Effect of Time and Temperature on DO Levels in River Waters

Ministry of Jal Shakti

Department of Water Resources, River Development & Ganga Rejuvenation,

CENTRAL WATER COMMISSION

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Cover page:

River Jhelum (Jammu & Kashmir)
Photograph courtesy by Tanya Shanker

EFFECT OF TIME AND TEMPERATURE ON DO LEVELS IN RIVER WATERS

River Data Compilation-2 Directorate

Central Water Commission

Department of Water Resources, River Development & Ganga Rejuvenation

MINISTRY OF JAL SHAKTI

सैयद मसूद हुसैन
अध्यक्ष
तथा पदेन सचिव, भारत सरकार

S. MASOOD HUSAIN
CHAIRMAN
& *ex-officio* Secretary
to the Government of India

सत्यमेव जयते

भारत सरकार
जल संसाधन, नदी विकास
और गंगा संरक्षण मंत्रालय,
केन्द्रीय जल आयोग

Government of India
Ministry of Water Resources,
River Development and
Ganga Rejuvenation,
Central Water Commission

Foreword

Central Water Commission, a premier technical organisation in the field of Water Resources under the Department of Water Resources, River Development & Ganga Rejuvenation, Ministry of Jal Shakti, is playing an active role in monitoring of river water quality of the country. At present, CWC is monitoring water quality at 531 key locations on various rivers covering all major river basins of India. For testing and analysis of water samples, it maintains three tier laboratory system in the country. There are five Level-III/II+ laboratories functioning at New Delhi, Varanasi, Hyderabad, Coimbatore and Guwahati where 41 parameters including heavy metals/ toxic parameters and pesticides are being analysed as per standard procedure and protocol.

Dissolved Oxygen (DO) is prominent among the important indicators of river water quality. At CWC sites, the samples for DO measurement are collected around 08.00 AM and analysed. Concerns were being raised that due to photosynthesis effects, the DO values being observed at 08.00 AM, provide a higher value than the average daily value. An effort was made to collect and analyse the samples all across the country on 3-hourly basis to get the diurnal variation of DO. This publication highlights the effect of temperature, sunlight and photosynthesis of aqua plants on DO concentration in river water on diurnal basis.

I appreciate the hard work done and efforts put in by Shri. Ravi Shanker, Chief Engineer, P&DO and Shri. Pankaj Kumar Sharma, Director, RDC-2 Directorate in bringing out this publication titled “Effect of Time and Temperature on DO levels in River Waters”. I also appreciate the work done by Dr. Jakir Hussain, Research Officer and Mr. N. Prabhakar Rao, Senior Research Assistant for data compilation and report preparation and by large number of staff posted at sampling sites & Divisional Water Quality Laboratories for collecting and analyzing the samples.

I hope this publication will prove to be a useful to all the stakeholders and agencies that are involved in various activities for conservation of river water quality.

(S. Masood Husain)

New Delhi
Date: 12th June, 2019.

दूसरा तल (द), सेवा भवन
आर. के. पुरम, नई दिल्ली-110066
दूरभाष : 011-26715351, 26195415
फैक्स : 011-26108614

2nd Floor (S), Sewa Bhawan
R. K. Puram, New Delhi-110066
Tel. : 011-26715351, 26195415
Fax : 011-26108614
Email : chairman-cwc@nic.in

जल क्रान्ति अभियान
जल बचत - जल संचय

आर. के. सिन्हा
सदस्य (नदी प्रबन्ध)
R. K. Sinha
**Member (River Management)
& *ex-officio* Addl. Secretary
to the Govt. of India
Ministry of Water Resources**

सत्यमेव जयते

भारत सरकार
जल संसाधन, नदी विकास
और गंगा संरक्षण मंत्रालय,
केन्द्रीय जल आयोग
Government of India
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River Development and
Ganga Rejuvenation,
Central Water Commission

PREFACE

Water is an essential commodity and it plays a vital role for socio-economic development of any country. Water is an absolute need, not only for survival of human beings, but also for animals, plants and all other living organisms. Ecological balance maintained by quantity and quality of water determines the way of life of people. River water quality is a key concern as it is used for drinking and domestic purpose, irrigation and aquatic life including fish and fisheries. The River water in India and abroad are being polluted in diversified manner due to increasing unplanned industrialization, urbanization, population explosion, biotic pressure and various other anthropogenic activities during last decades. One of the most important aspects of water quality is Dissolved Oxygen (DO) which indicates condition of any water body of its ecological health because survivability of aquatic life in water streams depends upon the dissolved oxygen available in water; without sufficient DO, aquatic life cannot survive.

The quantity of DO within a stream oscillates throughout the day due to diurnal photosynthetic and evaporative processes. In order to determine the variation in DO of river water due to diurnal effects, a comprehensive study was conducted at selected river Water Quality (WQ) stations of Central Water Commission on the important rivers in India. Accordingly, DO and temperature variation was assessed on selected sites round the clock on three hourly basis continuously for at least one week at sites on the important rivers. Selection of sites was based on different climatic condition, anthropogenic activities and type of rivers spread all around the country. Exercise was carried out at 19 water quality stations spread all across the country and their data have been considered in this study.

I appreciate the commendable efforts put in by Shri Ravi Shanker (Chief Engineer, P&DO) for bringing out this publication. Efforts put in by the officers of River Data Compilation-2 Directorate, Shri Pankaj Kumar Sharma, Director; Shri Rakesh Kumar Gupta, Dy. Director; Dr. Jakir Hussain, Research Officer; Mr. N. Prabhakarrao, Senior Research Assistant in the preparation of the report, are also appreciated. I also express sincere thanks to all field Chief Engineers of CWC for making arrangements for collection and analysis of river water samples. I extend my deep gratitude to all the scientific staff in divisional water quality laboratories of CWC for collecting and analyzing river water samples.

I hope this publication will be helpful in understanding the effect of temperature on DO concentration in river water.

New Delhi
Date: 12th June, 2019.

(R. K. Sinha)
Member (RM), CWC.

दूसरा तल (द), सेवा भवन
आर. के. पुरम, नई दिल्ली-110066
दूरभाष : 011-26103221
फैक्स : 011-26101749

2nd Floor (S), Sewa Bhawan
R. K. Puram, New Delhi-110066
Tel. : 011-26103221
Fax : 011-26101749
Email : mrm@nic.in

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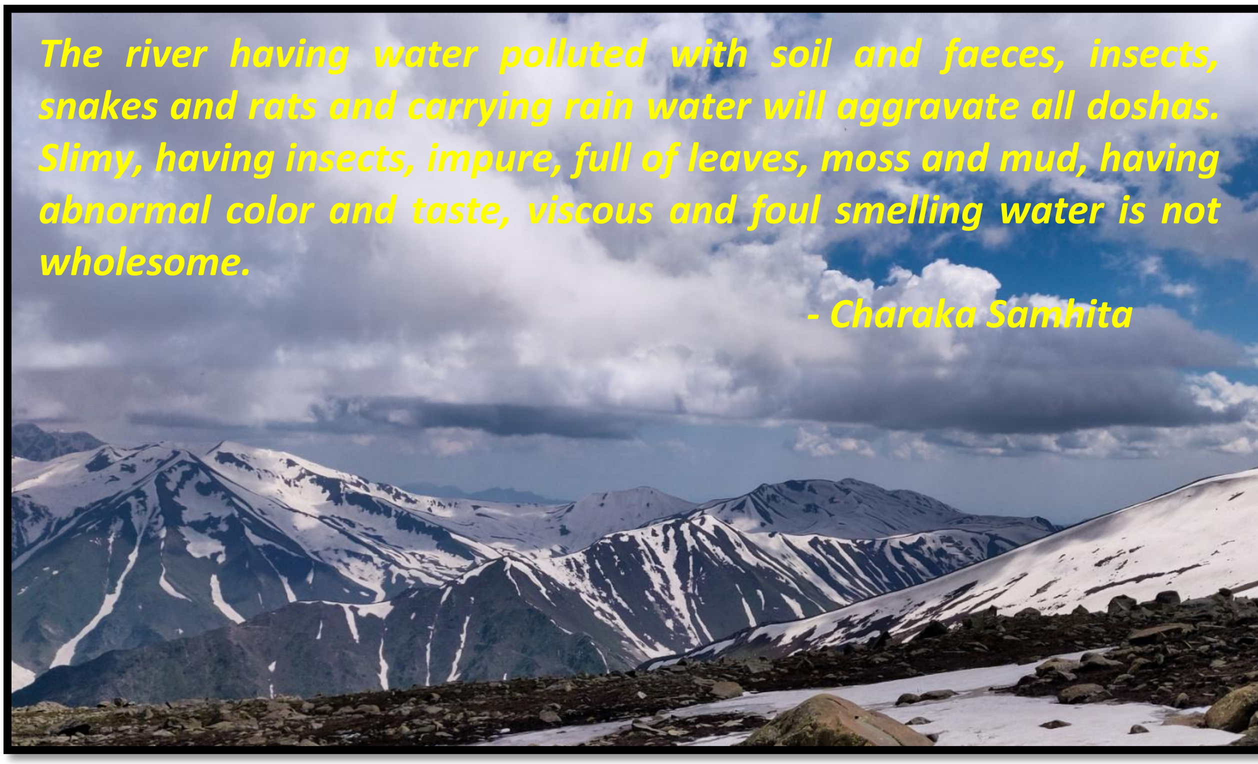
CONTENTS



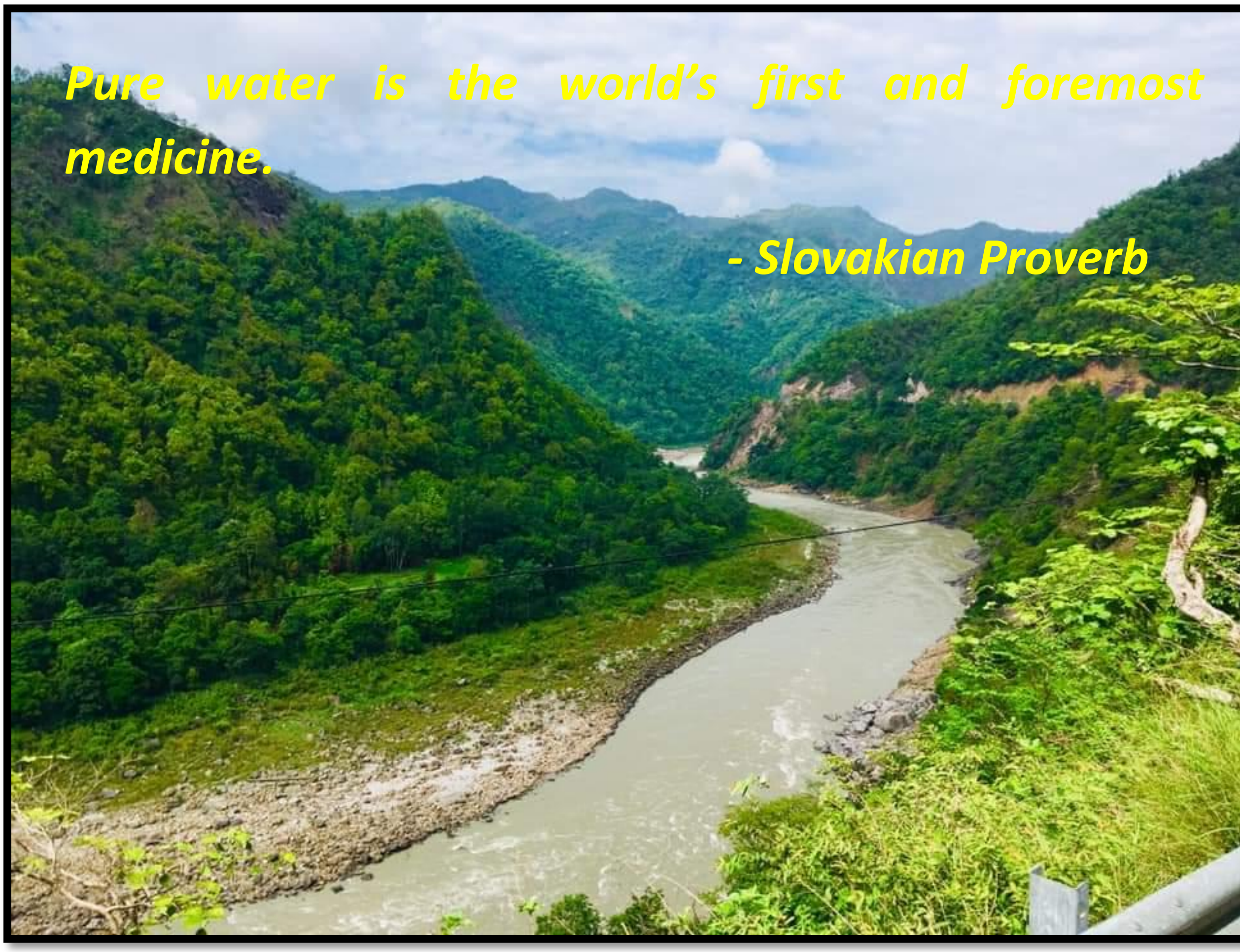
Photograph courtesy by Tanya Shanker

TABLES:

Photograph courtesy by Tanya Shanker

FIGURES:


Those who drink the water that I will give them will never be thirst again
- John 4:14


Pure water is the world's first and foremost medicine.
- Slovakian Proverb

EXECUTIVE SUMMARY

At many quarters, concerns were raised about variation of DO in the rivers with the time and seasons. A specific concern was raised that Central Water Commission generally collects the water sample between 8.00 to 10.00 AM from the rivers and at that time, there is ample sun light and photosynthesis by the aquatic plants and phytoplankton. This raises the DO content in the water. Whereas, during the night, there is no photosynthesis and DO is consumed by the aquatic plants, living creatures and plants for their respiration and decaying organic material (dead animals, plants, phytoplankton etc.). Concerns were raised that this reduces the content of DO in the water to near about Zero which is detrimental to aquatic life.

In order to clarify the above apprehension raised by different academicians/ scientists, Central Water Commission decided to monitor DO for river waters at selected locations round the clock for every 3 hours at least one week in different seasons. In different seasons, temperatures are different, so the saturation level of DO changes and the effect of photosynthesis on the water may also different. Selection of sites was based on different climatic condition, anthropogenic activities and type of rivers spread all around the country. This exercise was carried out at 19 water quality stations and their data have been considered in this study.

This complete study explained that, Dissolved oxygen and water temperature exhibited considerable diurnal variations at almost all the WQ stations. In this study, the suitability of water was confirmed by considering the prescribed limits for DO of CPCB water quality criteria for designated best use. Obtained results described that, out of 19 WQ stations monitored


CONDUCTIVITY METER
ION METER

for DO, 11 WQ stations were found within prescribed limits for all classes of water. DO concentration on other WQ stations was found falling in other than class A category in general (Details inside). However, at Delhi Railway Bridge WQ station located on Yamuna River, DO levels have been observed Zero in all the times during study period from 14/01/2019 to 16/01/2019 irrespective of variation in temperature.

Mostly, Minimum DO values were observed in night and early morning time because during night there is an absence of sunlight which minimized the photosynthesis activities. This resulted in depletion of DO content in water by consuming it in respiration process of aquatic organisms and plants. With increasing temperature, saturation of DO reduces. Even then, the daily DO maximum was observed during mid-afternoon, because in presence of sunlight, photosynthesis becomes dominant phenomenon. The DO concentration reduced in the night and the maximum reduction in DO was observed from 20.00 Hrs to 04.00 Hrs. However, generally DO levels were not found at such low level where aquatic life is in distress.

