
Chloride	1.000	.953	.932
Alk	1.000	.892	.503
Hard	1.000	.947	.962
SO4	1.000	.853	.951
PO4	1.000	.702	.525
NO3	1.000	.722	.497
MPN	1.000	.447	.667

Extraction Method: Principal Component Analysis

Thus from the **Table 8.5**, it can be very well stated that all the extracted communalities for both river and nallahs for all parameters are well defined by the extracted factors, since the communalities values are all higher than 0.5 except for MPN in river since several of the analysis data is presented in form of >1600 values and not the absolute number of colonies whereas O&G, NO_3& Alkalinity in Nallahs. However, there exist a lot of variations among the extracted communalities of the metals at different sampling locations as well as among the samples collected from same locations, which in turn indicates the influence of different sources for specific parameters. The communalities can be converted into percentage values that are defined by the extracted factors.

8.2.4 Total Variance

The **Tables 8.6** & **8.7**represents eigenvalues, variance explained, and cumulative variance explained for the factor solution for river and nallah respectively. The first panel gives values based on initial eigenvalues. For the initial solution, there are as many components or factors as there are variables i.e. 14 factors for 14physico-chemical and organic parameters as variables. The “Total” column gives the amount of variance in the observed variables accounted for by each component or factor. The “% of Variance” column gives the percent of variance accounted for by each specific factor or component, relative to the total variance in all the variables. The “Cumulative %” column gives the percent of variance accounted for by all factors or components up to and including the current one. For instance the Cumulative % for the second factor is the sum of the % of Variance for the first and second factors. In a good factor analysis, there are a few factors that explain majority of the variance and the rest of the factors explain relatively small amounts of variance and are not used for interpretation. The Extraction Sums of Squared Loadings group gives information regarding the extracted factors or components. For principal components extraction, these values will be the same as those reported under Initial Eigenvalues. The factor rotation results in the “Rotation Sums of Squared Loadings” group. The variance accounted for by rotated factors or components are normally different from those reported for the extraction but the Cumulative % for the set of factors or components will always be the same. In the present study either of the initial or rotated values are considered though both are depicted in the respective Tables, whichever are found to be more appropriate for ease of representation.

Table 8.6 Total Variance of Explained for River

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.396	38.541	38.541	5.396	38.541	38.541	4.167	29.761	29.761
2	2.155	15.389	53.930	2.155	15.389	53.930	2.959	21.133	50.894
3	1.939	13.851	67.781	1.939	13.851	67.781	2.187	15.624	66.518
4	1.243	8.877	76.658	1.243	8.877	76.658	1.340	9.573	76.091
5	1.042	7.440	84.098	1.042	7.440	84.098	1.121	8.007	84.098
6	.887	6.332	90.430						
7	.512	3.658	94.088						
8	.407	2.909	96.998						
9	.187	1.334	98.332						
10	.145	1.034	99.366						
11	.047	.337	99.702						
12	.025	.180	99.883						
13	.011	.080	99.962						
14	.005	.038	100.000						

Extraction Method: Principal Component Analysis

Table 8.7 Total Variance of Explained for Nallah

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.338	33.366	33.366	4.338	33.366	33.366	3.892	29.941	29.941
2	2.360	18.152	51.518	2.360	18.152	51.518	2.310	17.773	47.713
3	1.400	10.771	62.289	1.400	10.771	62.289	1.690	13.004	60.717
4	1.194	9.188	71.477	1.194	9.188	71.477	1.212	9.325	70.042
5	.961	7.392	78.869	.961	7.392	78.869	1.091	8.392	78.434
6	.947	7.284	86.154	.947	7.284	86.154	1.003	7.719	86.154
7	.826	6.351	92.504						
8	.604	4.646	97.150						
9	.262	2.018	99.168						
10	.038	.295	99.463						
11	.035	.266	99.729						
12	.020	.157	99.886						
13	.015	.114	100.000						

There are 14 & 13 factors resolved to explain the total variance of 100% for river and nallah respectively. However, maximum variance is explained by only a few factors i.e. 5 components that represents “Probable SOURCES” explaining about 84% variation i.e. contribution in river whereas 6 components explaining 86.1% contribution in nallahs. Thus, it can be stated that the factor analysis model hold good for physico-chemical & organic receptor modeling.

8.2.5 Extraction of Components and Component Matrix

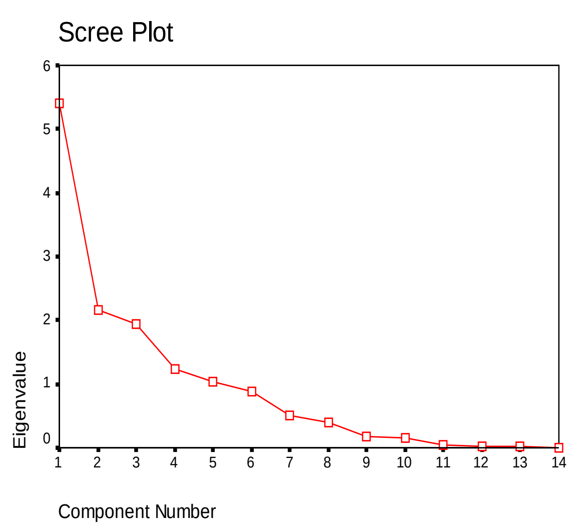
As stated earlier that the total variance is explained by a number of factors that equals the number of variables, however, only a few factors are responsible for characterizing the maximum variance, which has to be extracted selectively from the total variance analysis or from the cumulative variance data. However, one of the most frequently used methods for extraction of factors is the **Scree Plot**, which shows the variation of Eigenvalue with the number of components, thereby making it easy for the extraction of the components defining maximum variance.

The component matrix reports the factor loadings for each variable on the unrotated components or factors. Each number represents the correlation between the item and the unrotated factor. These correlations are be used to formulate an interpretation of the factors or components. This is done by looking for a common thread among the variables that have large loadings for a particular factor or component. It is common to see many items with large loadings on several of the unrotated factors, which can make interpretation difficult. In these cases, it can be helpful to examine a rotated solution.

The component matrix for river & nallahs with respect to physico-chemical and organic variables are represented in **Tables 8.8** &**8.9** respectively, with the Scree plots adjacent to the tables showing the number of extractable variables to define the maximum variance.

Table 8.8 Component Matrix for Physico-chemical and Organic Variables for River

	Component				
	1	2	3	4	5
pH	.708	-.359	-.241	.036	-.037
COD	.241	.892	.316	-.055	-.019
BOD	.205	.910	.283	-.081	-.025
TSS	.574	-.141	.714	-.155	-.113
O&G	-.075	-.143	-.083	-.649	.640
Cond	.729	.297	-.544	.117	.071
TDS	.967	-.099	.101	-.040	-.064
Cl^-	.974	-.008	-.060	-.006	-.028
Alk	.558	.212	-.611	.381	.132
Hard	.967	-.092	.057	-.015	-.034
SO_4	.695	-.382	.467	-6.035E-06	-.078
PO_4	-.432	-.020	.350	.613	.131
NO_3	-.359	-.111	-.239	-.179	-.701
MPN	.014	-.228	.319	.468	.273



The 5 components extracted through FA represent 5 different or combined sources contributing to the river water characteristics. Those parameters that are dependent on each other and are correlated to greater extent are highlighted by a common colour code which is almost in line with those presented Correlation matrix. The first component representing Conductivity, Chlorides, hardness, SO4, TDS & Alkalinity can be surely allocated to tidal influence i.e. sea water. For almost half of the river, tidal influence is prominently observed and thereby very high TDS and chloride contents ultimately resulting in higher conductivity. Thereby it can be predicted that almost **30%** of source characteristics in river is influenced by sea water intrusion. It is important to note that it is not the volume of water which is represented by these figures but only the characteristics.