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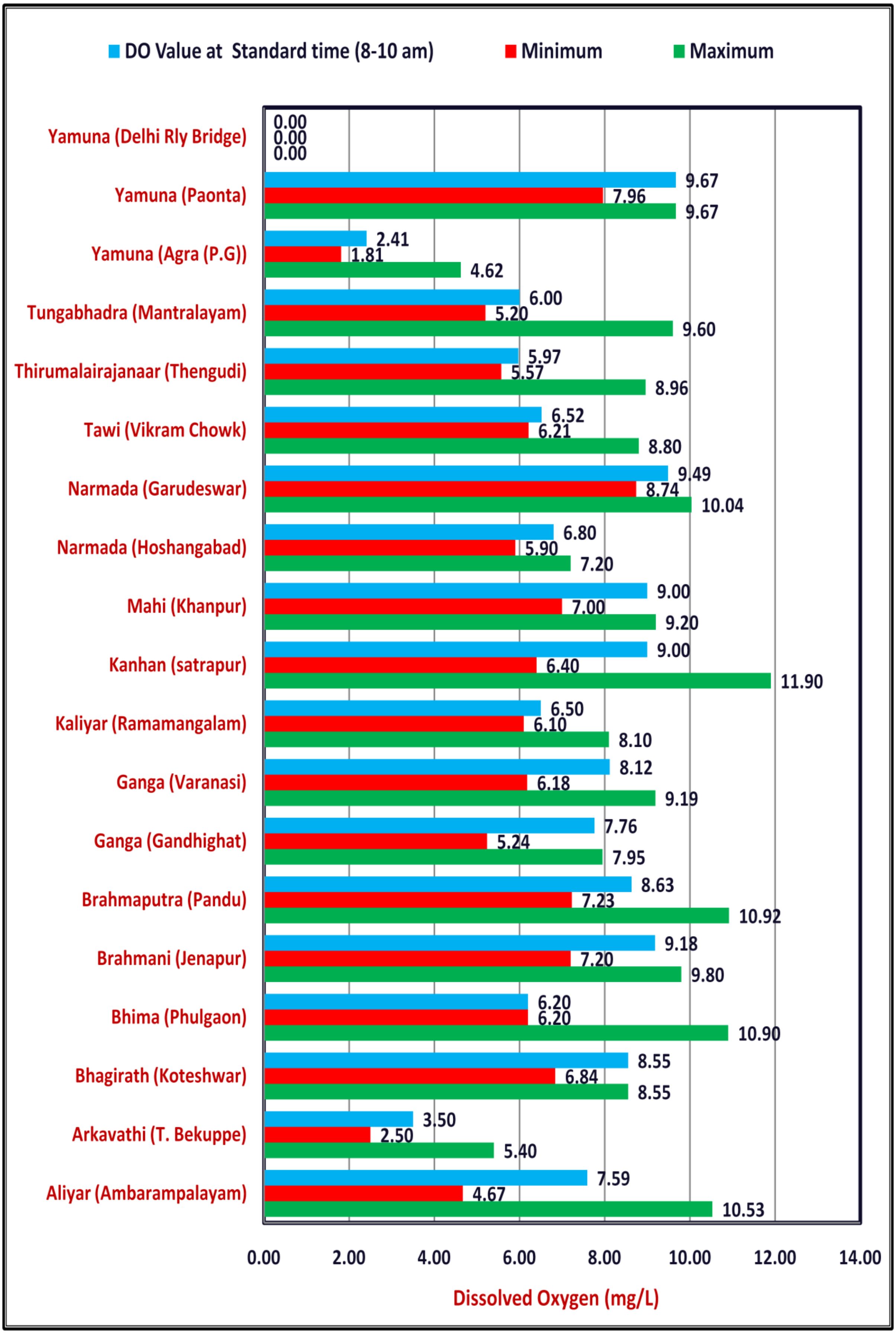


Summary on obtained DO values at Water Quality Stations with respect to the River

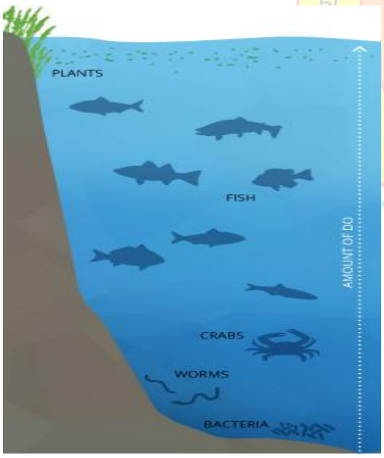

PUMA

CHAPTER-1

1.1 INTRODUCTION

Accessibility of clean water is an essential element for every living being on this earth. Too many people still lack access to safe water supplies and sanitization facilities. In this regard, sustainable development goal has been established by the UN in 2015. It calls for clean water and sanitization for all people. This is one of the seventeen sustainable development goals established by the UN. It is understood that there is sufficient fresh water available in this world but its management needs proper attention which hinders social and economic development.

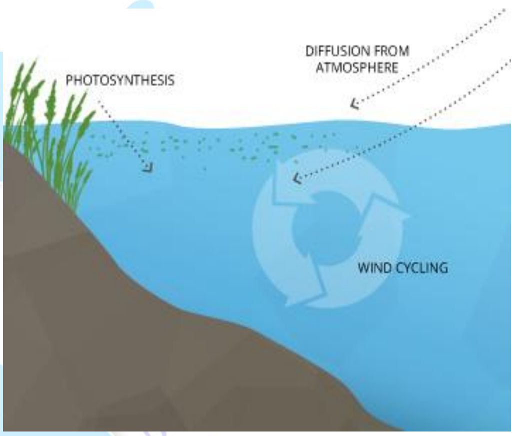
Fresh water pollution is gaining attention world wise because of its impact on socio-economic and health problems. Water Quality in total represents its physical, economical and biological conditions and tells about its ability to use for beneficial purposes. One of the most important aspects of water quality is Dissolved Oxygen (DO) which indicates condition of any water body of its ecological health because without sufficient DO, aquatic life cannot survive. The DO is free non-compound oxygen and it is not attached with any other element present in the water. Any water body gets DO by aeration from the atmosphere and by photosynthesis of the aquatic plants. Flowing rivers, water falling through the rapids, the ripples caused through the wind make the oxygen dissolve into the water [1].

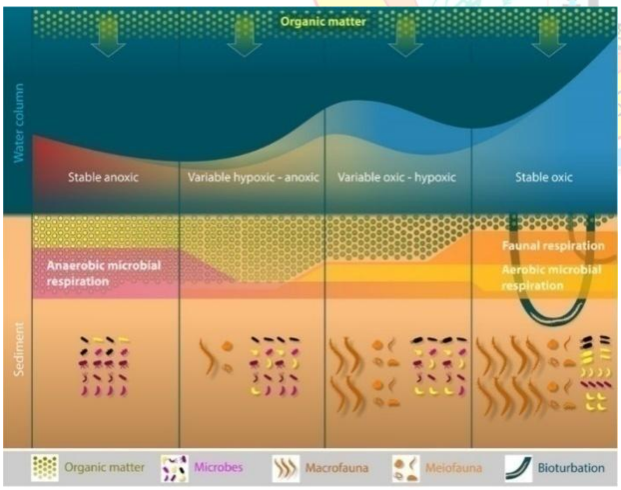


It is an important parameter in assessing water quality because of its influence on the organisms living within a body of water. A DO level that is too high or too low can harm aquatic life and affect water quality. DO is a key physiochemical parameter important in mediating a number of biological and ecological processes within aquatic ecosystems. Since all aerobic aquatic organisms survival depends on the oxygen concentration in order to live and reproduce, changes in the concentration of DO are often reflected in behavioral changes by organisms.

All organisms, from fish to insects to microscopic zooplankton, need oxygen for respiration. During respiration, organisms consume oxygen and give off carbon dioxide while absorbing food molecules to obtain energy for growth and maintenance. High oxygen contents are needed by some species, such as trout. Other species, including carp, catfish, water fleas, and zooplankton, have adapted to survive under low oxygen conditions. Some organisms can even live in environments where oxygen levels fluctuate significantly. Decomposition of dead plant and animal material also requires DO. In addition, DO concentration controls important chemical reactions in bottom sediments of lakes [2].

The DO concentration within a water body can experience large daily fluctuations. Aquatic plants and algae produce oxygen as a by-product of photosynthesis. But at night, they consume oxygen through respiration. Aquatic streams with large populations of aquatic plants or algae are likely to experience the greatest DO fluctuations. In such water systems, the DO concentration will usually rise from morning through the afternoon due to photosynthesis, reaching a peak in late afternoon. In some highly productive water bodies, DO is consumed by night-time respiration faster than it is replaced by oxygen diffusing from the atmosphere. Consequently, fish and other lake organisms may die from lack of oxygen [3].

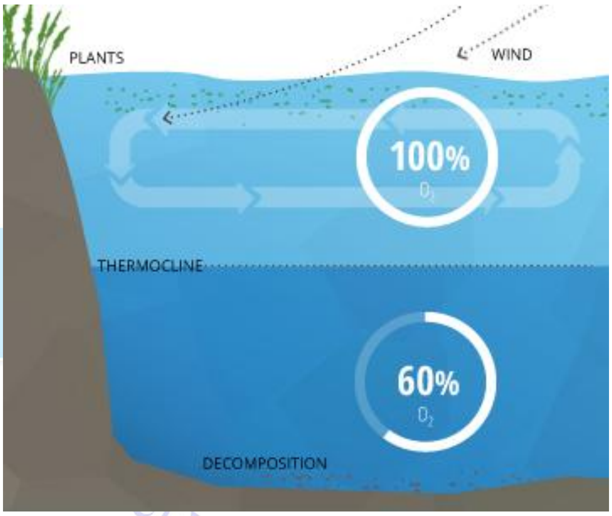




The DO conditions in aquatic systems are often categorized as aerobic, hypoxic, or anaerobic:

1. An "aerobic" (or oxic) condition is characterized by the presence of DO. "Aerobic" is also used to describe biological or chemical processes that occur in the presence of oxygen.
2. "Hypoxia" is an environmental condition in which the concentration of DO is low enough to have biological effects. The EPA defines hypoxic water as water with oxygen concentrations of 2 mg/L or less [4].

3. "Anaerobic" (or anoxic) condition is characterized by zero oxygen levels. Literally, anaerobic means "without oxygen". Practically, it is often used synonymously with anoxic in water quality studies, representing environmental conditions that contain very little or no oxygen. Anaerobic is also used to describe biological or chemical processes that occur in the absence of oxygen [1, 5-6].



In a stable body of water with no stratification, DO will remain at 100% air saturation. 100% air saturation means that the water is holding as many dissolved gas molecules as it can in equilibrium. At equilibrium, the percentage of each gas in the water would be equivalent to the percentage of that gas in the atmosphere i.e. its partial pressure [7].The water will slowly absorb oxygen and other gases from the atmosphere until it reaches equilibrium at complete saturation [8]. This process is speed up by wind-driven waves and other sources of aeration. In deeper waters, DO can remain below 100% due to the respiration of aquatic organisms and microbial decomposition[3]. Warm water and water with high salinity can reach 100% air saturation at a lower concentration, but can often achieve levels over 100% due to photosynthesis and aeration.

Supersaturation condition for dissolved oxygen in surface water:

Aquatic respiration and decomposition lower DO concentrations, while rapid aeration and photosynthesis can contribute to supersaturation. During the process of photosynthesis, oxygen is produced as a byproduct. This adds to the DO concentration in the water, potentially bringing it above 100% saturation. In addition, the equalization of water is a slow process (except in highly agitated or aerated situations). This means that DO levels can easily be more than 100% air saturation during the day in photosynthetically active bodies of water [9].

Rapid temperature changes can also create DO readings greater than 100%. As water temperature rises, oxygen solubility decreases. At these levels, the DO will dissipate into the surrounding water and air until it levels out at 100% [10].

Processes controlling DO spatial distribution in a river include the following:

- Oxidation of the BOD: BOD is used to represent all sinks of DO, such as the oxidation of carbonaceous and nitrogenous organic matter, the benthic oxygen demand, and the oxygen utilized by algal respiration.
- Reaeration of DO from the atmosphere: In addition to atmospheric reaeration, DO produced by photosynthesis and DO contained in incoming flows are also major oxygen sources.
- Transport due to the river flow: Advection and diffusion processes enhance DO mixing and reaeration within a river.

1.2 FACTORS AFFECTING ON DO LEVEL AND IT'S ENVIRONMENTAL IMPACT

Adequate DO is necessary for good water quality. Natural stream purification processes require adequate oxygen levels in order to provide for aerobic life forms. DO concentrations are constantly affected by diffusion and aeration, photosynthesis, respiration and decomposition. As DO levels in water drops below 5.0 mg/L, aquatic life is put under stress. Depletion of DO levels in water body might be caused by the overpopulation of bacteria, over fertilization of water plants by run-off from farm fields and weather conditions.

1.2.1 Eutrophication

Dissolved Oxygen concentrations fluctuate under natural conditions but can be lowered severely as a result of human activities, such as introducing large quantities of oxygen - demanding wastes or from eutrophication. The wastes are oxidized in the receiving waterbody and reduce the amount of DO available. When large amount of nutrients (e.g., phosphorus or nitrogen) are discharged into a river, the plants and algae begin to grow more rapidly than normal (algal bloom). As this happens, there is also an excess die - off of the plants and algae. These organic matters are later decomposed in water and add to the DO depletion. As a result, eutrophication often causes excessive oxygen production in surface waters (even super saturated DO in some cases) and hypoxia or even anoxia in deep waters.

1.2.2 Algae

Phytoplankton (free - floating algae) and aquatic plants (macrophytes) are the two major primary producers of oxygen in surface water. Primary producers are able to utilize light, carbon dioxide, and nutrients to synthesize new organic material. Algae affect the nitrogen cycle, the phosphorus cycle, the DO balance, and the food chain, primarily through nutrient uptake and algae death.

Diurnal and seasonal DO variations can be significantly affected by algal processes. During the day, algae increase DO concentrations via photosynthesis. At night, algae reduce the DO concentrations via respiration. The algal production may also affect seasonal DO variations, since the organic materials derived from algae settle to the bottom and later (especially in the summer) become a major source of oxygen depletion. In addition to nutrient cycles and DO variations, algal growth can significantly change pH value. When algae consume dissolved CO_2 for growth during the day, the value of pH increases. The value of pH decreases when algae release CO_2 during respiration at night. Nuisance algae and anaerobic organisms (that live without oxygen) may also become abundant in waters with low levels of DO.

1.2.3 Decomposition of Organic Carbon

Bacteria decompose organic material to obtain energy for growth, break it down into simpler substances such as CO_2 and H_2O, and eventually convert it into inorganic substances. This decomposition exerts an oxygen demand and removes DO from the water column.

1.2.4 Total suspended solids

Total suspended solids (and water turbidity) may influence DO concentration via: (1) light availability, (2) water temperature, and (3) DO consumption. High TSS increases the light attenuation coefficient and reduces the amount of light available for photosynthesis. This leads to less DO production. Suspended particles absorb heat and cause water temperature to increase. The ability of water to hold oxygen is influenced by temperature and salinity. Since warm water holds less DO than cold water, a temperature increase causes a reduction in DO concentrations. A total suspended solid often consists of a large content of suspended organic matters. Their decomposition also consumes oxygen.

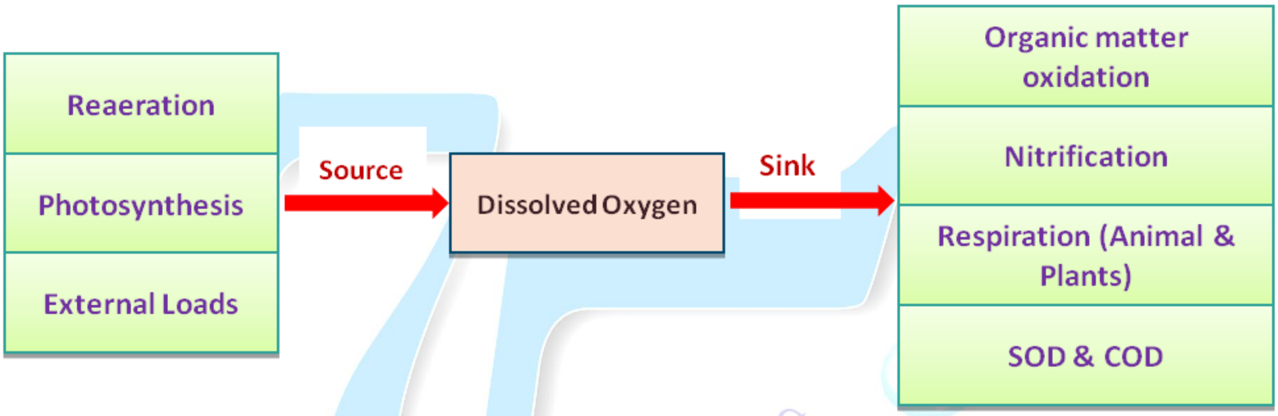
1.2.5 Effect on aquatic life

The generally accepted minimum amount of DO that will support a large population of various fishes is from 4 to 5 mg/L. When the DO drops below 3 mg/L, even the most tenacious fish would die. Even though, there may be enough DO to keep an adult alive, reproduction may be hampered by the need for higher DO for eggs and immature stages. Depletion in DO can cause major shifts in the kinds of aquatic organisms found in water bodies. In general, with lower concentration of DO, the stress will be greater on aquatic life. Oxygen levels that remain below 1-2 mg/L for a few hours can result in large fish kills. But, how much DO an aquatic organism needs depends upon its species, its physical state, water temperature, pollutants present, and more. Fish are cold-blooded animals. They use more oxygen at higher temperatures because their metabolic rates increase [11].

Just as low DO can cause problems, so too can high concentrations. Supersaturated water can cause gas bubble disease in fish and invertebrates; however, this is a very rare occurrence. Significant death rates occur when DO remains above 115%-120% air saturation for a period of time. Total mortality occurs in young salmon and trout in under three days at 120% DO saturation. Invertebrates, while also affected by gas bubble disease, can usually tolerate higher levels of supersaturation than fish [12]. The bubbles or emboli block the flow of blood through blood vessels causing death. External bubbles (emphysema) can also occur and be seen on fins, on skin and on other tissue.

1.2.6 Aeration and Photosynthesis processes

Water obtains oxygen directly from the atmosphere via reaeration and from plants via photosynthesis. Vertical mixing between surface and deep waters transfers DO to lower levels. Reaeration from the atmosphere occurs in direct proportion to the DO deficit in the waterbody. The DO deficit is the difference between the saturated DO concentration and the existing DO concentration in the waterbody. With adequate sunlight, algae and aquatic plants consume nutrients and produce oxygen as a result of photosynthesis. In water layers where photosynthetic rates are very high, such as during an algal bloom, the water may become supersaturated, that is, the oxygen content may exceed the DO saturation concentration. During periods of strong stratification, photosynthesis is the only potential source of DO in the deeper waters, and this occurs only if light penetrates to the deeper layers. External loads can be either a DO source increasing the DO concentration in the receiving water or a DO sink decreasing the DO concentration, depending on the inflow DO concentration. In surface water systems, DO concentrations will vary by season, location and water depth. Consumption of oxygen can be most damaging at night and on very cloudy days when sunlight necessary for photosynthesis is lacking and when the production of oxygen by photosynthesis does not occur. Majority of aquatic organisms consumes DO through respiration for the energy production to grow and move. This process is continuous, 24-hours a day, for plants and animals. It can reduce oxygen concentrations, sometimes to harmfully low levels [13, 14].



Major DO sinks consist of (1) oxidation of organic matter, (2) nitrification, (3) algal respiration, (4) sediment oxygen demand due to sediment diagenesis in the bed, and (5) chemical oxygen demand due to reduced substances released from the sediment bed. The daily DO maximum commonly occurs in mid - afternoon during which time photosynthesis is the dominant mechanism. The daily DO minimum typically occurs in the early morning during which time respiration and decomposition have the greatest effect on DO, and photosynthesis is not occurring.

Reaeration is the most important route for introducing oxygen into surface waters. Reaeration is a process by which oxygen is transferred across the interface between the atmosphere and a waterbody, usually resulting in the net transfer of oxygen to the water. Natural processes, such as winds and water waves, can enhance the rate of oxygen transfer. The oxygen in the air dissolves into the water and replenishes the DO. The rising air bubbles also cause the bottom waters to rise to the surface where they take on more oxygen from the atmosphere.

Moreover, oxygen affects a vast number of other water indicators, not only biochemical but aesthetic ones like the odour, clarity and taste. Consequently, oxygen is perhaps the most well-established indicator of water quality. As such, DO levels can range from less than 1 mg/L to more than 20 mg/L depending on how all of these factors interact. While water equilibrates toward 100% air saturation, DO levels will also fluctuate with temperature, salinity and pressure changes.

1.2.7 The temperature effect

Dissolved Oxygen and temperature are two of the fundamental variables in river ecology. Water temperature is important because it not only establishes the maximum oxygen-holding capacity of water, but also has direct influence on rates of biochemical reactions and transformation processes occurring within the water column and in the sediment bed. Warmer temperatures decrease oxygen solubility in water by increasing molecular activity of the warm water pushes the oxygen molecules out of the spaces between the moving water molecules. In addition, it increases the metabolic rates that affect BOD decay, sediment oxygen demand, nitrification, photosynthesis, and respiration which subsequently causes depletion in DO. By measuring DO and temperature, one can gauge the overall condition of water body. Aquatic organisms need DO for their survival. While water temperature also directly influences aquatic organisms, it regulates DO concentrations within a water streams.

The solubility of oxygen decreases as temperature increases. This means that cooler and deeper fresh waters have the capability to hold higher concentrations of DO, but due to microbial decomposition, lack of atmospheric contact for diffusion and the absence of photosynthesis, actual DO levels are often far below 100% saturation. Warm, shallow saltwater reaches 100% air saturation at a lower concentration, but can often achieve levels over 100% due to photosynthesis and aeration. Shallow waters also remain closer to 100% saturation due to atmospheric contact and constant diffusion. If there is a significant occurrence of photosynthesis or a rapid temperature change, the water can achieve DO levels over 100% air saturation i.e supersaturation. The amount of oxygen that water can hold also decreases as the barometric pressure of the atmosphere decreases Barometric pressure generally decreases as the altitude or elevation of the water body increases. For example the barometric pressure in the mountains is less than the barometric pressure near the ocean; thus at higher altitudes, 0 ^{0}C temperature water holds less DO than 0 ^{0}C at lower altitudes.

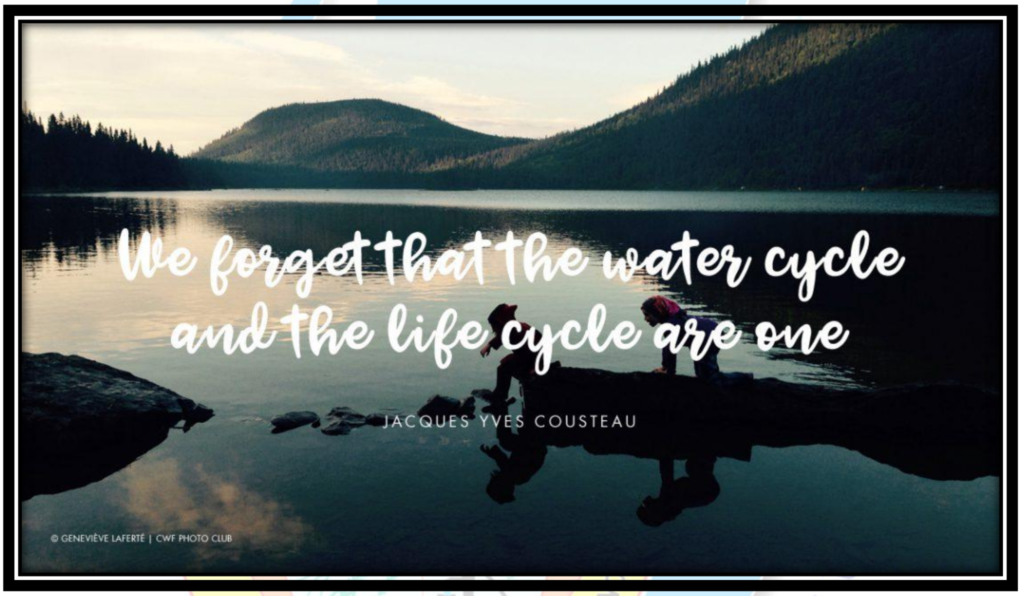
Table 1: Relationship between temperatures and the solubility of oxygen (100% saturation) [15].

TEMPERATURE degrees C.	SOLUBILITY mg/L	TEMPERATURE degrees C.	SOLUBILITY mg/L
0	14.6	16	10.0
1	14.2	17	9.8
2	13.8	18	9.6
3	13.5	19	9.4
4	13.1	20	9.2
5	12.8	21	9.0
6	12.5	22	8.9
7	12.2	23	8.7
8	11.9	24	8.6
9	11.6	25	8.4
10	11.3	26	8.2
11	11.1	27	8.1
12	10.9	28	7.9
13	10.6	29	7.8
14	10.4	30	7.7
15	10.2	31	7.4

Finally, the diurnal variation in DO is primarily caused by the diurnal variation of sunlight, photosynthesis, respiration of algae & aquatic plants and diurnal variation of water temperature. Nevertheless, photosynthesis causes a much larger DO variation than does water temperature, and the diurnal variation shown largely the result of algal photosynthesis.

“Dissolved oxygen (DO) refers to the concentration of oxygen gas incorporated in water. Oxygen enters water by direct absorption from the atmosphere, which is enhanced by turbulence. Water also absorbs oxygen released by aquatic plants during photosynthesis. Sufficient DO is essential for growth and reproduction of aerobic aquatic life”

-United States Environmental Protection Agency


We forget that the water cycle
and the life cycle are one
JACQUES YVES COUSTEAU
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CHAPTER-2

2.1 STUDY AREA

Dissolved Oxygen concentrations in a water body can fluctuate largely within a short period of time due to the dynamics of physical, chemical, and biological processes in that system. Photosynthesis adds oxygen to a water body, while respiration and degradation of organic matter consume oxygen. Aeration may add or remove DO from the water depending on the DO saturation level. A number of environmental factors can influence photosynthesis and aeration rates in a water body including light, wind, and temperature, which can fluctuate both regularly and spontaneously during a day. Due to the complexity and variability of these many influences, predicting high frequency DO changes in a natural water body is challenging [16].

To evaluate the diurnal and seasonal variation in DO in flowing waters, it was decided to conduct a comprehensive study at selected river Water Quality (WQ) stations of Central Water Commission on important rivers in India. In this context, a letter was issued to all field Chief Engineers of Central Water Commission with a request to monitor DO and temperature round the clock on three hourly basis continuously for at least one week at sites on important rivers. Suggested list of carefully selected 25 water quality stations was suggested. Selection of sites was based on different climatic condition, anthropogenic activities and type of rivers spread all around the country. Out of 25 water quality stations suggested, exercise was carried out at 19 water quality stations and their data have been considered in this study.

This report describes to understand the effect of temperature on DO concentration in river water. And the list of water quality stations taken under consideration for this study is given in Table 2.

Table 2: List of Water Quality Stations taken under consideration for the Dissolved Oxygen (DO) and Temperature (T) Study at important locations round the clock on three hourly basis.

S. No	River	Station Name	District	State	Division	Organization
1	Brahmaputra	Pandu	Kamrup (Metro)	Assam	Middle Brahmaputra Division, Guwahati	B&BBO, Shillong
2	Arkavathi	T.Bekuppe	Ramanagaram	Karnataka	Cauvery Division, Bangalore	MSO, Bangalore
3	Thirumalairajanaar	Thengudi	Thiruvaruru	Tamilandu	Hydrology Division, Chennai	CSRO, Coimbatore
4	Kaliyar	Ramamangalam	Emakulam	Kerala	South Western River Division, Kochi	CSRO, Coimbatore
5	Aliyar	Ambarampalayam	Coimbatore	Tamilnadu	Southern River Division, Coimbatore	CSRO, Coimbatore
6	Tawi	Vikram Chowk	Jammu	Jammu & Kashmir	Chenab Division, Jammu	IBO, Chandigarh
7	Tungabhadra	Mantralayam	Kurnool	Andhra Pradesh	Lower Krishna Division, Hyderabad	KGBO, Hyderabad
8	Bhima	Phulgaon	Pune	Maharastra	Upper Krishna Division, Pune	KGBO, Hyderabad
9	Ganga	Gandhighat	Patna	Bihar	Middle Ganga Division-V, Patna	LGBO, Patna
10	Kanhan	Satrapur	Nagpur	Maharastra	Wainganga Division, Nagpur	MCO, Nagpur
11	Brahmani	Jenapur	Jajpur	Odisha	Eastern Rivers Division, Bhubaneswar	MERO, Bhubaneswar
12	Narmada	Hoshangabad	Hoshangabad	Madhya Pradesh	Narmada Division, Bhopal	NBO, Bhopal
13	Mahi	Khanpur	Anand	Gujarat	Mahi Division, Ahmedabad	MTBO, Gandhinagar
14	Narmada	Garudeswar	Narmada	Gujarat	Tapi Division, Surat	MTBO, Gandhinagar
15	Bhagirath	Koteshwar	Tehri	Uttarakhand	Himalayan Ganga Division, Dehradun	UGBO, Lucknow
16	Ganga	Varanasi	Varanasi	Uttar Pradesh	Middle Ganga Division-III, Varanasi	UGBO, Lucknow
17	Yamuna	Agra (P.G.)	Agra	Uttar Pradesh	Lower Yamuna Division, Agra	YBO, New Delhi
18	Yamuna	Paonta	Simaur	Himachal Pradesh	Upper Yamuna Division, New Delhi	YBO, New Delhi
19	Yamuna	Delhi Rly Bridge	North Delhi	Delhi	Upper Yamuna Division, New Delhi	YBO, New Delhi

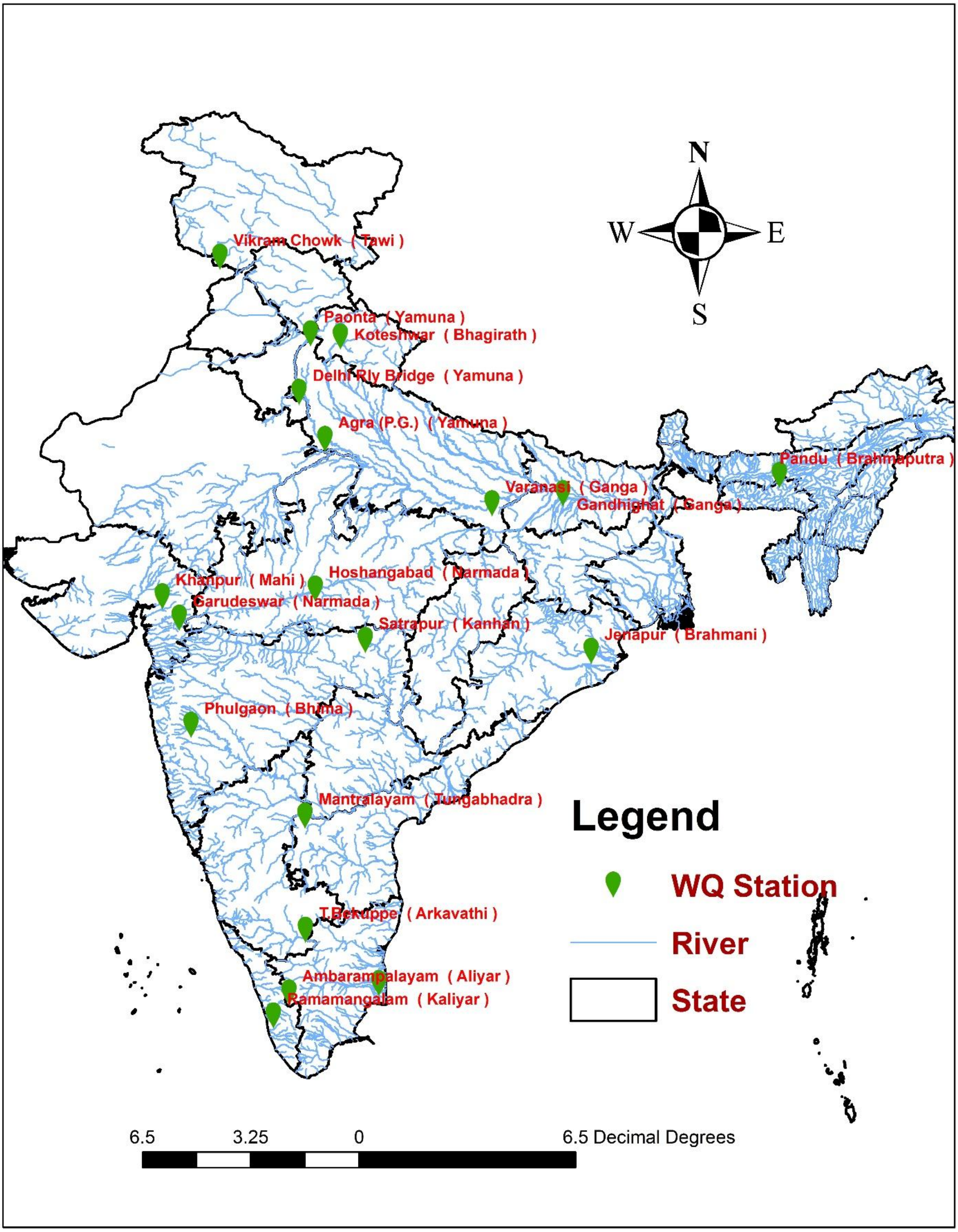


Figure 1: Study Area

2.2 SAMPLING

Samples will be collected from well mixed section of the river (main stream) 30 cm below the water surface using a weighted bottle or DO sampler. Collecting a sample for DO analysis requires special sampling equipment: a purpose-built DO sampler, for collection of undisturbed samples from surface waters. This sampler prevents air bubbles from entering into the sample and changing the DO concentration of the sample. To collect the sample, insert the special ground glass-stoppered bottle (a 'BOD bottle') into the DO sampler. Submerge the sampler, such that water enters the BOD bottle directly by means of a dippipe thus displacing all air from the bottle. Retrieve the sampler after it is full, and then immediately seal the full bottle with a ground glass stopper.

Sample Stabilization

When a sample is being collected for DO analysis by the 'Winkler' method, it is important that, because the DO concentration in the sampling bottle can change rapidly from its original value, the sample is chemically 'fixed'. This ensures that the DO concentration determined is as near as possible to that which prevailed in the water body. Chemical fixing of DO is carried out by adding 1 mL of manganous sulphate solution, 1 ml of alkaline iodide-azide solution and 1 mL of concentrated sulphuric acid to a 300 mL water sample and mixing. The analytical determination may then be carried out up to 8 hours later with no loss of accuracy.

2.3 LABORATORIES INVOLVED IN STUDY

CWC has got large network of WQ stations and testing facilities. There are 23 no's of level-II and 5 no's of Level-III/II+ laboratories. All testing was done in house in the laboratories of CWC mentioned as in Table 3.

Table 3: laboratories of central water commission involved in the study.