The 2nd component which presents very highly correlated COD and BOD forms the source of domestic water. It is further substantiated by sewage water characteristics of almost 90% of nallahs showing consistent COD to BOD ratio of 2.5 to 3.5 which otherwise from industrial areas seem to be highly variable. Research and publications across the globe have established COD & BOD correlation and have assigned these variables to sewage sources and thereby in Mithi River it can be stated that almost **21%**of characteristics are directly from COD-BOD bearing parameters i.e. sewage.

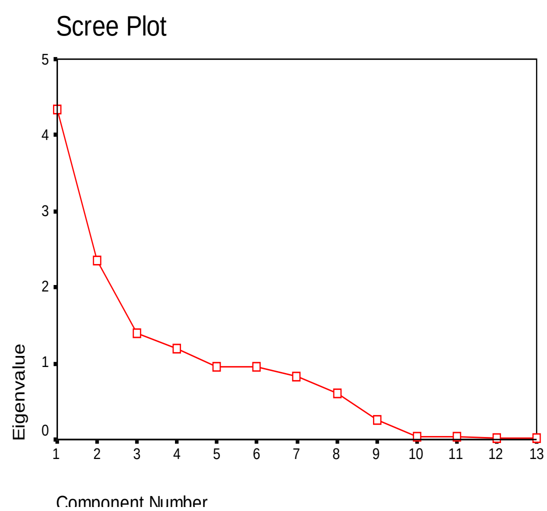
Sewage wastewater also reflects other characteristic features that are represented by the components 3 & 4 in form of correlation for Total Suspended Solid load [TSS] & Most Probable Number [MPN] & PO_4. Interestingly enough TSS has been associated with raw sewage which is known to be directly discharged into Mithi and thereby it would be more appropriate to assign the same to sewage inputs. On the other hand MPN value is definitely associated with sewage finding its way via human excreta whereas though PO4 can be associated with either sewage or agricultural runoffs, in this particular case since there are not agricultural inputs around the Mithi RoW area, it can be assumed to be aligning sewage sources. Thereby these two sources representing domestic wastewater can be assumed to contribute about 15.6% & 9.5% respectively.

The 5th component represents an independent source with single parameter i.e. Oil and Grease. It is evident from the characteristics of source sampling carried out in industrial areas as well as portions of nallahs from these industrially active zones around Mithi that several samples were observed to have extremely high oil and grease content to the extent that it was impossible to carryout some of the analysis associated with microbiology. Samples from KBM compound, Bamandaya Pada representing industrial zones show maximum O&G concentrations >1000mg/lit substantiating O&G to represent industrial sources. These assumptions are further clarified by survey details that present automobile washing centre to be one of the most prominent industrial activities around the banks of Mithi in almost all critical sections of the river. Thereby, the 5th component contributing to almost 7 to 8% can be attributed to industrial sources as far as characteristics of Mithi River are concerned.

In conclusion, within the ambit of 84% variations explained by 5 components presenting sources of contribution to Mithi River as per the Correlation Matrix and computed using Component Matrix, 7 to 8% is contributed by Industrial Sources whereas 30% by Sea Water under tidal influence and almost 50% by domestic sewage. A more elaborate micro level analysis achieved by extracting all 14 components further substantiates sewage water contributes to about 60% to 65% variations in Mithi.

Table 8.9 Component Matrix for Physico-chemical and Organic Variables for Nallahs

	Component					
	1	2	3	4	5	6
COD	-.250	.904	-.129	-.136	-.076	.057
BOD	-.253	.909	-.120	-.139	-.056	.054
TSS	.690	.216	-.519	-.078	.023	-.123
O&G	-.098	-.180	-.140	-.339	.228	.873
Cond	.392	.048	.814	-.321	-.044	.004
TDS	.969	.070	-.153	.013	.044	.019
Cl^-	.939	.029	-.166	.148	.007	.069
Alk	.204	.279	.303	.493	.432	.043
Hard	.963	.075	-.169	-.068	.045	.011
SO_4	.859	.087	.422	-.183	-.019	.050
PO_4	-.125	.626	.192	.202	.425	.026
NO_3	-.149	-.373	-.172	-.092	.680	-.197
MPN	.079	-.081	.036	.762	-.252	.338



In order to ascertain the assumptions considered in assigning sources to component matrix and correlation matrix, parameters of nallah effluents are too subjected to similar interpretation only to reveal that TDS, chlorides, hardness & SO_4 forms the 1st component resembling tidal influence in nallahs too. This would be a subject of debate though as already stated most of the confluence points of nallahs entering Vakola forming almost 50% of samples considered in the nallah water receptor model are subjected to tidal intrusion and thereby resulting in such behavior of component characteristics. This may not be of significant impact in this particular discussion since nallah receptor modeling is used only to substantiate the industrial source characterization that is represented as 6th Component again contributing 7.7% similar to that observed in case of river samples. On the other hand receptor model for nallah also supports and signifies contribution of domestic wastewater through 4 of extracted components in form of COD-BOD, TSS, MPN and NO_3 attributing about 50% cumulative variance which again is in line with those represented by receptor model of river water.

8.2.6 Factor Scores

The Factor Score Coefficient Matrix shows values used to compute factor scores for each case. For each case, the factor score is computed by multiplying variable values by factor score coefficients. The Factor Score Coefficient Matrix shows values used to compute factor scores for each case. For each case, the factor score is computed by multiplying variable values by factor score coefficients. For principal component models, these give exact component scores as depicted in **Table 8.10**for river& **Table 8.11** for Nallahs.