S.No	Name of the Laboratory	Station Name	River	Division	Organization
1	Middle Brahmaputra Divisional Water Quality Laboratory, Guwahati	Pandu	Brahmaputra	Middle Brahmaputra Division, Guwahati	B&BBO, Shillong
2	Upper Cauvery Water Quality Laborator, Bangalore	T.Bekuppe	Arkavathi	Cauvery Division, Bangalore	CSRO, Coimbatore
3	East Flowing Rivers Water Quality Laboratory, Chennai	Thengudi	Thirumalairaj anaar	Hydrology Division, Chennai	CSRO, Coimbatore
4	West Flowing Rivers Water Quality Laboratory, Kochi	Ramamangal am	Kaliyar	South Western River Division, Kochi	CSRO, Coimbatore
5	Lower Cauvery Water Quality Laboratory, Coimbatore	Ambarampal ayam	Aliyar	Southern River Division, Coimbatore	CSRO, Coimbatore
6	Chenab Divisional Water Quality Laboratory, Jammu	Vikram Chowk	Tawi	Chenab Division, Jammu	IBO, Chandigarh
7	Krishna & Godavari River Water Quality Laboratory, Hyderabad	Mantralayam	Tungabhadra	Lower Krishna Division, Hyderabad	KGBO, Hyderabad
8	Upper Krishna Divisional Water Quality Laboratory, Pune	Phulgaon	Bhima	Upper Krishna Division, Pune	KGBO, Hyderabad
9	Middle Ganga Divisional-V Water Quality Laboratory, Patna	Gandhighat	Ganga	Middle Ganga Division-V, Patna	LGBO, Patna
10	Wainganaga Divisional Water Quality Laboratory, Nagpur	Satrapur	Kanhan	Wainganga Division, Nagpur	MCO, Nagpur
11	Eastern River Water Quality Laboratory, Bhubaneswar	Jenapur	Brahmani	Eastern Rivers Division, Bhubaneswar	MERO, Bhubaneswar
12	Narmada Divisional Water Quality Laboratory, Bhopal	Hoshangaba d	Narmada	Narmada Division, Bhopal	NBO, Bhopal
13	Mahi Divisional Water Quality Laboratory, Ahmedabad	Khanpur	Mahi	Mahi Division, Ahmedabad	MTBO, Gandhinagar
14	Tapi Divisional Water Quality Laboratory, Surat	Garudeswar	Narmada	Tapi Division, Surat	MTBO, Gandhinagar
15	Himalayan Divisional Water Quality Laboratory, Dehradun	Koteshwar	Bhagirath	Himalayan Ganga Division, Dehradun	UGBO, Lucknow
16	Upper & Middle Ganga River Water Quality Laboratory, Varanasi	Varanasi	Ganga	Middle Ganga Division-III, Varanasi	UGBO, Lucknow
17	Lower Yamuna Water Quality Laboratory, Agra	Agra (P.G.)	Yamuna	Lower Yamuna Division, Agra	YBO, New Delhi
18	National River Water Quality Laboratory, New Delhi	Paonta	Yamuna	Upper Yamuna Division, New Delhi	YBO, New Delhi
19	National River Water Quality Laboratory, New Delhi	Delhi Rly Bridge	Yamuna	Upper Yamuna Division, New Delhi	YBO, New Delhi

2.4 DISSOLVED OXYGEN ANALYSIS METHOD

Here are three methods available for measuring DO concentrations. Modern techniques involve an electrochemical or optical sensor, the colorimetric method and the Winkler titration method. Former two methods quick and inexpensive but limited in scope and subject to error due to other redoxing agents that may be present in the water.

The traditional method is the Winkler titration. This method was developed by L.W. Winkler, a Hungarian chemist, in 1888. Also known as the iodometric method, the Winkler method is a titrimetric procedure based on the oxidizing property of DO. This method has long been the standard for accuracy and precision when measuring DO. Herein, analysis for the DO has been done by Azide-Winkler's method [17, 18].

<u>Wrinkler method (Azide Modification Method)</u>

The method is based upon reactions that release iodine equivalent to the amount of oxygen originally present in the sample. The principle involved in this method of determination of DO is to bring about the oxidation of potassium iodide to iodine with the DO present in the water sample after adding $MnSO_4$, NaOH, KI and H_2SO_4. The DO present in the sample oxidizes the Mn^{2+} in alkaline conditions to its higher valiancy Mn^{+3}[MnO(OH)] and Mn^{+4}[$MnO(OH)_2$] or hydrated MnO_2, which precipitates as a brown hydrated oxide after the addition of NaOH and KI. On acidification, the manganese reverts back to the divalent state and an equivalent amount of iodine is liberated from the KI present. This liberated iodine is titrated against standard sodium thiosulfate (hypo) solution using starch as indicator.

In the ***<u>first step</u>*** manganous sulphate and alkali iodide reagents are added. If no oxygen is present the manganous ion reacts only with the hydroxide ion to form a white precipitate of manganous hydroxide.

$$Mn^{+2} + 2OH^- \longrightarrow Mn(OH)_2 \text{ (white precipitate)}$$

If oxygen is present the manganous ion is oxidized and brown precipitate of manganese dioxide of formed.

$$Mn^{+2} + 2OH^- + \frac{1}{2} O_2 \longrightarrow MnO_2 \text{ (Brown precipitate)} + H_2O$$

In the ***second step*** upon addition of sulphuric acid (H_2SO_4) iodine (I_2) is formed by oxidation of iodide (KI).

$$MnO_2 + 4H^+ + 2I^- \longrightarrow Mn^{+2} + I_2 + 2H_2O$$

In the ***third step*** Sodium thiosulphate standard solution is used to titrate iodine (I_2).

$$Na_2S_2O_3 + I_2 \longrightarrow Na_2S_4O_6 + 2\ NaI$$

The end point of titration is obtained by first titrating iodine to a pale straw colour and then adding starch indicator, which combine with iodine to give a blue colour. The titration is continued till the iodine complexed with starch is also reacted and the blue colour disappears.

Interferences:

Iron, nitrite and microbial mass are the chief sources of interference in this method. Nitrites if present in the sample cause interference by oxidizing iodide.

$$2\ NO_2^- + 2\ I^- + 4\ H^+ \longrightarrow I_2 + NO + 2H_2O$$

NO in turn, is oxidized by oxygen entering the sample during titration:

$$NO + ½\ O_2 + H_2O \longrightarrow 2NO_2^- + 2H^+$$

Thus, it become impossible to reach a definite end point and high results are obtained. The procedure has to be modified depending upon the nature of the interfering substance. Adding sodium azide (NaN_3) can eliminate the interference due to nitrite.

$$2NaN_3 + H^+ \longrightarrow HN_3 \text{ (Hydrazoic acid)} + Na^+$$

$$HN_3 + NO_2^- + H^+ \longrightarrow N_2 + N_2O + H_2O$$

The results obtained discussed in appropriate sections

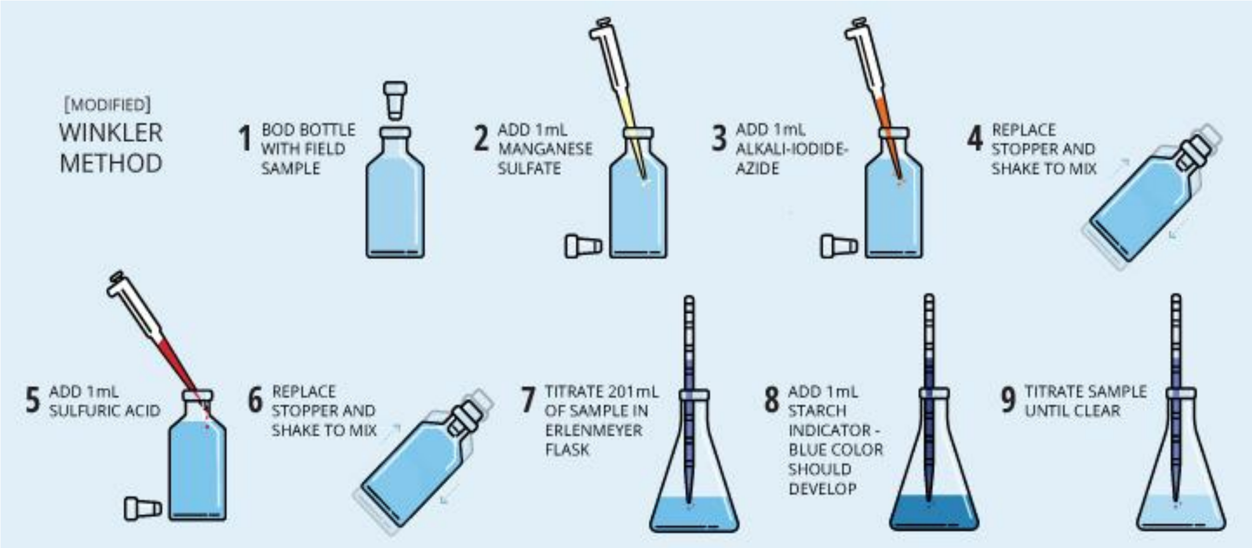


Figure 2: Schematic Diagram of DO analysis procedure

Prescribed limits for DO as per CPCB water quality criteria for designated best use of fresh water are given in Table 4.

Table 4: Prescribed Limits for DO as per CPCB water quality criteria for designated best use of fresh water.

Class	Designated Best Uses	Dissolved Oxygen Concentration Limit
A	Drinking Water Source without conventional treatment but after disinfection	> 6 mg/L
B	Outdoor Bathing (Organised)	> 5 mg/L
C	Drinking water source after conventional treatment and disinfection	> 4 mg/L
D	Propagation of wild life and Fisheries	> 4 mg/L

CHAPTER-3

3.1 RESULTS AND DISCUSSION

At many quarters, concerns were raised due to variation of DO in the rivers with the time and seasons. A specific concern was raised that Central Water Commission generally collects the water sample between 8.00 to 10.00 AM from the rivers and at that time, there is ample sun light and photosynthesis by the aquatic plants and phytoplankton. This raises the DO content in the water. Whereas, during the night, there is no photosynthesis and DO is consumed by the aquatic plants, living creatures and plants for their respiration and decaying organic material (dead animals, plants, phytoplankton etc.). Concerns were raised that this reduces the content of DO in the water to near about Zero which is detrimental to aquatic life.

In order to clarify the above apprehension raised by different academicians/ scientists, Central Water Commission decided to monitor DO for river waters round the clock for at least one week in different seasons. Samples were taken from the rivers every 3 hourly and DO levels were analysed. Care was also taken that such samples are taken in different seasons so that the sun light hours are different and the effect of photosynthesis on the water may be different. In different seasons, temperatures are also different, so the saturation level of DO changes. In totality, 19 nos. of sites on different rivers throughout the country were selected and their results were analysed. The data of the observed DO at different time on different sites is placed at Table-5.

Table 5: Summary on Results obtained for Dissolved Oxygen (DO) & Temperature at WQ Stations

S.No	River	Station Name	Division	Organization	Period for which data received	Maximum			Minimum			DO Value at Standard time (8-10 am)
						DO (mg/L)	Temp (^{0}C) corsps to DO	Date & Time	DO (mg/L)	Temp (^{0}C) corsps to DO	Date & Time	
1	Aliyar	Ambarampalayam	Southern River Division, Coimbatore	CSRO, Coimbatore	30/10/2018 to 06/11/2018	10.53	28	30/10/2018 & 13:00 Hrs	4.67	26	02/11/2018 & 04.00 Hrs	7.59
2	Arkavathi	T.Bekuppe	Cauvery Division, Bangalore	MSO, Coimbatore	14/11/2018 to 21/11/2018	5.4	25	14/11/2018 & 13:00 Hrs	2.5	25	16/11/2018 & 04:00 Hrs	3.50
3	Bhagirath	Koteshwar	Himalayan Ganga Division, Dehradun	UGBO, Lucknow	01/11/2018 to 07/11/2018	8.55	16.1	05/11/2018 & 06:00 Hrs	6.84	17.8	02/11/2018 & 15:00 Hrs	8.55
4	Bhima	Phulgaon	Upper Krishna Division, Pune	KGBO, Hyderabad	27/10/2018 to 02/11/2018;	10.9	28	27/10/2018 & 17:00 Hrs	6.2	24	31/10/2018 & 08:00 Hrs	6.20
5	Brahmani	Jenapur	Eastern Rivers Division, Bhubaneswar	MERO, Bhubaneswar	18/12/2018 to 24/12/2018	9.8	-	23/12/2018 & 15:00 Hrs	7.2	-	18/12/2018 & 18:00 Hrs	9.18
6	Brahmaputra	Pandu	Middle Brahmaputra Division, Guwahati	B & BBO, Shillong	22/10/2018 to 29/10/2018	10.92	24.1	23/10/2018 & 05:30 Hrs	7.23	25.5	22/10/2018 & 20:30 Hrs	8.63
7	Ganga	Gandhighat	Middle Ganga Division-V, Patna	LGBO, Patna	29/10/2018 to 04/11/2018	7.95	28.5	01/11/2018 & 08:00	5.24	27	04/11/2018 & 20:00	7.76
8	Ganga	Varanasi	Middle Ganga Division-III, Varanasi	UGBO, Lucknow	15/12/2018 to 22/12/2018	9.19	20	21/12/2018 &15.:00 Hrs	6.18	18.5	18/12/2018 & 03:00 Hrs	8.12
9	Kaliyar	Ramamangalam	South Western River Division, Kochi	CSRO, Coimbatore	13/11/2018 to 20/11/2018	8.1	23.5	16/11/2018 & 21:00 Hrs	6.1	25	18/11/2018 & 24:00 Hrs	6.50
10	Kanhan	Satrapur	Wainganga Division, Nagpur	MCO, Nagpur	10/12/2018 to 16/12/2018	11.9	28.3	10/12/2018 & 15:00 Hrs	6.4	20.5	11/12/2018 & 06:00 Hrs	9.00
11	Mahi	Khanpur	Mahi Division, Ahmedabad	MTBO, Gandhinagar	03/12/2018 to 09/12/2018	9.2	24	03/12/2018 & 13:00 Hrs	7	21	03/12/2018 & 19:00 Hrs	9.00
12	Narmada	Hoshangabad	Narmada Division, Bhopal	NBO, Bhopal	24/10/2018 to 30/10/2018	7.2	22	26/10/2018 & 06:00 Hrs	5.9	31	27/10/2018 & 15.00 Hrs	6.80
13	Narmada	Garudeswar	Tapi Division, Surat	MTBO, Gandhinagar	28/01/2019 to 04/02/2019	10.04	18	30/01/2019 & 18:30 Hrs	8.74	18	01/02/2019 & 00:30 Hrs	9.49
14	Tawi	Vikram Chowk	Chenab Division, Jammu	IBO, Chandigarh	11/02/2019 to 15/02/2019	8.8	12.5	14/02/2019 & 05:30 Hrs	6.21	13	11/02/2019 & 11:30 Hrs	6.52
15	Thirumalairajanaar	Thengudi	Hydrology Division, Chennai	CSRO, Coimbatore	27/01/2019 to 02/02/2019	8.96	30	27/01/2019 & 15:00 Hrs	5.57	23	31/01/2019 & 06:00 Hrs	5.97
16	Tungabhadra	Mantralayam	Lower Krishna Division, Hyderabad	KGBO, Hyderabad	17/11/2018 to 24/11/2018	9.6	13	18/11/2018 & 14:00 Hrs	5.2	29	20/11/2018 & 14:00 Hrs	6.00
17	Yamuna	Agra (P.G.)	Lower Yamuna Division, Agra	YBO, New Delhi	17/12/2018 to 23/12/2018	4.62	14	21/12/2018 & 12:00 Hrs	1.81	11	17/12/2018 & 21:00 Hrs	2.41
18	Yamuna	Paonta	Upper Yamuna Division, New Delhi	YBO, New Delhi	01/12/2018 to 31/12/2018;	9.67	-	01/12/2018 & 08:00 Hrs	7.96	-	02/12/2018 & 17:00 Hrs	9.67
19	Yamuna	Delhi Rly Bridge	Upper Yamuna Division, New Delhi	YBO, New Delhi	14/01/2019 to 16/01/2019	0	11.8	16/01/2019 & 03:00 Hrs	0	15.5	14/01/2019 &12:00 Hrs	0.00

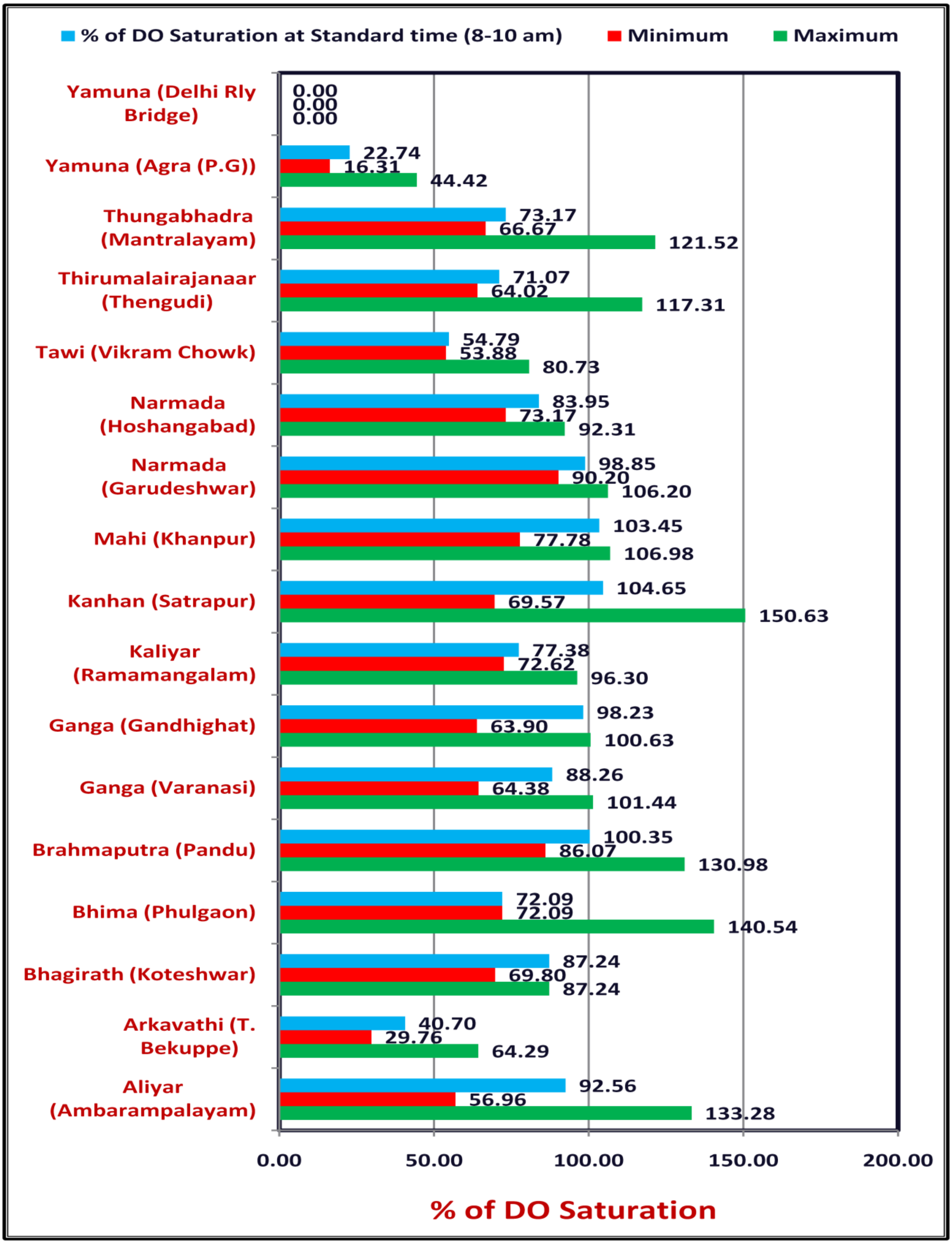


Figure 3: Summary on Results obtained for DO saturation at WQ Stations with respect to River

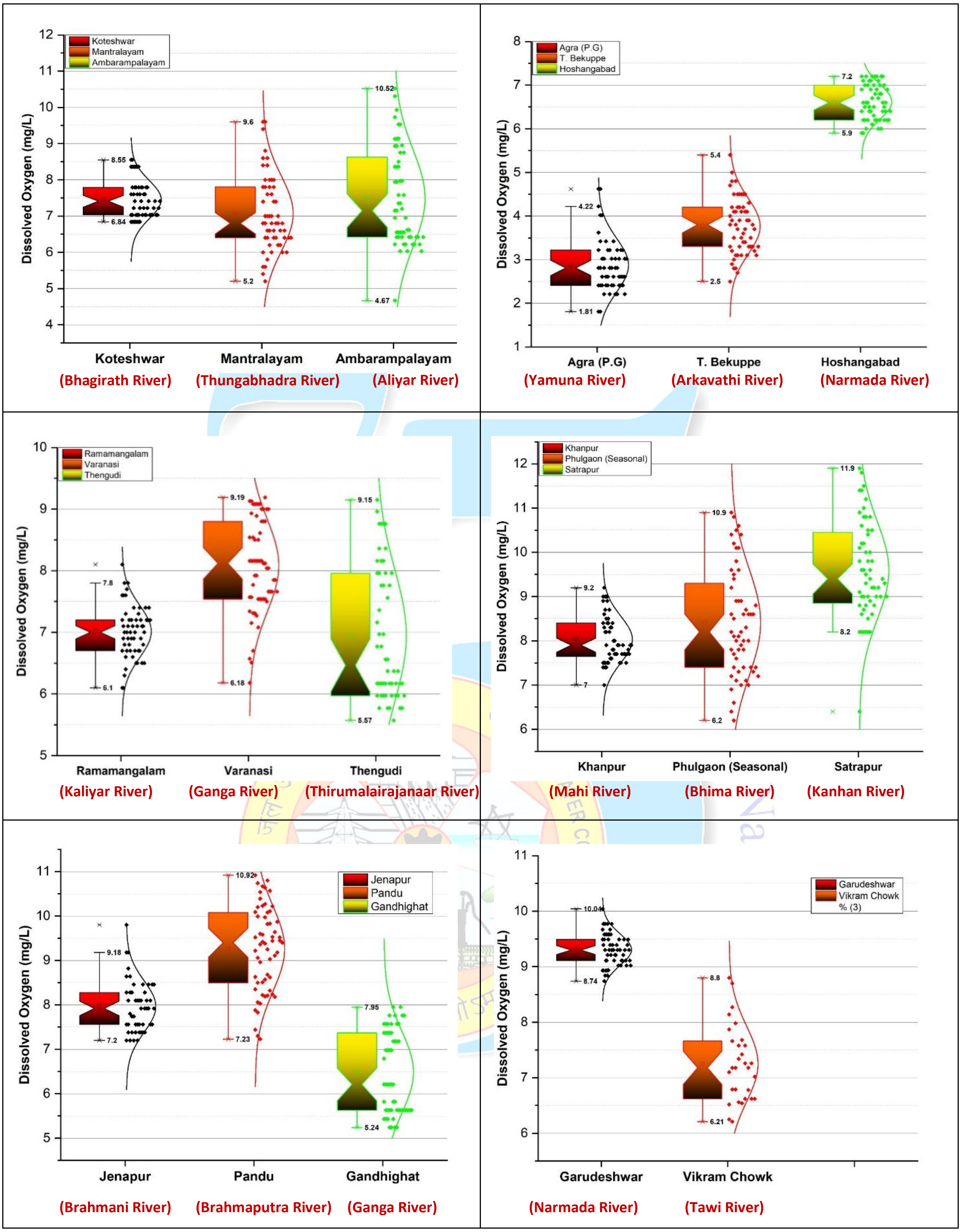
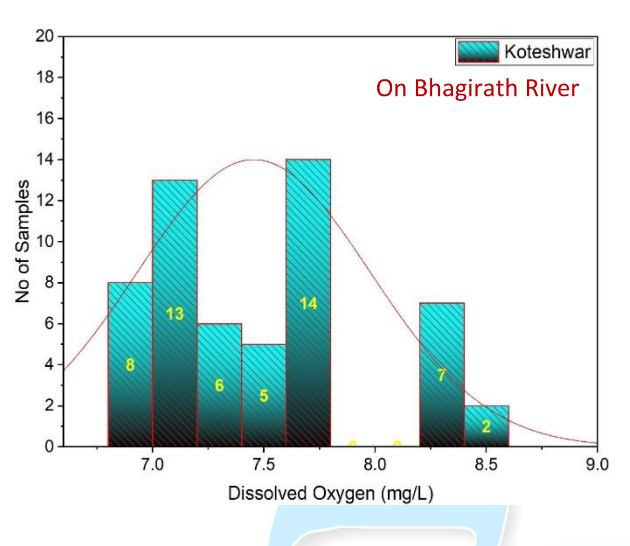
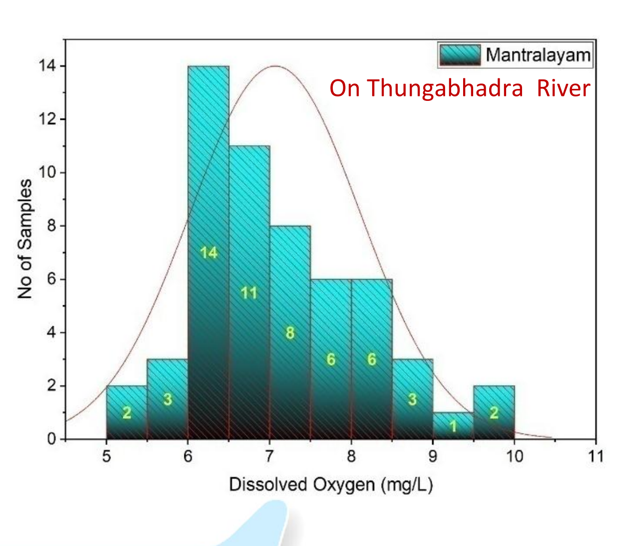
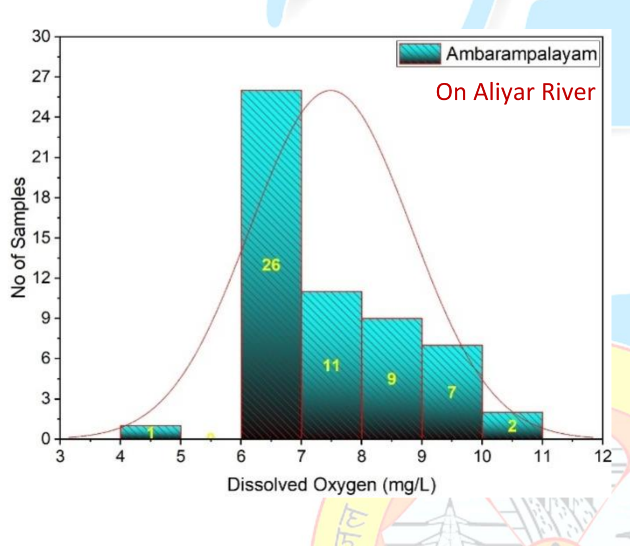
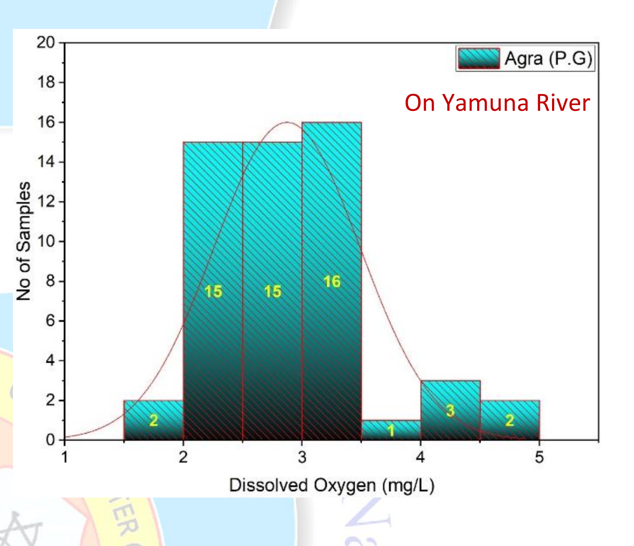


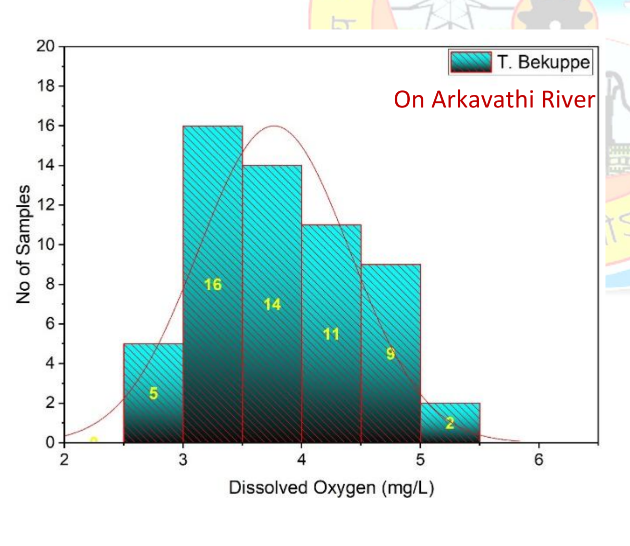
Figure 4: Whisker Box Diagram of all Water Quality Stations

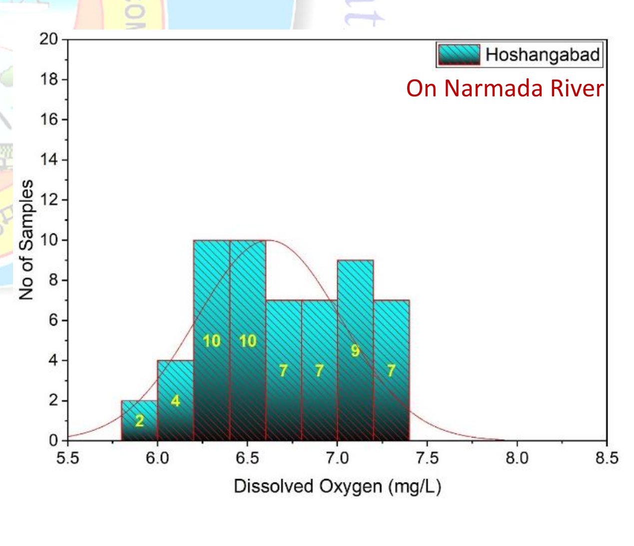

Koteshwar
On Bhagirath River
No of Samples
Dissolved Oxygen (mg/L)

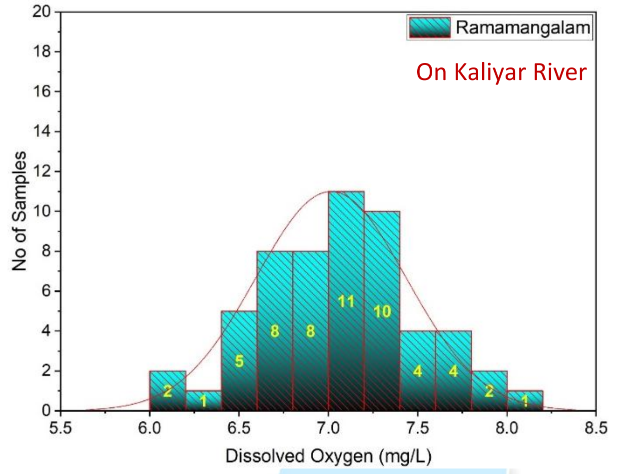

Mantralayam
On Thungabhadra River
No of Samples
Dissolved Oxygen (mg/L)

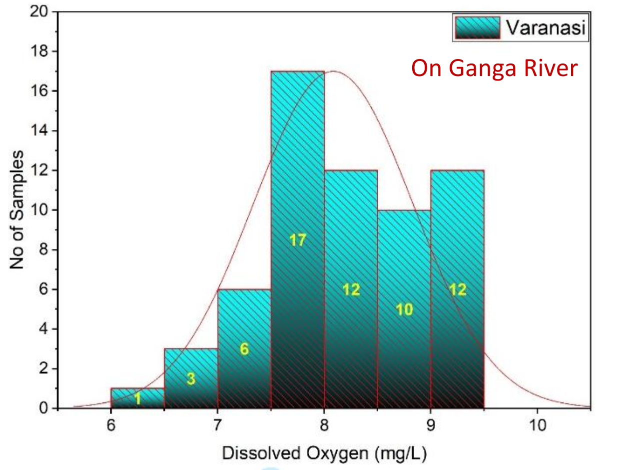

Ambarampalayam
On Aliyar River
No of Samples
Dissolved Oxygen (mg/L)

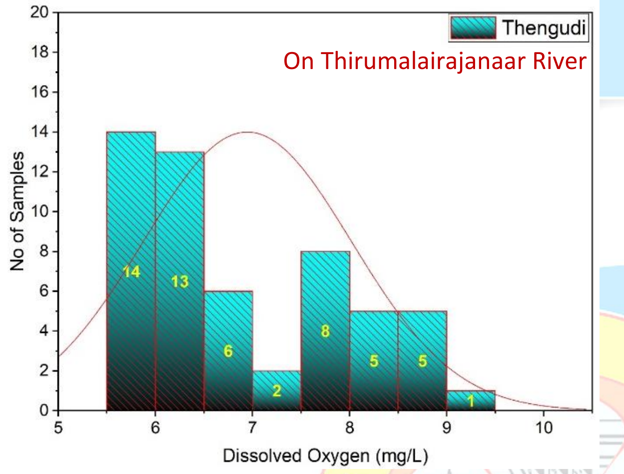

Agra (P.G)
On Yamuna River
No of Samples
Dissolved Oxygen (mg/L)