Table 8.10 Component Score Coefficient Matrix for River

	Component				
	1	2	3	4	5
pH	.101	.130	-.182	-.040	-.025
COD	-.008	-.023	.448	-.021	-.018
BOD	-.020	-.022	.450	-.047	-.011
TSS	.310	-.271	.092	.009	-.020
O&G	-.030	-.049	-.025	-.074	.804
Cond	-.087	.345	.041	-.038	.008
TDS	.196	.034	.002	-.040	-.022
Cl^-	.137	.117	.011	-.041	-.010
Alk	-.155	.426	-.025	.140	-.063
Hard	.178	.063	-.003	-.020	-.010
SO_4	.281	-.143	-.062	.074	-.051
PO_4	-.066	.020	.011	.509	-.186
NO_3	.026	-.144	-.107	-.497	-.465
MPN	.019	.046	-.059	.493	.003

Table 8.11 Component Score Coefficient Matrix for Nallah

	Component					
	1	2	3	4	5	6
COD	.030	.422	-.013	-.032	.003	.033
BOD	.028	.421	-.011	-.016	-.012	.035
TSS	.298	.106	-.241	-.106	-.137	-.069
O&G	.021	.041	.020	.009	.038	.999
Cond	-.127	-.009	.632	.015	-.069	.000

	Component					
	1	2	3	4	5	6
TDS	.251	-.007	-.026	.027	-.005	.025
Cl^-	.242	-.035	-.071	.056	.112	.033
Alk	-.007	-.086	-.011	.654	.046	-.004
Hard	.256	.011	-.011	-.013	-.055	.039
SO_4	.077	-.001	.387	.022	-.013	.041
PO_4	-.024	.130	-.002	.529	-.123	.044
NO_3	.028	-.235	-.215	.361	-.597	.056
MPN	-.021	-.111	-.155	.182	.729	.065

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.

8.2.7 Industrial Source Characterization using Receptor Model for Metal

From the receptor model runs of river and nallah samples, it is amply clear that industrial sources contribute about 7 to 8% variations in characteristics of Mithi River. However, further attempt is made in order to assess which types of industries are responsible for such characters within the 7 to 8% industrial source using metals are predominant parameters emerging from industrial sources only. Though it is very preliminary, this could form a framework that could be taken to its logical conclusions through more rigorous and extensive sampling and analysis of industrial sources. **Table 8.12** represents correlation matrix for metals from industrial source sampling.

Table 8.12 Covariance Matrix for Metals from Industrial Sources

	Component		
	1	2	3
Cr+6	.700	-.297	-.190
Cu	.741	.578	.267
Fe	-.083	.852	.023
Pb	-.051	.592	-.047
Mn	-.057	.899	.120
Ni	-.031	-.070	.979
Cd	-.115	-.705	.146
CO	.980	.006	.001
Zn	.980	.010	.005

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.
A Rotation converged in 4 iterations.

Co, Zn are almost perfectly correlated whereas Cr^{+6} too finds its way of significance in the 1st source of industrial contamination that is assumed to influence overall industrial source contribution whereas Fe and Mn forms 2nd source through extracted components in Varimax rotation. The third component is independent and present Ni as the parameter of significance thereby explaining almost 76.6% cumulative variance of source contributions as presented in **Table 8.13**.

Table 8.13 Total Variance Explained for Industrial Samples

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.092	34.351	34.351	3.092	34.351	34.351	2.988	33.196	33.196
2	2.716	30.181	64.532	2.716	30.181	64.532	2.809	31.212	64.408
3	1.094	12.158	76.690	1.094	12.158	76.690	1.105	12.282	76.690
4	.902	10.025	86.715						
5	.584	6.488	93.204						
6	.361	4.016	97.219						
7	.216	2.399	99.618						
8	.034	.382	100.000						
9	6.608E-06	7.343E-05	100.000						

Extraction Method: Principal Component Analysis

Almost 34% i.e. the 1st source as characterized by Co and Zn and some part of Cr^{+6} may be from dye, intermediates & bleaching processes whereas the 2nd source which also seem to contribute about 31% is attributed by Fe and Mnthat may be contributed through sources of Oilfrom auto sectors especially car washing which is observed to discharge used oil at several of the industrial sampling locations (Tasic M., et. Al., 2009) and finally the 3rd source characterized by independent variable i.e. Ni contributes about 12% that may found its way through car washing and its presence in well known in oil and grease as contaminant thereby adding to the overall 76.6% variations in characteristics of industrial sources that indeed result into about 7% of the overall industrial contribution to Mithi River characteristics.

In conclusion, thus auto washing and other automobile facilities around Mithi contributes to about 44% of the overall characteristics of industrial effluents whereas dye and bleaching units contribute to about 34% especially found near Bamandaya Pada and KBM compound.

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Chapter IX

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Chapter IX

Conservation Management Plan

9.0 Background

Chapter III of this report outlined environmental – physical setting of Mithi River providing insight to the land-use details of areas within RoW and their probable influence in terms of wastewater discharges leading to pollution potential which is further corroborated by Chapters V & VI demonstrating physic-chemical and biological parameters that account for the pollution. Critical stretches of Mithi that needs prioritized intervention delineated in Chapter VII further helps describe aspects of Mithi that have been part of discussions by various authors and agencies publishing data regarding pollution in Mithi which is attempted & confirmed through Source Receptor Modeling to assess contribution of domestic v/s industrial inputs to Mithi that is yet to be reported by others and had been practically impossible to evaluate by conventional means.

This chapter takes the discussions to a new level through conservation management planning and outlines designing & implementation needs for particular priority areas from the outputs of earlier chapters forming this report. Attempt is also made to put forth detailed site specific plans with budgetary estimates in order for decision to be made from a holistic point of view.

9.1 Conservation Management Philosophy

Conventionally environmental management of wastewater is proposed through evaluating needs of installing and operating sewage treatment plants which has also been part of earlier published reports for Mithi and though the authors fully endorse such measures, the philosophy for conservation in this report is in line with criticality indices developed for Mithi & thoroughly based 3 principles i.e. at source, in path and end of the pipe. The identification of particular sources, its physic-chemical and biological characteristics, hydraulics and extent of impacts in study domain are all taken into account for planning environmental management that are outline in the following sections.

9.1.1 At the Source Mitigation / Management Plan

The criticality indices supported by ground survey and discussions with locals have identified 3 main issues at source that probably have led to potential pollution in Mithi though restricted in some of the stretches.

9.1.1.1 Open Defecation

Stretches I, II, III i.e. Origin of Mithi to JVLR through Filterpada and Gautam Nagar & finally Stretch 16 i.e. Kalanagar to Mahim witnesses prominent open defecation not only aesthetically hampering Mithi but also leading to potential hazards. These areas include slum populations ranging from 2000 to 4000 dwelling almost on the banks of the river in each stretch. Though some of the areas were previously provided with toilet blocks, most of them are now non-functional and tampered with. Limited or no water supply to such facilities has also led to abolish its use for the desired purposes. Thereby it is essential that these Stretches be immediately provided with toilet blocks in line with Sulabh Sauchalaya that should be manned continuously to avoid tampering with infrastructure and malpractices thereby limiting the very foremost potential source of pollution in the initial part of Mithi itself. These facilities shall also be augmented with in-situ sewage treatment units requiring minimal or no operation and maintenance.

Considering the maximum population and worst case scenario of trends of growth in Mumbai, each of these 4 stretches would require about 80 toilet blocks according to MCGM guidelines (www.mcgm.gov.in giving details of city development plan) generating about 80 to 100CMD of wastewater but will help segregate grey water from these areas thereby making it of secondary concern though surely needs to be addressed.