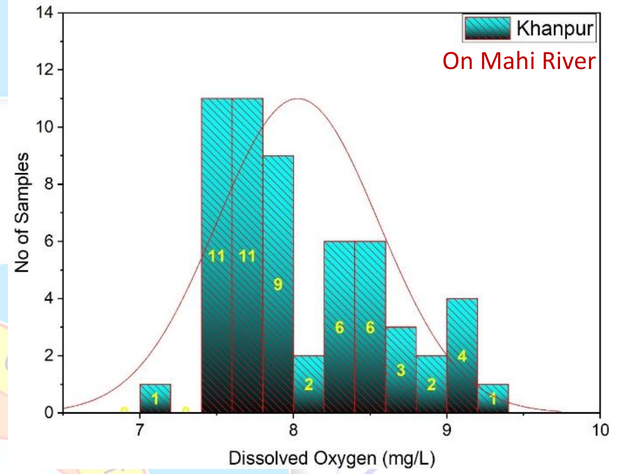

T. Bekuppe
On Arkavathi River
No of Samples
Dissolved Oxygen (mg/L)

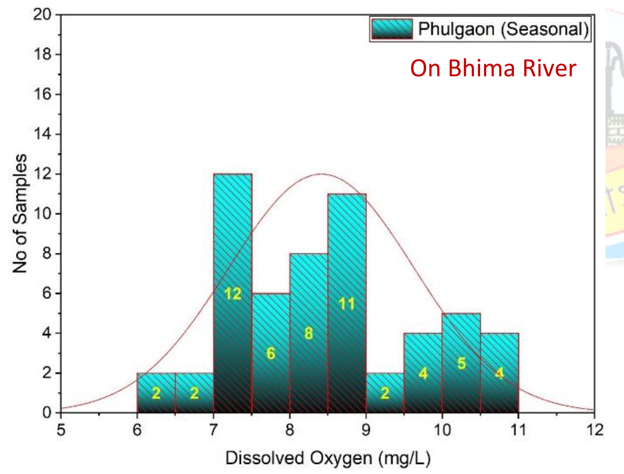

Hoshangabad
On Narmada River
No of Samples
Dissolved Oxygen (mg/L)

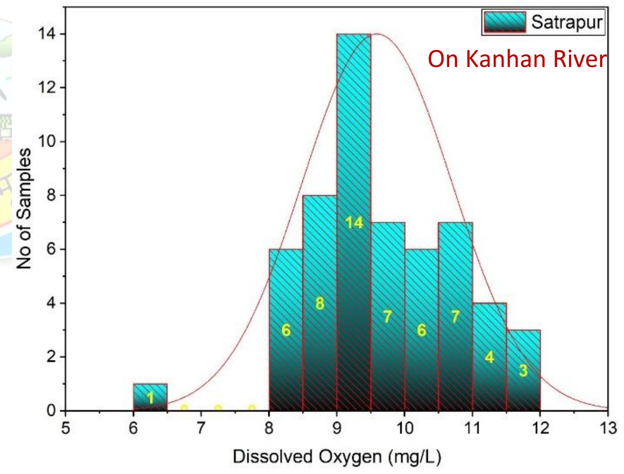

Ramamangalam
On Kaliyar River
No of Samples
Dissolved Oxygen (mg/L)


Varanasi
On Ganga River
No of Samples
Dissolved Oxygen (mg/L)


Thengudi
On Thirumalairajanaar River
No of Samples
Dissolved Oxygen (mg/L)


Khanpur
On Mahi River
No of Samples
Dissolved Oxygen (mg/L)


Phulgaon (Seasonal)
On Bhima River
No of Samples
Dissolved Oxygen (mg/L)


Satrapur
On Kanhan River
No of Samples
Dissolved Oxygen (mg/L)

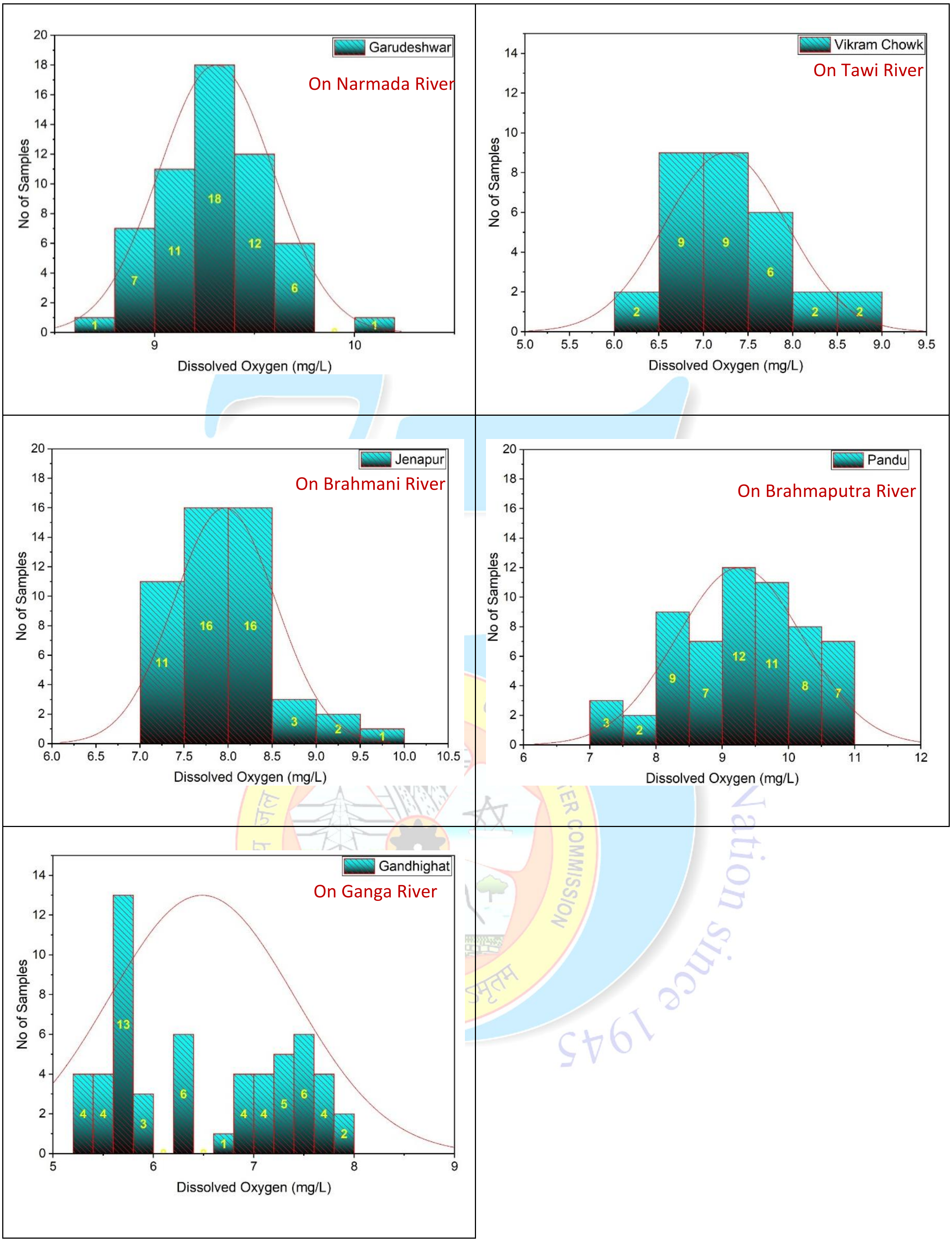


Figure 5: Frequency Distribution Diagram of all Water Quality Stations

3.1 DISSOLVED OXYGEN AND TEMPERATURE VARIATION WITH RESPECT TO TIME FOR WQ STATIONS

Herein, to explain the suitability of water, prescribed limits for DO has been taken into consideration according to the CPCB water quality criteria for designated best use of fresh water.

YAMUNA RIVER

Yamuna River The river Yamuna, a major tributary of river Ganges, originates from the Yamunotri glacier near Banderpoonch peaks (38° 59' N 78° 27' E) in the Mussourie range of the lower Himalayas at an elevation of about 6387 meters above mean sea level in district Uttarkashi (Uttrakhand). The catchments of Yamuna river system cover parts of Uttar Pradesh, Uttrakhand, Himachal Pradesh, Haryana, Rajasthan, Madhya Pradesh & Delhi states.