9.1.1.2 Open Dumping of Solid Waste

Almost all the stretches which faced open defecation as a critical issue also had solid waste dumping identified as another cause of concern. Regular dumping of solid waste into the river was often citied during the survey. Interestingly solid waste in most of the stretches such as I, II, III & V were observed to form heaps in the river bifurcating and obstructing flow. Most of the solid waste appeared to be household in form of plastics, paper and green waste however, none of the places had visual evidence of hazardous waste though the same cannot be ruled out knowing industrial habitation along the banks of river.

The solid waste also must result in leaching thereby polluting river water to considerable extent and thereby needs a full-fledged solid waste management plan. Thereby it is recommended that collection system such as door to door / ghanta gadis as available in other parts of urban Mumbai are in place for slums surrounding Mithi. BMC shall install community bins to accommodate about 1.5 to 2tons of waste from each of these stretches every day and further put in place transfer and treatment facilities. In-vessel treatment technologies such as Organic

Waste Convertor can be very useful though a thorough training and implementation of waste segregation practices would be essential for slum dwellers. Pune Model of Rag Pickers Association providing door to door collection and segregation might be handy in such stretches whereby empowerment of rag pickers through insurance and assured income has been implemented.

Biodegradable Waste to the tune of about 0.75 to 1ton/day can be accommodated in Waste to Compost through OWC or Biogas facility shall be placed in each stretch whereas Recyclers shall be brought in the chain to handle about 0.4 to 0.5tons/day in each stretch for managing recyclables. Successful revenue models across India are already available that could be tailored to adapt to this scenario around Mithi River.

9.1.1.3 Industrial Discharges

Out of the 79odd representative source samples identified and analyzed for pollution potential in different stretches of the river RoW, most of the large scale industrial units housed full-fledged environment infrastructure that were fully functional whereas some of the small scale units too had provided for ETP though none of them were found to be functional. Additionally, none of the small scale of medium scale units provided for sewage treatment and almost all of it is passed untreated directly into the nearby sewers ultimately connected to Mithi River. **Table 9.1** presents representative major and critically polluting industrial sources surveyed during the study period classifying 3 main categories of industrial effluent flows i.e. 0.1 to 5.0m^3/day, 5.0 to 20.0m^3/day and up to 200m^3/day other than domestic wastewater flows that is highly variable ranging from ranging from 5.0m3/day for a single storied apartment to about 1 to 3MLD for townships.

Table 9.1 Representative Industrial Types and Hydraulics Surveyed alongside Mithi River Banks

Type		Representative Nos.	Type of w/w	Approximate Flow(M^3/Day)
Residential area		27	Sewage	Variable
Commercial	Laundry clusters	7	Dyes and Bleach	10.0 to 200
	Hotels and Bakers	4	Sewage/ Effluents	1.0 to 50.0
	Hospitals	2	Effluents/ Laundry	5.0 to 20.0
Industrial	Car washing units	6	Oil and Grease	5.0 to 10.0
	Chemical industries	6	High COD and Toxic	5.0 to 50.0
	Metal plating clusters	2	Metals and acids	0.2 to 5.0
	Bottle washing units in Premnagar	4	Mixed effluent	0.5 to 1.0
	Jewelers clusters	2	Metals	0.5 to 10.0

It is essential that at source effluent treatment facility be provided for those industries that are letting out raw effluent of critical nature directly into the river and thereby leading to causes of serious concern. In addition to the facility development, MPCB being the regulator of industrial pollution, it is essential to first inventorize these industries through dialogue that would bring at least identifiable and registered small and medium scale enterprises in the ambit of its pollution control system. It is very well known that the Aurangabad Regional Office of MPCB in 2010-11 carried out one such successful mission of bringing in all car washing and automobile care centre's in the ambit of pollution control through Personal Hearing for each of those identified ones and obtaining Bank Guarantees against submission of ETP design and implementation within stipulated time of 2 to 3 months.

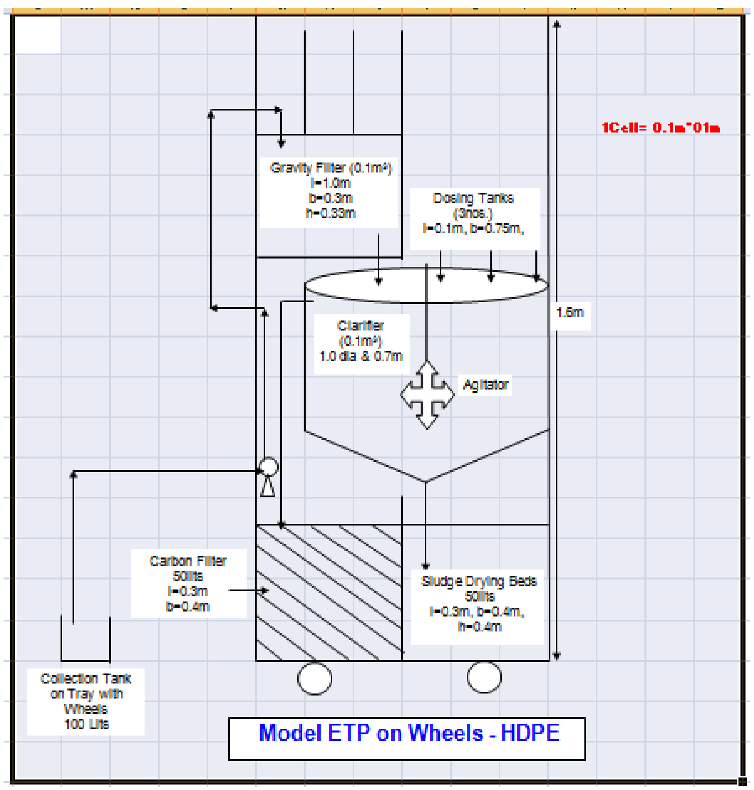
Similar mechanisms of deterrence through appropriate BG and timelines for implementation of at source control for industries along river banks could be one of the most important interventions that are expected to resolve industrial effluent discharge into river as an immediate and top priority.

Discussions with owners of various such industries / vendors / hotel/restaurant have revealed that there would be about 700 – 800 bakeries out of which 5 are large generating about 20m^3/day of effluent whereas other may generate mere 0.2 to 0.5m^3/day. Premnagar and Dharavi areas house most of the bottle and drum washing activities with around 100 to 200 odd such unorganized centre's each generating between 0.1 to 0.2m^3/day of effluent. There is expected to be about 3000 to 5000 small Restaurants, hotels & eateries other than the street vendors other than the Large Residential ones located on the banks of Mithi housing anywhere between 10 to 50 seats with potential to generating 0.5 to 2.5m^3/day.

In all, the hydraulic load of industrial effluents as computed from study or source receptor modeling tends to be about 7 to 8% in worst case scenario which also includes those from immediate sources of hotels and restaurants considered as part of industrial cluster represented by oil and grease parameter as indicated by segregated independent source observed in the modeling domain. Since the survey revealed numerous small eateries alongside river, it would not be way off the mark to consider about 50% of the characteristics behavior of source to be represented by these and therefore most conservative estimate of 18 to 20MLD from direct and indirect industrial sources can be accounted for from industries that are outlined in **Table 9.1**& described for their hydraulics above.

To cater to the source based industrial sources, 2 different sets of simple and unique design of ETP to be able to handle variable hydraulic and organic [COD] loads is proposed. The ETP is based on Primary Chemical followed by Tertiary Filtration technique and shall be able to handle hydraulic loads of 2CMD Batch Type &1m^3/hour Continuous Process as represented in **Figure 9.1** & **9.2** respectively.

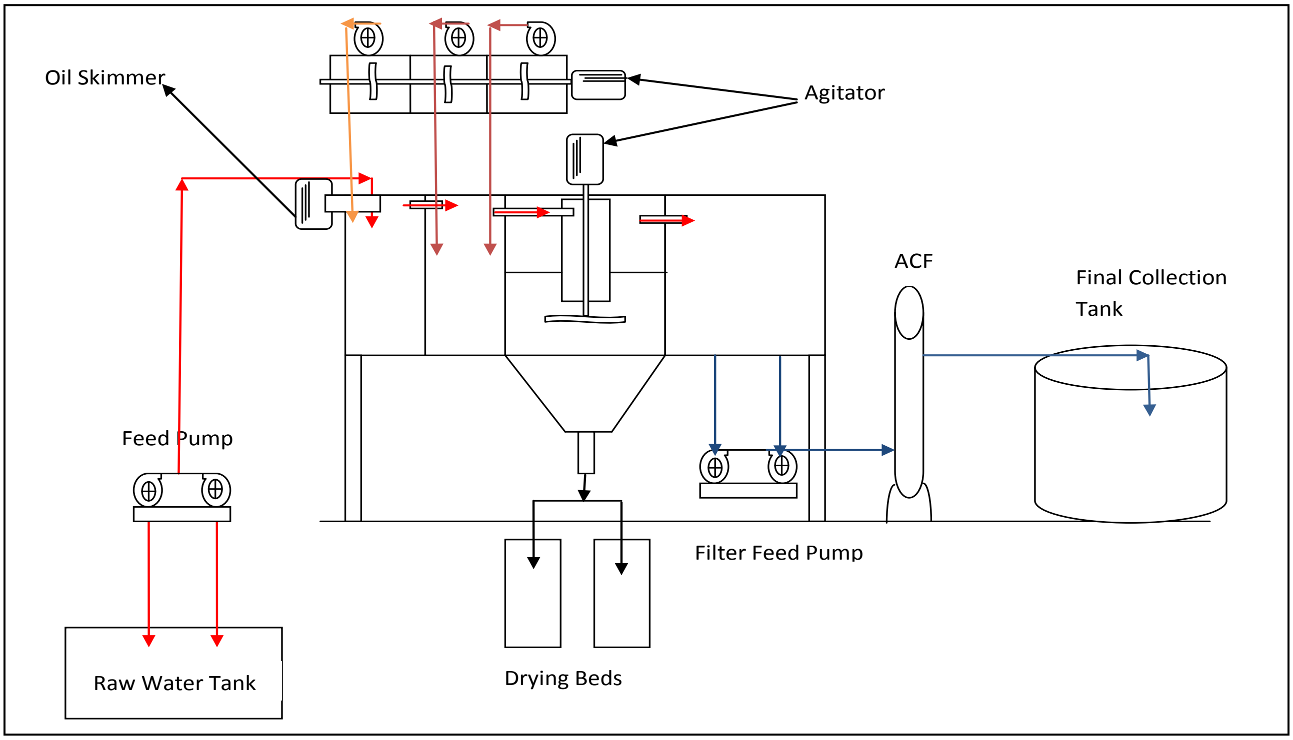
Figure 9.1 2CMD Batch Type ETP Design for Chemical & Car Washing Centre



In case of chemical industries carrying effluents having excessive oil and grease, COD loads and recalcitrant components can invariably adopt this technology wherein oil and grease trap along with belt type skimmer shall help separate oil directly and and/or by HCL cracking make it available for resale to oil recyclers. The reaction can be done using 2 different types of chemicals i.e. for COD <1000mg/lit combination of alum/lime and polyelectrolyte can be used and for those above 1000mg/lit can deploy use of Fenton's Reagent using Fe and H2O2 for oxidation of almost all kinds of recalcitrant components followed by tertiary filtration of pressure sand and activated carbon filters resulting in BOD and COD values much within the desired limits of 30 and 100mg/lit respectively.

On the other hand for flows in the range of 20 to 25m^3/day, though the treatment scheme shall be restricted to alum/lime and polyelectrolyte, the hydraulic load handling design needs to be altered accordingly.

Figure 9.2 1M^3/Hour Continuous Type ETP Design especially for Car Washing Centre



Sludge generated through the primary process shall qualify as hazardous and need to be sent to CHWTSDF. The units are designed to be Portable in nature and requires not more than maximum area of 3m x 1.5m area which is quite affordable & available with most of the industrial units. The unit details along with tentative financial estimates & pictures of implemented systems are outlined in **Annexure IX – I**.

For a better governance and monitoring needs in terms of successful implementation, these units can be fitted with low cost online conventional parameters monitoring equipments such as pH, TDS and conductivity and in certain cases organics as the case may be which could be indeed connected to the online portal of MPCB generating data to support efficiency and continuous operation of these units.

In case of residential establishments such as single or multiple storied apartments and townships alongside the banks of Mithi, it is essential that domestic waste is treated and discharged into the river. Technologies such as conventional septic tanks followed by soak pits for smaller flows up to $50 m^3$/day and Activated Sludge Process, MBBR, SBR for flows >$50 m^3$/day be adopted. Though capital costs may not be a limiting factor, it has been observed across urban and rural India that electricity and O&M requirements forms one of the major constraints in functionality of such STP’s and thereby effort shall also be made to evaluate use of non-conventional technologies requiring minimal O&M and electrical inputs. One such technology that has been successfully implemented in several areas is the NEERI know-how based Phytorid technology though area requirement may lead to certain limitations. Nevertheless, such technologies shall find its way into resolving issues of successful operations. The details of Phytorid technology for various hydraulic modules along with successful models are presented in **Annexure IX – II**.

9.1.2 In The Path Mitigation / Management Plan

As it has been observed in case of Mithi, many a times it is not the known sources that contribute to the high pollution load in river but those fugitive ones that are either physically unable to be tapped contribute to the maximum pollution load. **Table 9.2** delineates summary of characteristics of nallahs according to their critically as assessed in **Chapter VII** in order to prioritize management / mitigation needs.