3.1.1 Agra (P.G) on Yamuna River:

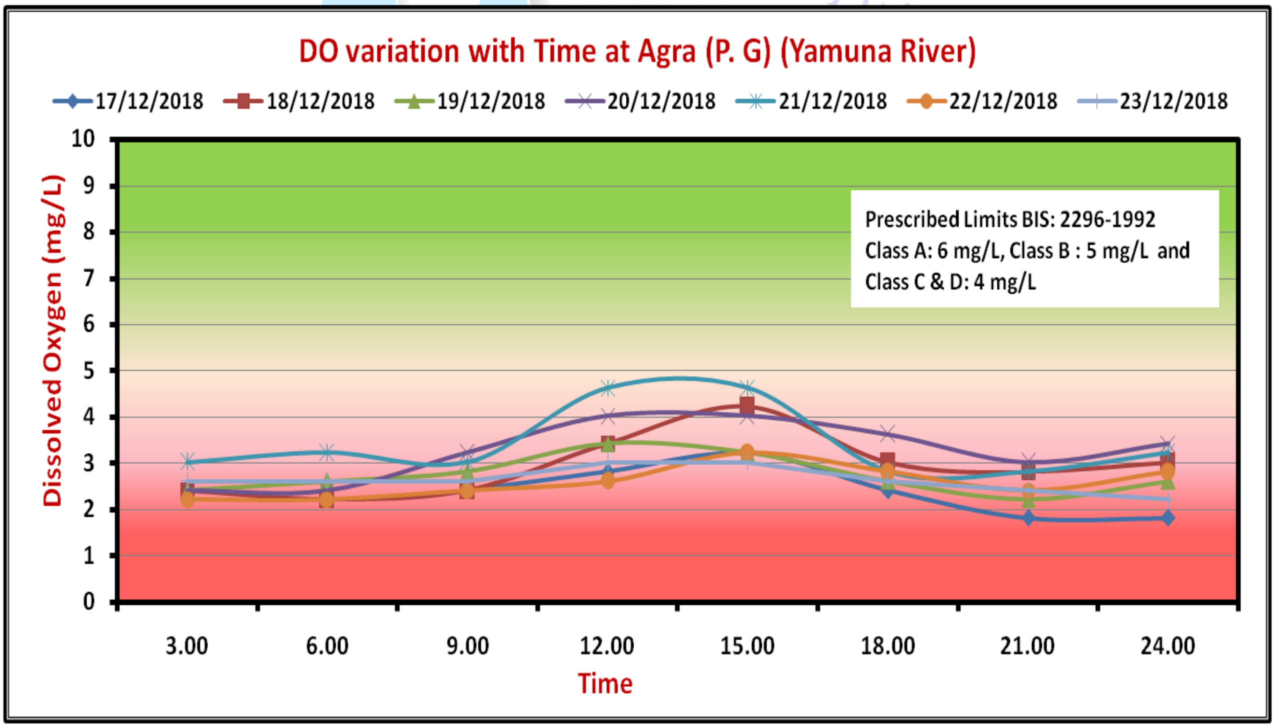


Figure 6: DO variation with Time at Agra (P.G.) on Yamuna

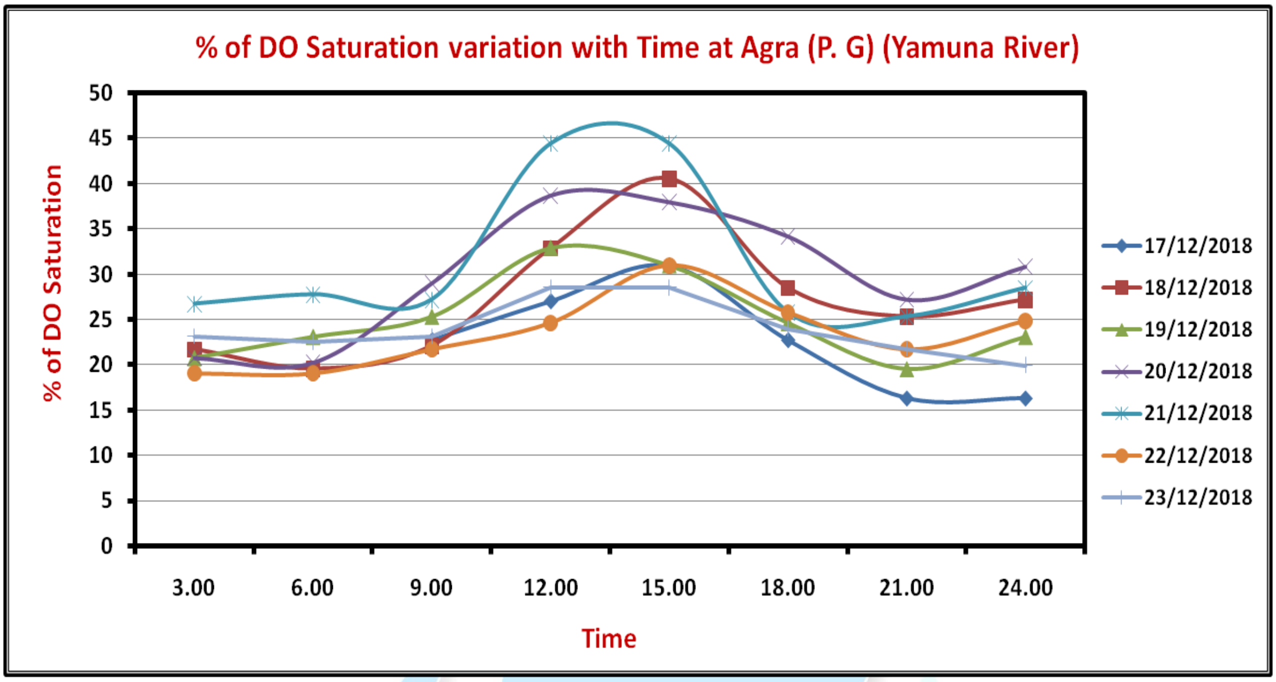


Figure 7: % of DO saturation variation with time at Agra (P.G.) on Yamuna

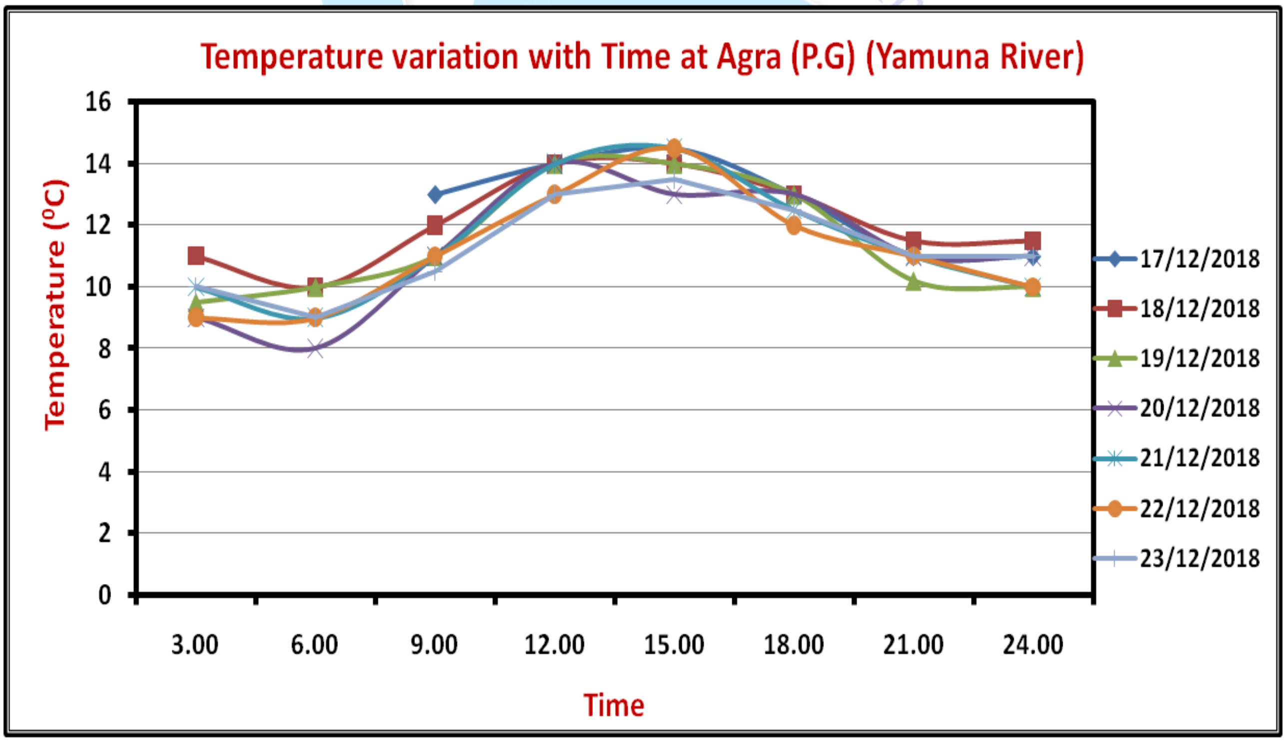


Figure 8: Temperature variation with time at Agra (P.G.) on Yamuna

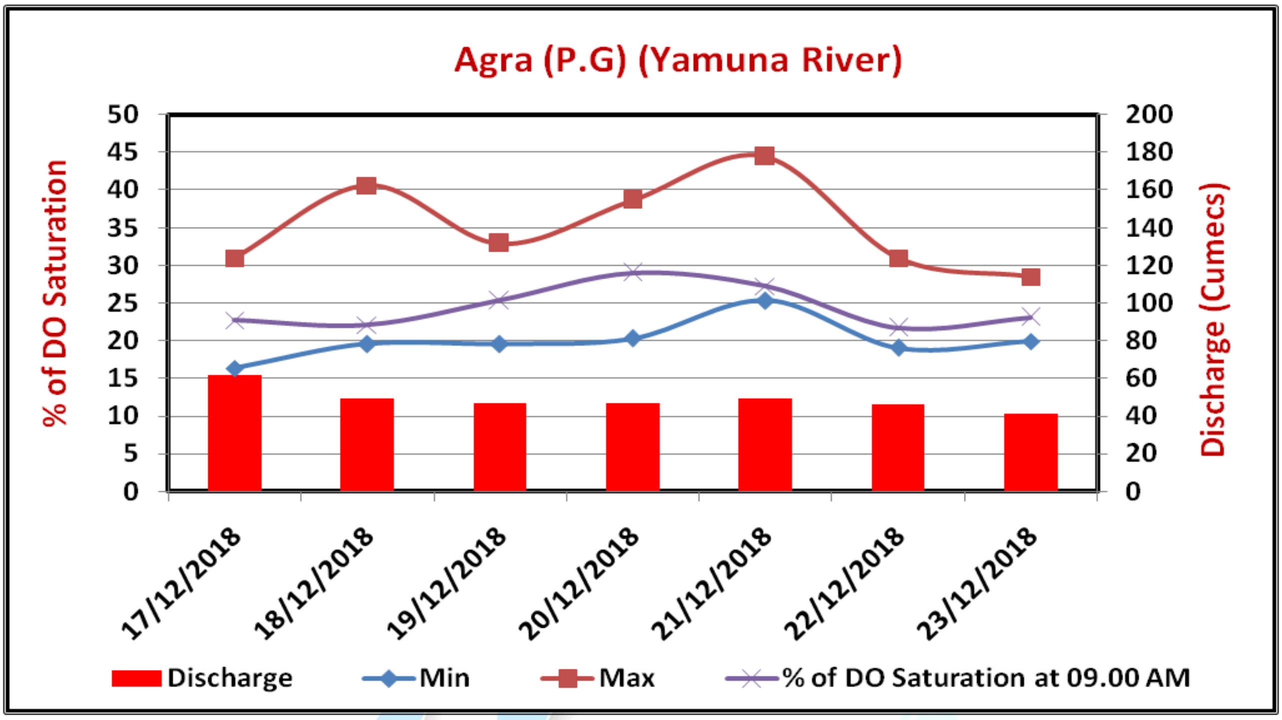


Figure 9: Relation between % of DO saturation and Discharge at Agra (P.G.) on Yamuna

Both DO and Temperature graphs showing almost similar trends with respect to time during all the days of study period from 17/12/2018 to 23/12/2018. Temperature lies between 8 ^{0}C and 14.5 ^{0}C during the study period. Maximum DO value observed was 4.62 mg/L (DO Saturation=44.42%) on 21/12/2018 at 12:00 Hrs at temperature of 14 ^{0}C and Minimum DO value observed was 1.81 mg/L (DO Saturation = 16.31%) on 17/12/2018 at 21:00 Hrs. at temperature is 11 ^{0}C. From the DO vs Time graphs it can be explained that, majority of the times DO values found below permissible limits for Class C and D except on 21/12/2018 at 12:00 Hrs & 15:00 Hrs for Class B. Further, obtained DO values have been found below the permissible limits for Class A throughout the study period. By comparing temperature graph and DO saturation graphs it can be seen that DO concentration is increasing with Temperature i.e during the daytime. This relationship can be attributed to photosynthesis activities in river water. However, no clear relationship was seen between quantity of flow and DO saturation.

3.1.2 Delhi Railway Bridge on Yamuna River:

DO levels have been found Zero in all the time during study period from 14/01/2019 to 16/01/2019 irrespective of variation in Temperature.

DO level in Yamuna from its origin to Palla is found normal, but beyond that it started decreasing. After Wazirabad the DO level starts decreasing drastically. Most of the times the DO has been found nil at Delhi water quality station. The river Yamuna receives discharge from 22 drains at downstream of Wazirabad. At Delhi in river Yamuna, a huge amount of organic waste has been added into the river augments, the microbial activity of the aquatic system resulting in the escalation of BOD and depletion of DO. Downstream of Yamuna at Delhi i.e. Nizamuddin; in addition to wastewater via drains, the river also receives a major load discharged from Hindon cut carrying wastewater from U.P. The main reasons for the poor river quality are addition of huge quantity of wastewater generated from the city and no fresh water flow in the river, as also studied by few water quality modeling studies.

However, this condition of Yamuna improved after Etawah due to confluence of Chambal, Ken and Betwa in Yamuna. There are no major towns situated in the reach between Agra and Etawah and the flow increases only due to addition of sub soil flow along the course. In view of absence of fresh addition of organic load and due to the bacteriological/ biological oxidation of organic the condition of river got improved. Further, it is also due to receiving water from Chambal and other its tributaries that Yamuna gets a respite by reducing BOD levels due to dilution.

3.1.3 Paonta on Yamuna River:

It can be seen from the graphs, DO graphs following almost similar trend with respect to time during all the days of study period from 01/12/2018 to 07/12/2018. Maximum DO value was observed 9.67 mg/L on 01/12/2018 at 08:00 Hrs., and Minimum DO value observed was 7.96 mg/L on 02/12/2018 at 17:00 Hrs. From DO vs Time graphs it can be explain that, DO concentrations found within prescribed limits for all classes of water.

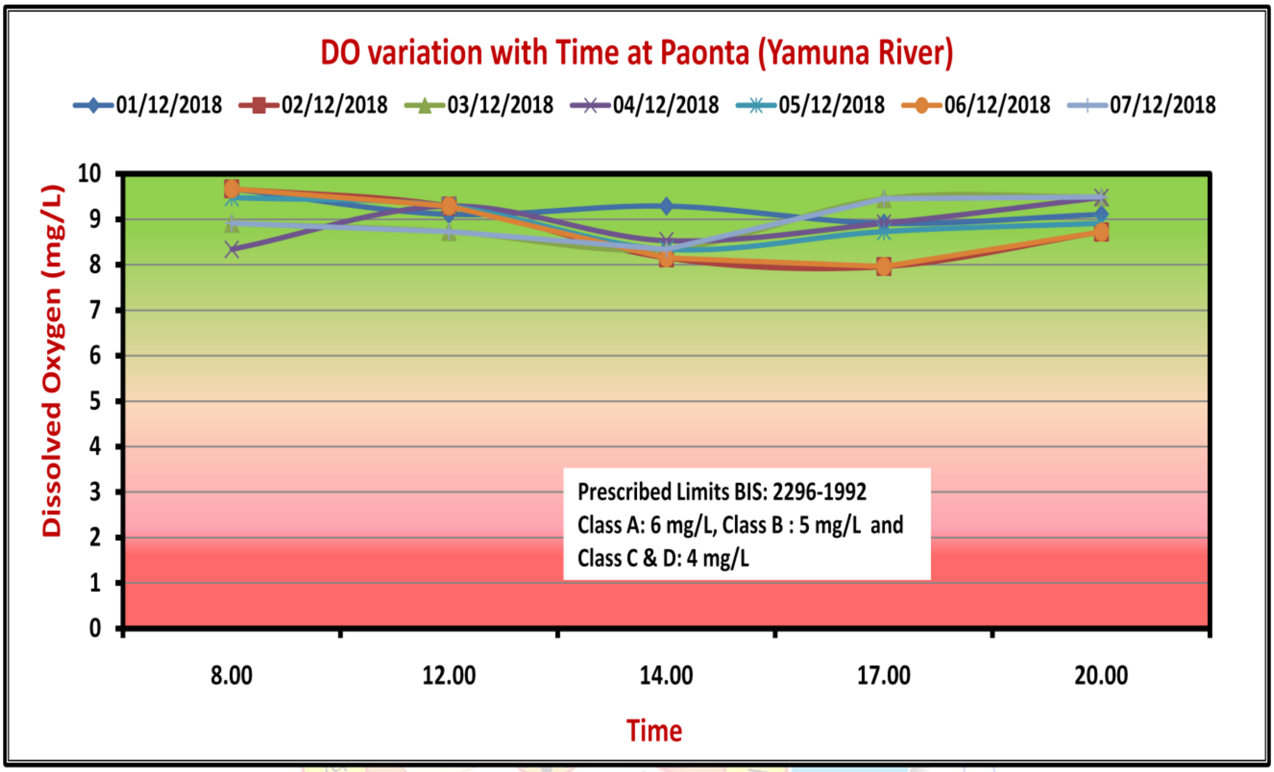


Figure 10: DO variation with Time at Paonta on Yamuna

NARMADA RIVER

Narmada is the largest west flowing river of the peninsular India. It rises from Maikala range near Amarkantak in Anuppur district of Madhya Pradesh, at an elevation of about 900 m. The total length of the river is 1,312 km and its important tributaries are the Burhner, the Banjar, the Sher, the Shakkar, the Dudhi, the Tawa , the Ganjal, the Kundi, the Goi and the Karjan which join from left whereas the Hiran, the Tendoni, the Barna, the Kolar, the Man, the Uri, the Hatni and the Orsang join from right. Narmada drains into the Arabian Sea through the Gulf of Khambhat.

3.1.4 Garudeswar on Narmada River

Both DO and Temperature graphs showing almost similar trends with respect to time during all the days of study period from 28/01/2019 to 04/02/2019. Temperature lies between 17 ^{0}C and 20 ^{0}C during the study period. Maximum DO value observed was 10.04 mg/L (DO Saturation = 106.20%) on 30/01/2019 at 18:30 Hrs at temperature 18 ^{0}C and Minimum DO value observed was 8.74 mg/L (DO Saturation = 90.20%) on 01/02/2019 at 00:30 Hrs at temperature 18 ^{0}C. From the DO vs Time graphs it can be explain that, obtained DO concentrations falls within permissible limits for all classes of water throughout study period and there is no much considerable variation observed in DO values. It can be seen from the DO saturation graphs, DO saturation is increasing with time during day time.