Table 9.2 Criticality Based Characteristics of Nallahs

Nallah No	Stretch of Mithi	Criticality	Flow (MLD)
N11, N507	Stretch II Gautam Nagar		0.01, 0.05
N14, N509	Stretch III JVLR Bridge	Pink i.e. Worst	0.22, 0.81
N526, N528	Stretch XIV Vakola Nallah		Unable to measure
N7, N9	Stretch II Gautam Nagar		0.019, 0.058
N17	Stretch V KBM Compound		Unable to measure
N512	Stretch VI Marol		0.0192
N19	Stretch VII Sakhinaka		Unable to measure
N515			0.025
N35	Stretch X BMK Compound	Grey i.e. Bad	0.173
N519, N520	Stretch XI of CST		Unable to measure
N23,N24, N522, N524, N540	Stretch XIV Vakola Nallah		Unable to measure
N531, N533			0.052

As per the classification based on criticality indices for those nallahs that were able to support sampling and are representative of particular stretches of Mithi River, none of them were found to be critical as per the indices probably due to use of General Discharge Standards for Public Sewer i.e. Schedule VI of EPA 1986, (b) category which stipulates extremely high limits for both COD and BOD much beyond the general characteristics of sewage thereby even if small hydraulic flows of industries add to the overall nallahs, the extremely high sewage content that probably mixes in almost every such major nallah sampled makes it irrelevant in terms of criticality.

However, 6 Pink coloured representing Worst and 14 Grey coloured representing Bad characteristics needing priority of mitigation measures. Though 2 of Worst nature and 7 of Bad nature are entering into Vakola which can be treated as a separate category from treatment point of view, out of the other 27 nallahs identified & restricted along only 5 to 6 stretches of Mithi requiring immediate intervention.

Most of these nallahs that were able to be approached physically and measured for hydraulics showed extremely low flows ranging from 0.1 to 1.0MLD whereas N20 being an Open Nallah located in Sakhinaka seemed to carry 22.6MLD wastewater and N503 that originated from Dharavi and other surrounding areas also an Open Nallah entering Mithi in Kalanagar carried 604.8MLD other than the N2 nallah in Vakola carrying about 5.69MLD of wastewater also an Open Nallah.

Being Open channels carrying either complex mixed effluents or sewage in entirety, these nallahs require out of the box technology that can be implemented in-situ and thereby most rigid in terms of accommodating highly variable hydraulic and organic load, requiring minimal or no operation maintenance and mostly free from any electricity needs i.e. not even pumping or pressure filtration. These nallahs being traversing through several residential habitations shall also be welcomed if aesthetically pleasing in design and eco-friendly in nature. A typical visual sketch of a design for open nallah like one in discussion can be use of using Constructed Wetland Technology [CWT] option as depicted in **Figure 9.3& 9.4** that tends to incorporate all such features though it could be not very well adopted for extremely high flow like that of N503 which may also be under tidal influence.

CWT in these open channels shall have local species of semi-aquatic grasses such as typhasps., canna sps., umbrella palm sps., etc and supported on metal or other appropriate material grid / coconut husk / coir/ etc. whereby the roots of these grasses shall lead to effective retention of wastewater thereby adding oxygen and reducing organics load also augmented by turbulence creation through simple engineering means to lead to almost 80 – 90% pollution load reduction.

Figure 9.3 Visuals of Typical CWT Design for Open Nallahs Entering Mithi River

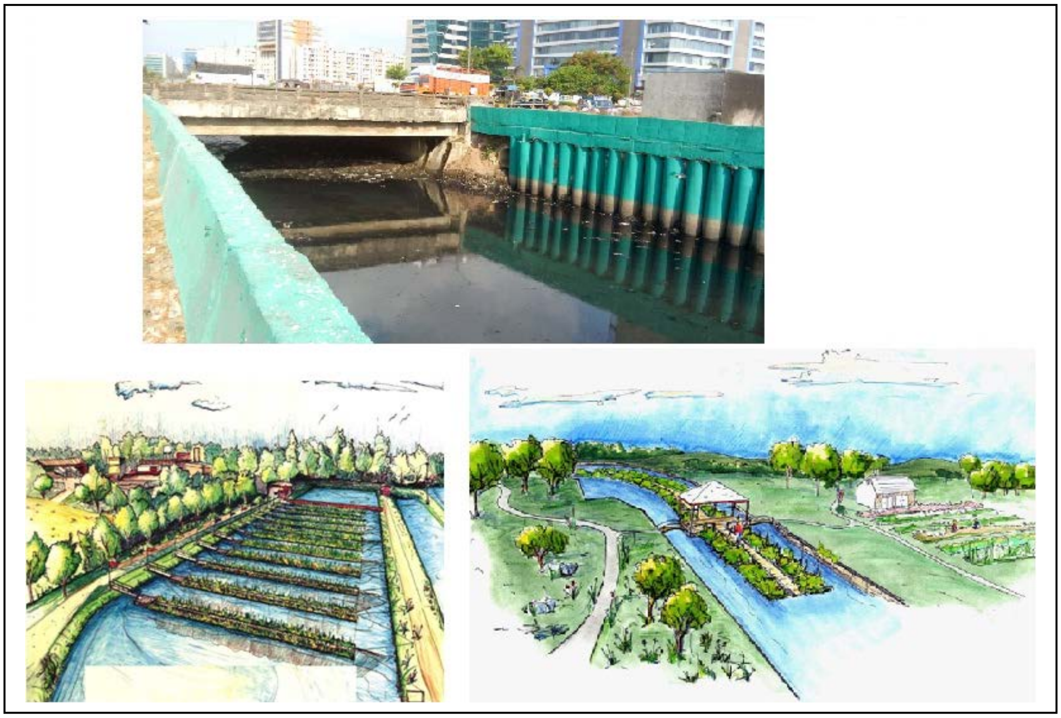
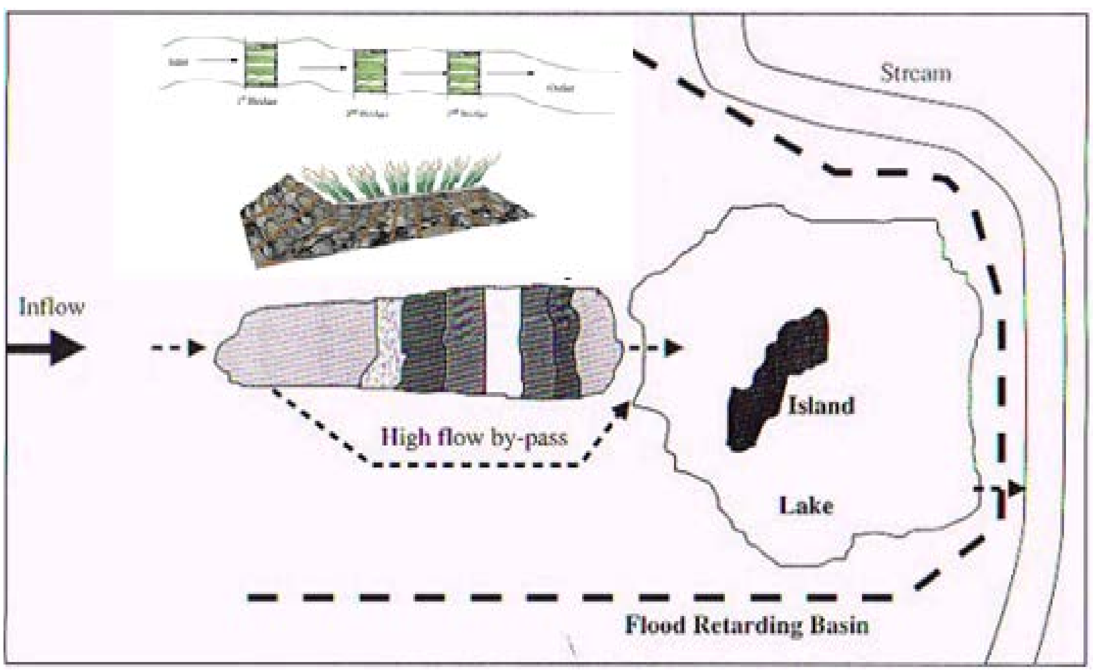


Figure 9.4 Typical CWT Design for Open Nallahs



Even after thorough investigations of sources and in the path applications of technology for wastewater treatment, it is inevitable that certain portions of wastewater shall find its way in to the river since it is impossible that all the sources could be tapped and all those nallahs carrying such waste loads be deployed with treatment technologies. Hence it would be essential that all such remaining wastewater which in this case would be considerable in volume but mostly devoid of critical characteristics of either industrial or direct toxic / recalcitrant load that would find its way through major nallahs like the one from originating around Dharavi area described earlier and could not be fitted with non-conventional / in-situ options shall require End of Pipe facility such as Sewage Treatment Plant.

From the criticality point of view, these nallahs essentially carry only sewage and showed parameters just within or marginally crossing the prescribed standards and thereby can be fitted with simpler versions of technologies that can be easily & continuously operated. Although MCGM and MMRDA through its recommendations as outlined in the summary of earlier studies in **Chapter I** have already earmarked STP needs, a more elusive but complimentary recommendation is discussed for end of pipe treatment.

Table 9.3outlines stretches of Mithi River which shall need intervention of varying degrees in order to maintain the quality of Mithi waters to the desired standards of 30mg /lit BOD and TSS. Since the river shows stretches mostly in the range of Bad to Worst based on Criticality Indices, it would be appropriate that full-fledged technology intervention in terms of simple and conventional technology shall be sufficient for desired purpose although hi-tech treatment process shall surely be an added advantage provided they could be afforded in terms of recurring expenditures.

Table 9.3 Prioritized Stretches of Mithi River Requiring End of Pipe Treatment

Stretch of Mithi River	Colour Index	Cumulative Hydraulic Flow (MLD)	STP Capacity (MLD)
Filterpada	Pink i.e. Worst	2.0	2.0
Gautam Nagar		4.7	3.0
KBM Compound		57.6	10.0
Downstream of Sakhinaka		103.7	35.0
Downstream of CST		183.6	45.0
Downstream of Airport and		102.9	10.0
Downstream of Kalanagar		3927.3	Under tidal influence
Upstream of BamandayaPada		48.8	40.0
Upstream of Mahim		3888.0	Under tidal influence
Downstream of JVLR	Grey i.e.	8.6	3.5

Stretch of Mithi River	Colour Index	Cumulative Hydraulic Flow (MLD)	STP Capacity (MLD)
Downstream of BamandayaPada	Bad	48.8	Not required – already included in upstream
Downstream of BMK Compound		140.0	27.0
Downstream of Marol		67.8	9.0
Upstream of CST Bridge		183.6	Not required – already included in downstream
Upstream of Airport		111.5	Not required – already included in downstream
Safed Pool		100.1	15.0
MTNL Bridge		500.9	Under tidal influence

An interesting proposition is to directly have STP designed for equivalent hydraulic flows of particular to a Stretch of Mithi through compensating for the earlier stretch and those that represent Blue i.e. Average quality river water as per Criticality Index. Thereby as depicted in **Table 9.3** if at all STP's to treat stretch specific hydraulic loads via disposing back the treated water into river are proposed it would be much more beneficial in long run.

The same shall need to have a closed loop system of collection of wastewater and put in place sewage treatment plant using appropriate technology in each stretch identified as above and maintaining the minimum flow in river through disposal of treated waters into it. The only stretch near MTNL Bridge needs further investigation since the flow of 448MLD seems to have tidal influence. Vakola too can be separately treated which shows a flow of about 80 to 90MLD though tidal influence is also witnessed here.

Thereby the 3 fold mitigation plan as proposed if applied complimentary to each other appropriately at sources of criticality, in-situ nallahs wastewater treatment and end of pipe application of STP by tapping nallahs fugitive and let out wastewater via earlier options ultimately disposing treated water back into river in same stretch would not only reduce synergistic pollution potential but would also reduce loads on hydraulic requirement in subsequent stretches of river leading to desirable standards of Mithi.

9.1.4 Regulation Through Online/ Other Monitoring Mechanism

In the process of management, monitoring plays crucial role for not only governance but also helps better understanding of efficient implementation on one hand and operation / functioning of treatment processes on the other. To achieve a win-win situation, it is proposed that each of the virtual stretch upstream and downstream of management measures applied shall be equipped with installations of online criteria pollutant monitors to analyze pH, TDS, Conductivity & DO. It is also advisable to install monitors for TOC & BOD online in river. These can be directly linked to MPCB portal and information is made public which shall not only help evaluate efforts of MPCB but also help create sense of responsibility amongst those involved illegal discharges as well as those who are implementing management measures.

It is also recommended to explore possible use of Bio-Assay Test to serve acceptability of extent of pollution to common person and Sediment Analysis to substantiate re-surfacing of pollutants in certain stretches as well as background pollution/ accumulation if any.

9.1.5 Sensitization Program

It is highly recommended that MPCB along with other stakeholders should plan a sensitization program for at least along RoW of Mithi for Rejuvenation and Conservation incorporating means and measures to connect to people and carryout inclusive management.

9.2 Priority Based Management

The existing use of Mithi River water does not have a pre-defined desirable end-use and thereby it has been compared with the surface water discharge standards. It is equally interesting to know that these discharge standards when translated into Criticality criteria reflects certain stretches of river having marginally high concentration of few parameters. Thereby, in accordance with the survey and discussions, since the existing use of Mithi River is not aligned to any particular one and almost all part of the water in river ultimately flows to Arabian Sea through Mahim Creek, it is recommended that preliminary treatment facilities at all the sources especially industrial as mentioned in **Table 9.1** above shall be necessary to achieve minimum quality of river water in line with the desirable inland surface discharge standards in the following manner so as to achieve BOD & COD concentration of 30mg/l & 100mg/l. All other parameters shall be in line with desirable inland water discharge standards respectively. **Table 9.4** summarizes the stretch-wise proposed management plan based on the observed sources of pollution in each of the stretch.

Table 9.4 Source Based Categorization of the Stretches

Stretch	Source of wastewater	Proposed Management Plan
I- Filterpada	Domestic	STP with capacity of Approx. 2MLD
II- Gautam Nagar	Domestic	STP with capacity of Approx. 3MLD
III - JVLR Bridge	Industrial Mixed with domestic	CETP of capacity Approx.3.5MLD
IV – Bamandaya Pada	Domestic	STP of capacity 40MLD at the upstream

Stretch	Source of wastewater	Proposed Management Plan
V - KBM Compound	Industrial Mixed with domestic	CETP of capacity 10MLD at source for industries and domestic wastewater
VI - Marol	Industrial Mixed with domestic	CETP of capacity 9MLD
VII - Sakhinaka	Industrial Mixed with domestic	CETP of capacity 35MLD at the downstream
VIII - Domestic Airport	Domestic	STP of capacity 10MLD
IX - Safed Pool	Mostly Domestic	STP of capacity 15MLD
X - BMK Compound	Domestic	STP of capacity 27MLD at the downstream
XI - CST Bridge	Domestic	STP of capacity 45MLD at the downstream
XII - MTNL Bridge	Domestic	Under tidal influence
XIII - BKC	Domestic	Under tidal influence
XIV - Vakola Nallah	Domestic	Under tidal influence
XV - Kalanagar	Domestic	Under tidal influence
XVI - Mahim	Domestic	Under tidal influence

ETP to be installed as per recommended for industrial sources in all the stretches

9.2.1 Short Term Mitigation Measures

1. At The Source treatment facilities adopted as the first step for unorganized and small clusters of industries such as auto-service centre, bakeries, laundries, bottle washing units, etc.
2. Effective implementation of Operation and Maintenance of ETP/STP in Organized & large scale industries including hotels & restaurants
3. Control over Open Defecation / solid waste dumping through installation of sulabh sauchalaya concept and in-situ solid waste treatment facility in each stretch as described earlier
4. Treatment facility to be installed for all designated Pink & Orange Colour coded Nallahs as per Criticality Indices - either in-situ or ex-situ as defined in **Table 9.2**
5. All river stretches falling in the Pink colour indices shall be treated for equivalent flow and disposing treated water back for maintaining minimum flow in the river
6. The treatment options shall all be confined mostly to those stretches of river with no tidal influence whereas it shall be applicable to all nallahs and industrial source irrespective of its location
7. Effective collection and transfer mechanism for sewage, industrial or otherwise source wastewater shall be implemented and connected to proposed treatment facilities
8. Silt accumulation and removal though already an ongoing practice needs to be improved by enhanced scientific & effective removal followed by scientific disposal especially silt accumulated in the nallahs at the mouth of the river
9. Black coloured pigmentation observed on banks of river in certain stretches such as downstream of confluence of Vakola Nallah on left bank of Mithi & downstream of CST

Bridge which may be probably resurfacing of historic pollutants needs to be scientifically remediated

9.2.2 Long Term Management Measure

Long term management plan for Mithi refers to achieving designated use of contact purpose that shall be also desirable quality for Outdoor Bathing that could be termed as contact purpose water i.e. 3mg/l of BOD as per Class B of the Primary Water Quality Standards that could also be translated as approximately 10mg/l of COD though COD is not specified in the standards. Tough not specified as standards, Metals shall be absent other than from crustal sources.

1. All those stretches of river represented by Pink colour code of Criticality as per indices shall be equipped with tertiary and quaternary treatment facilities
2. The earlier fitted STP's and treatment facilities for at source wastewater generators for short term mitigations shall need up-gradation through installing polishing quaternary treatment units
3. All nallahs that represent Orange & Blue colour code as per Criticality index shall require full-fledged treatment facility to achieve stringent standard of 20mg/l BOD concentration
4. There might also be need for mechanical agitation / aeration through natural or other means within the course of river especially in the first half of river stretches for effectively adding up and maintaining DO levels above 6mg/l
5. Absolute vigilance and zero disposal of solid waste or entry of runoffs carrying open defecated matter shall find its way into the river at any point of time
6. Cluster development based on typical / representative generator of particular type of waste such as scrap dealers, bottle washing units, buffalo sheds (Gothas), electroplaters & laundry through allotting locations that are equipped with environment infrastructure facilities
7. Eventually all automobile service / washing centre to adopt zero discharge policy

9.2.3 Strategies for Transforming River Water Quality Based on Designated Use

Presently, the main source of river water which is overflow from Powai and Vihar lake are only perennial fed thereby Mithi in fact actually is fed with wastewater sources except during precipitation period. More so ever, being fully aware about the source of Mithi River during non-monsoon period, there is no defined/ known designated use of this water which makes it more or less difficult to either compare with the standards or classify as per the existing norms. Nevertheless, for Mithi to have a successful management planning and implementation, it is extremely important to designate some use in terms of space and time with a continual improvement strategy. Thereby, **Table 9.5** outlines a probable transition from present day use to a more prominent futuristic end use and probable management measures for achieving the same.

Table 9.5 Transitional Designated End Use Based Management Strategy for Mithi

<table>
<tr><th rowspan="2">Stretch</th><th rowspan="2">Existing COD/BOD</th><th colspan="2">Target I – For Recreational/ Contact Purpose Designated Use</th><th colspan="2">Target II – Fisheries/ Wildlife Propagation Designated Use</th></tr>
<tr><th>20mg/l BOD</th><th>100mg/l COD</th><th>5mg/l BOD</th><th>30mg/l COD</th></tr>
<tr><td>I – Filterpada</td><td>184/ 58.9</td><td colspan="2" rowspan="16">• All nallahs represented with Pink colour to have ETPs /STPs as per Table 9.2 and 9.3
• All industries to have at source ETP
• All Grey coloured nallahs to have STP
• All ETP/ STP to have primary, secondary and tertiary treatment facility
• Prioritized treatment for stretches as per Table 9.4
• All open nallahs to have equivalent in the path treatment facility such as Constructed Wetland System
• All solid waste dumping and open defecation sources to be totally eradicated</td><td colspan="2" rowspan="16">In addition to the Target I management efforts following needs to be added
• All nallahs represented by Blue colour to have STPs
• All STP and ETP installed for achieving Target I to be upgraded with Quaternary facilities
• Installation of in-situ mechanical systems for additional Dissolved Oxygen Augmentation
• Specific area protection schemes for particular stretches designated for propagartion</td></tr>
<tr><td>II – Gautam Nagar</td><td>99.75/ 36.72</td></tr>
<tr><td>III – JVLR Bridge</td><td>83.5/25.5</td></tr>
<tr><td>IV – Bamandaya pada</td><td>98/31.5</td></tr>
<tr><td>V – KBM Compound</td><td>180/ 60.7</td></tr>
<tr><td>VI – Marol</td><td>60.7/19.5</td></tr>
<tr><td>VII – Sakhinaka</td><td>130/ 37.7</td></tr>
<tr><td>VIII – Airport</td><td>56/18.7</td></tr>
<tr><td>IX – Safed Pool</td><td>79/24.3</td></tr>
<tr><td>X – BMK Compound</td><td>89/27</td></tr>
<tr><td>XI – CST Bridge</td><td>333/125</td></tr>
<tr><td>XII – MTNL bridge</td><td>71/21</td></tr>
<tr><td>XIII – BKC</td><td>261/81</td></tr>
<tr><td>XIV – Vakola</td><td>70/21</td></tr>
<tr><td>XV – Kalanagar</td><td>109/34</td></tr>
<tr><td>XVI - Mahim</td><td>190/62</td></tr>
</table>