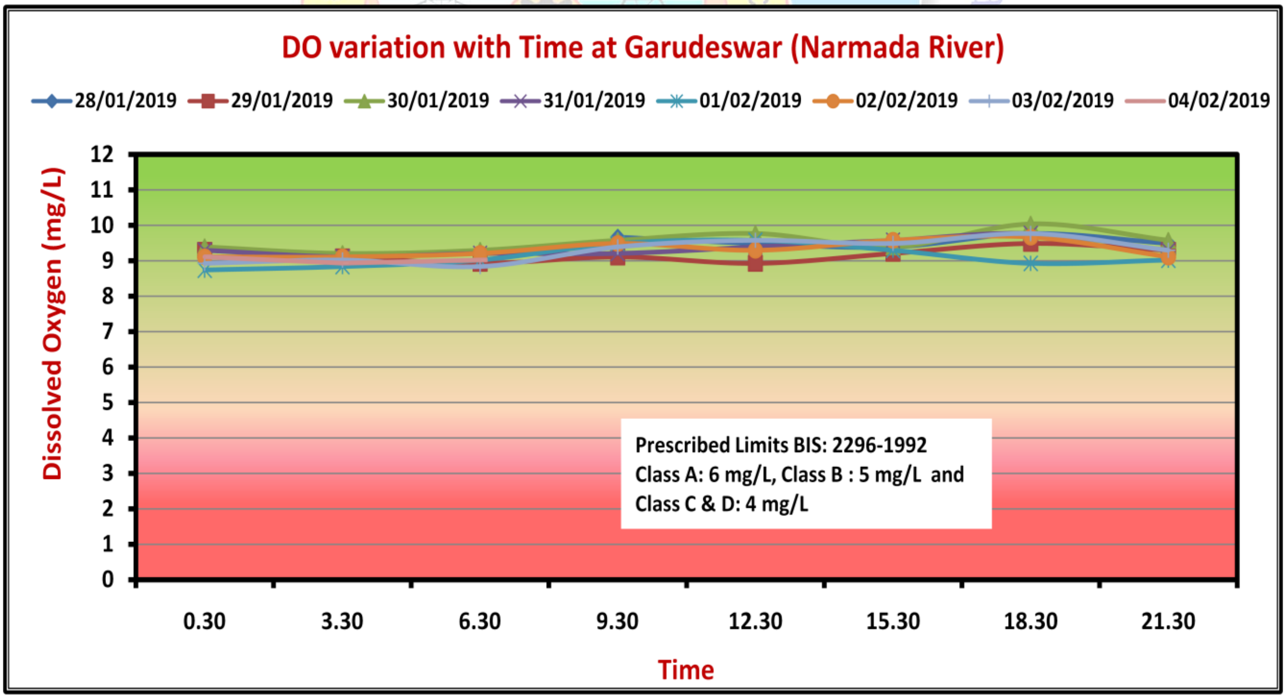


Figure 11: DO variation with Time at Garudeswar on Narmada River

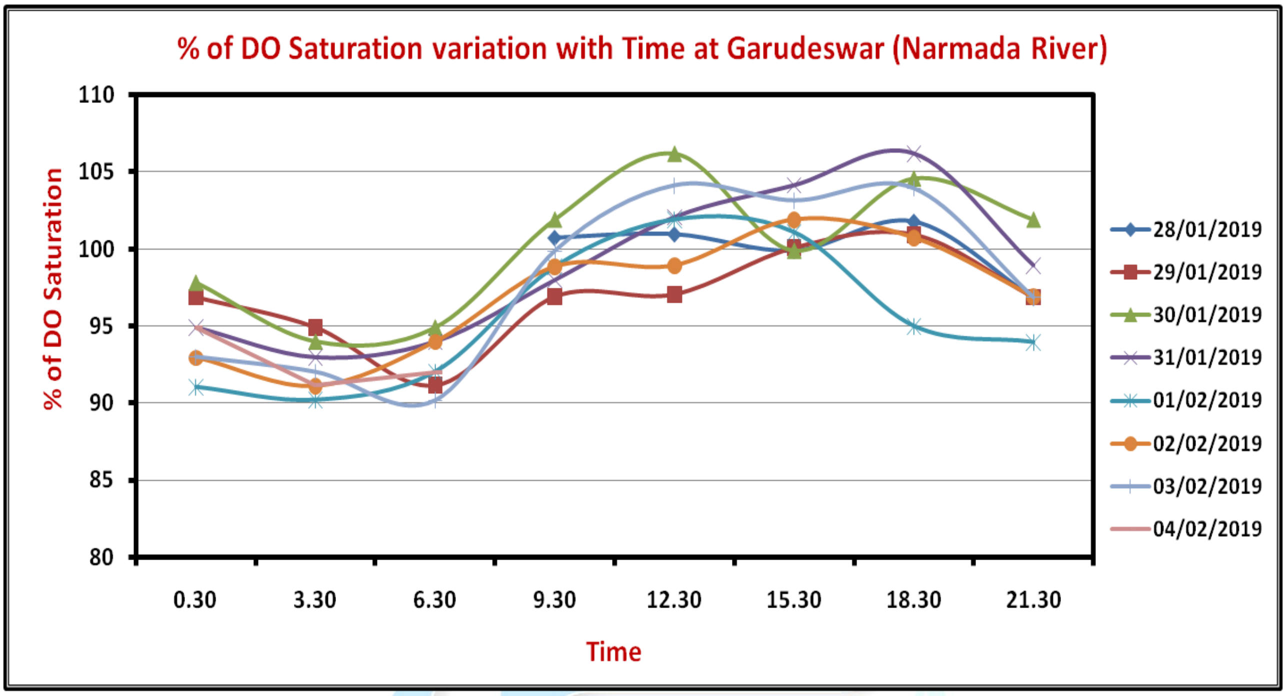


Figure 12: % of DO saturation variation with time at Garudeswar on Narmada River

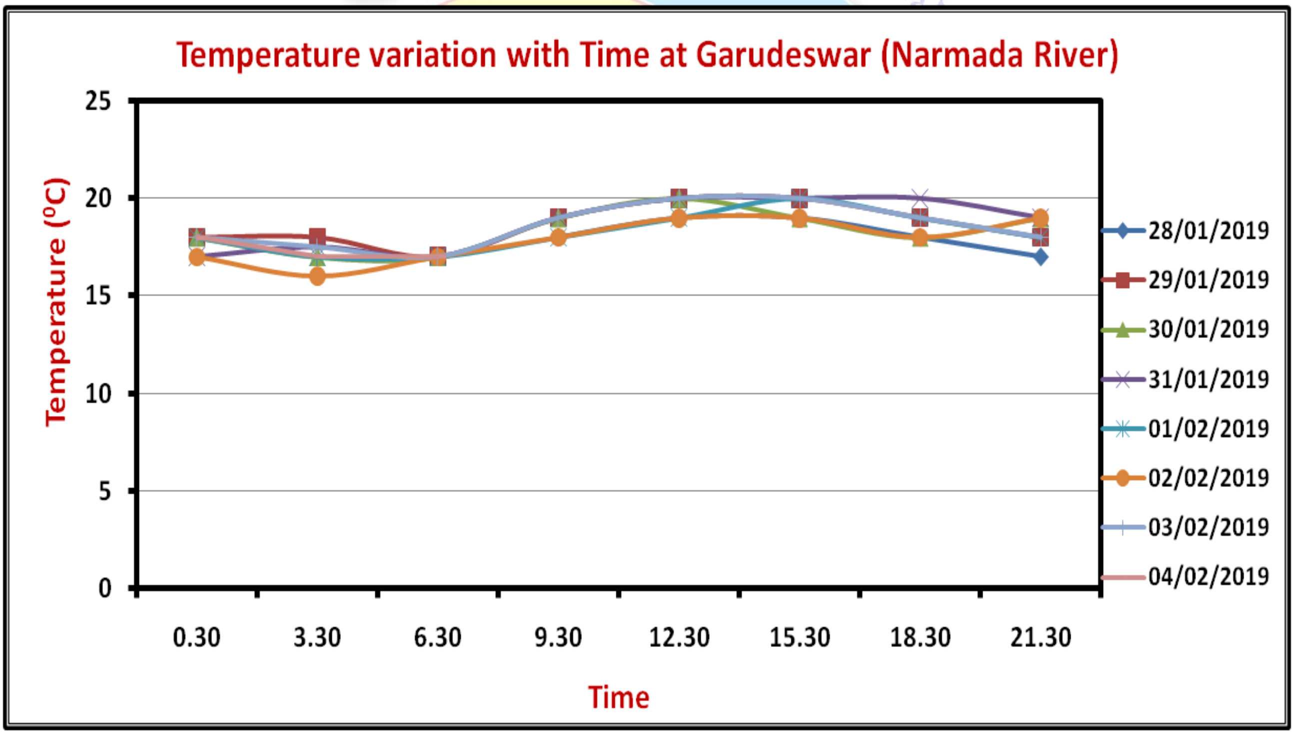


Figure 13: Temperature variation with time at Garudeswar on Narmada River

3.1.5 Hoshangabad on Narmada River

Both DO and Temperature graphs showing almost similar trends with respect to time during all the days of study period from 24/10/2018 to 30/10/2018. Temperature lies between 22 ^{0}C and 31 ^{0}C during the study period. Maximum DO value observed was 7.2 mg/L (DO Saturation = 92.31%) on 26/10/2018 at 06:00 Hrs at temperature 22^{0}C and Minimum DO value observed was 5.9 mg/L (DO Saturation = 73.17%) on 27/10/2018 at 15:00 Hrs at temperature 31^{0}C. From the DO vs Time graphs it can be explain that, majority of the times DO value found within permissible limits for all classes of water except on 25/10/2018 at 15:00 Hrs (within for Class B, C and D). Further, by comparing temperature graph and DO saturation graphs it can be seen that DO concentration is increasing with Temperature during day time. This might be caused by the photosynthesis activities in river water. However, no clear relationship was seen between quantity of flow and DO saturation.

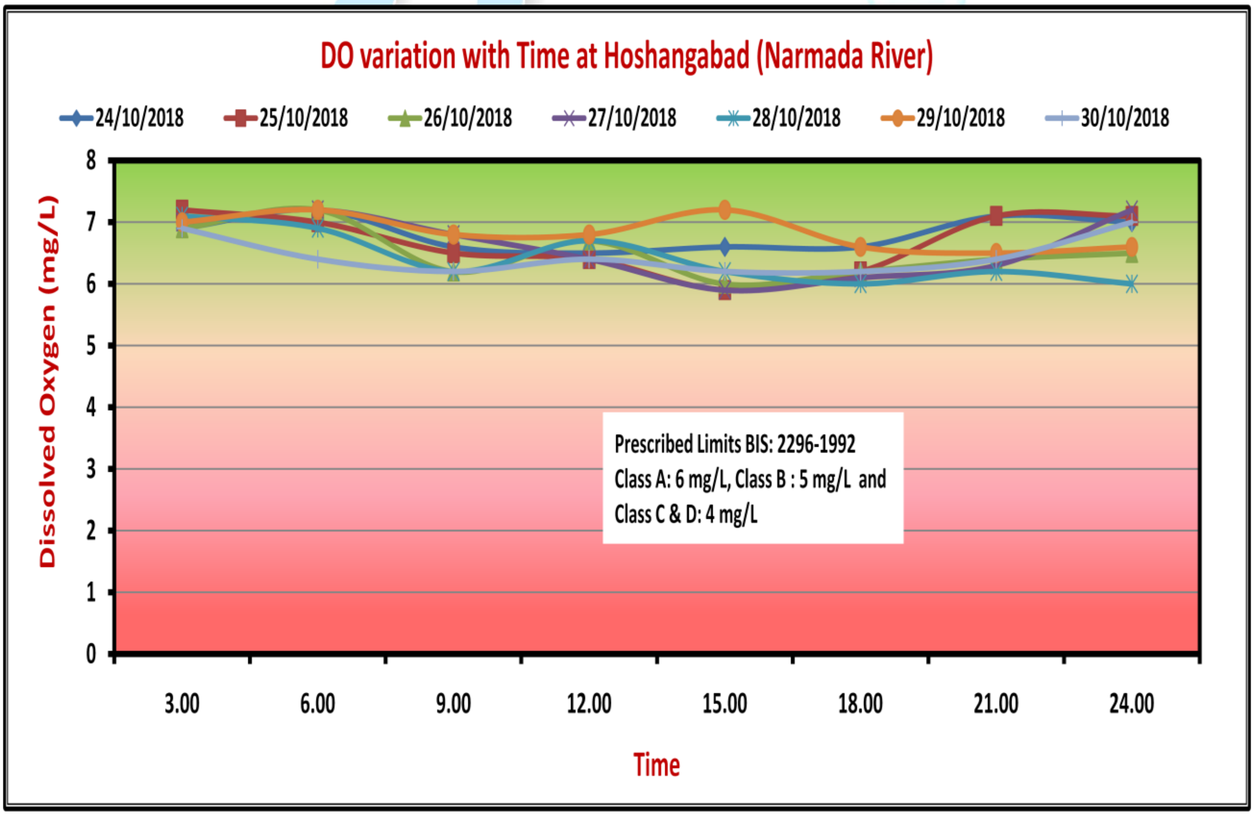


Figure 14: DO variation with Time at Hoshangabad on Narmada River

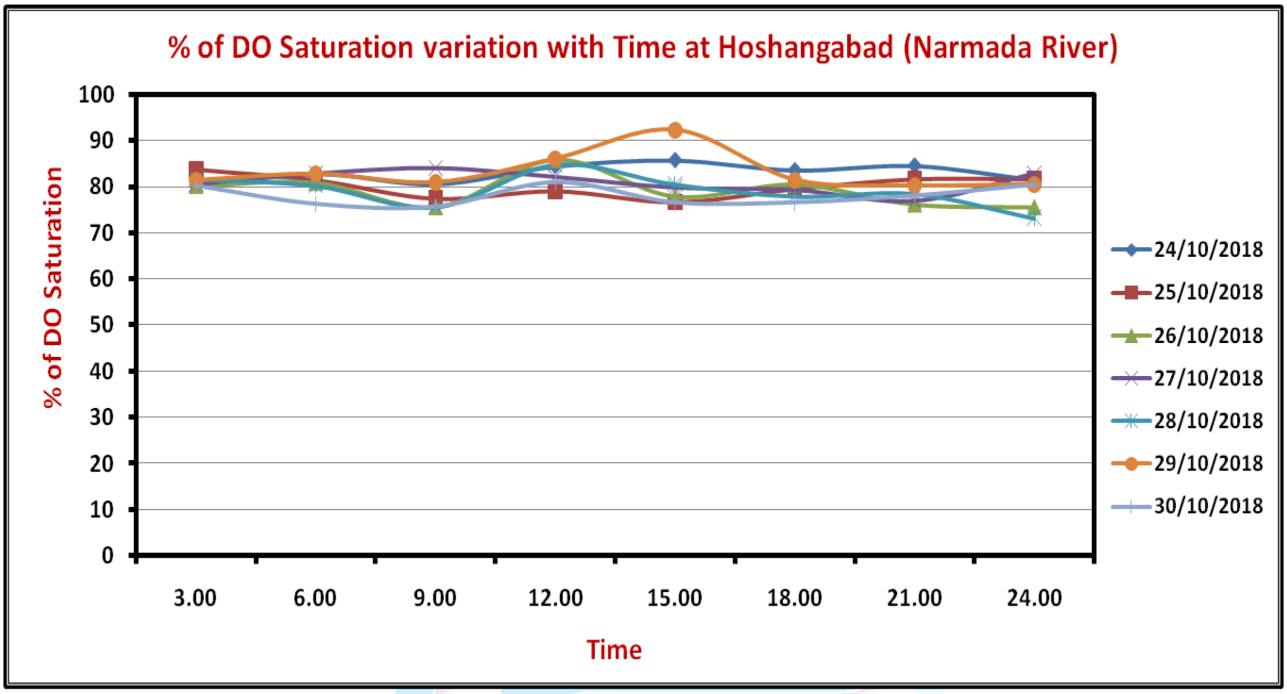


Figure 15: % of DO saturation variation with time at Hoshangabad on Narmada River

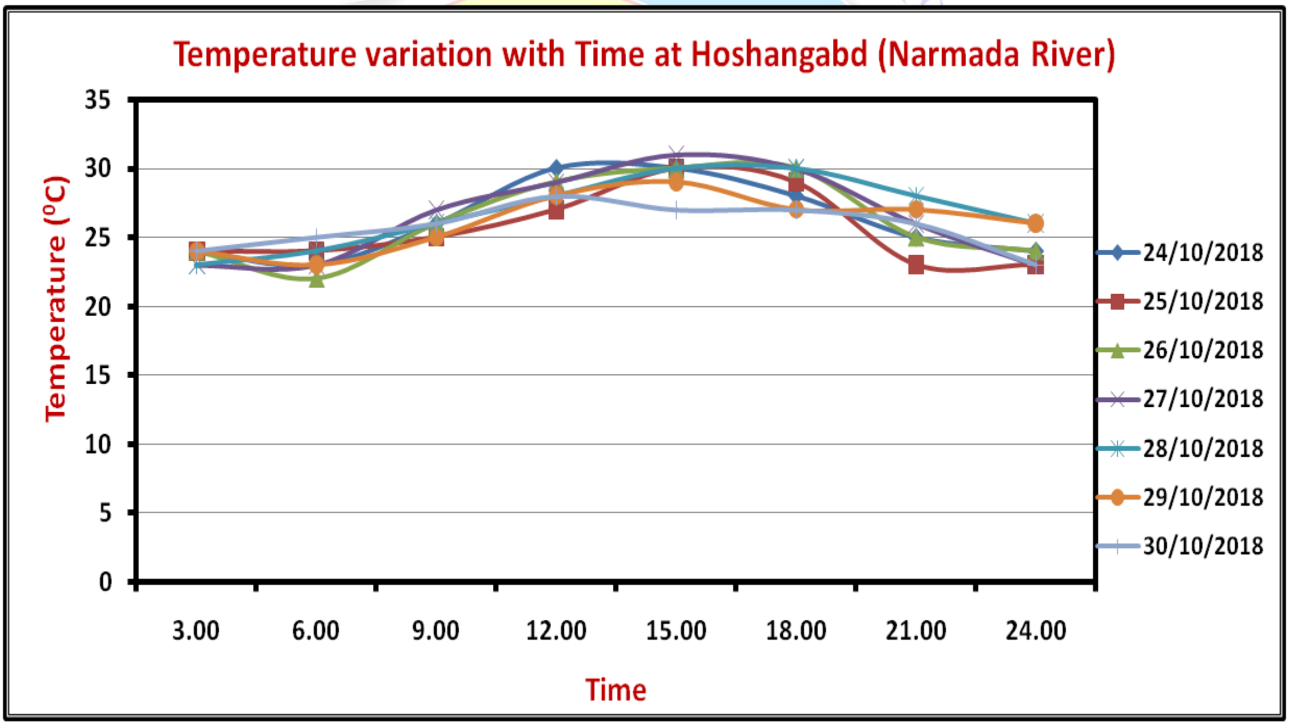


Figure 16: Temperature variation with time at Hoshangabad on Narmada River

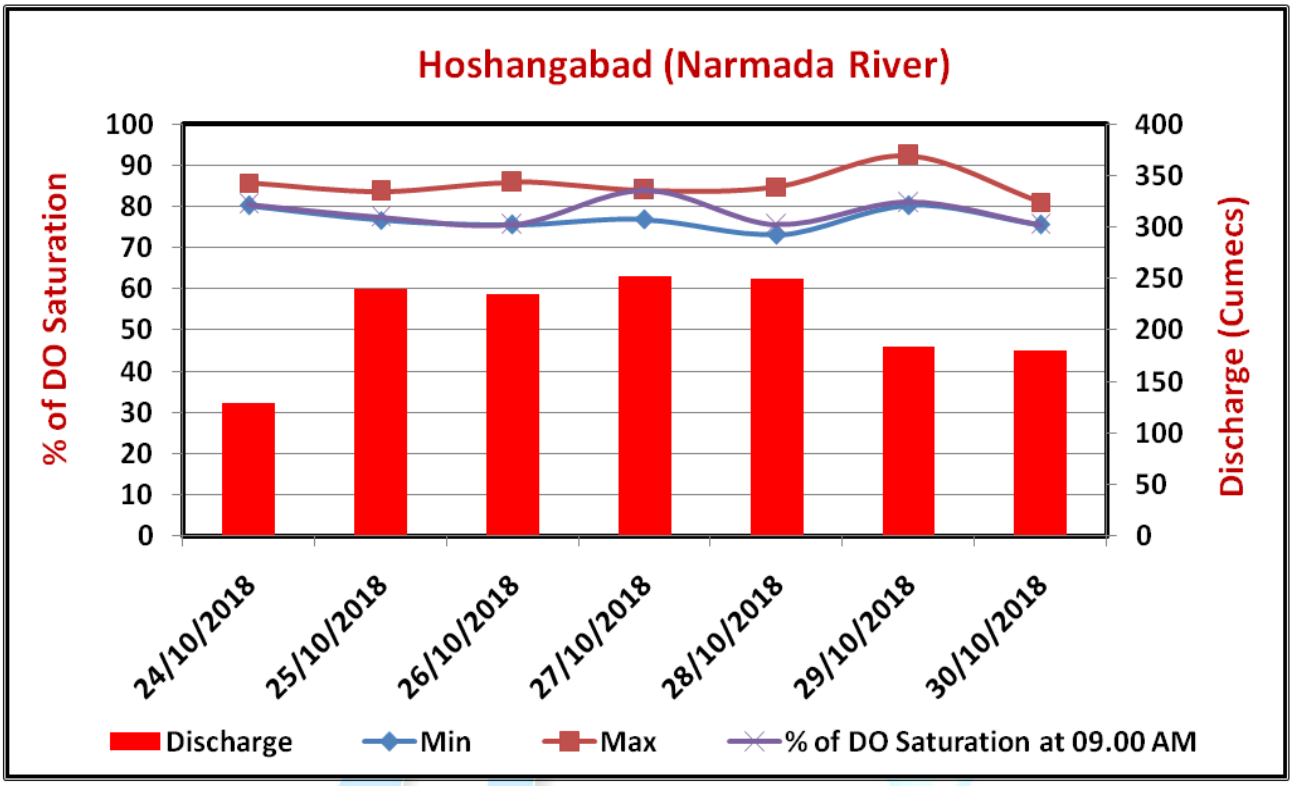


Figure 17: Relation between % of DO saturation and Discharge at Hoshangabad on Narmada River

3.1.6 Ambarampalayam on Aliyar River:

Both DO and Temperature graphs showing almost similar trends with respect to time during all the days of study period from 30/10/2018 to 06/11/2018. Temperature lies between 24 ^{0}C and 30 ^{0}C during the study period. Maximum DO value observed was 10.53 mg/L (DO Saturation = 133.28%) on 30/10/2018 at 13:00 Hrs at temperature 28 ^{0}C and Minimum DO value observed was 4.67 mg/L (DO Saturation = 56.96%) on 02/11/2018 at 04:00 Hrs at temperature 26 ^{0}C. From the DO vs Time graphs can be explain that, majority of the times DO value found within permissible limits for all classes of water except on 02/11/2018 at 04:00 (within for Class C & D). Further, Minimum DO values observed from 19:00 Hrs to 07:00 during study period, it might be caused by the cloudy climate conditions due to which consumption of oxygen dissolved in water takes place. By comparing temperature graph and DO saturation graph it can be see that DO concentration is increasing with Temperature during day time and from 16.00 hrs. DO saturation starting decreasing during night time. This phenomenon can be explained by photosynthesis activities of river water.

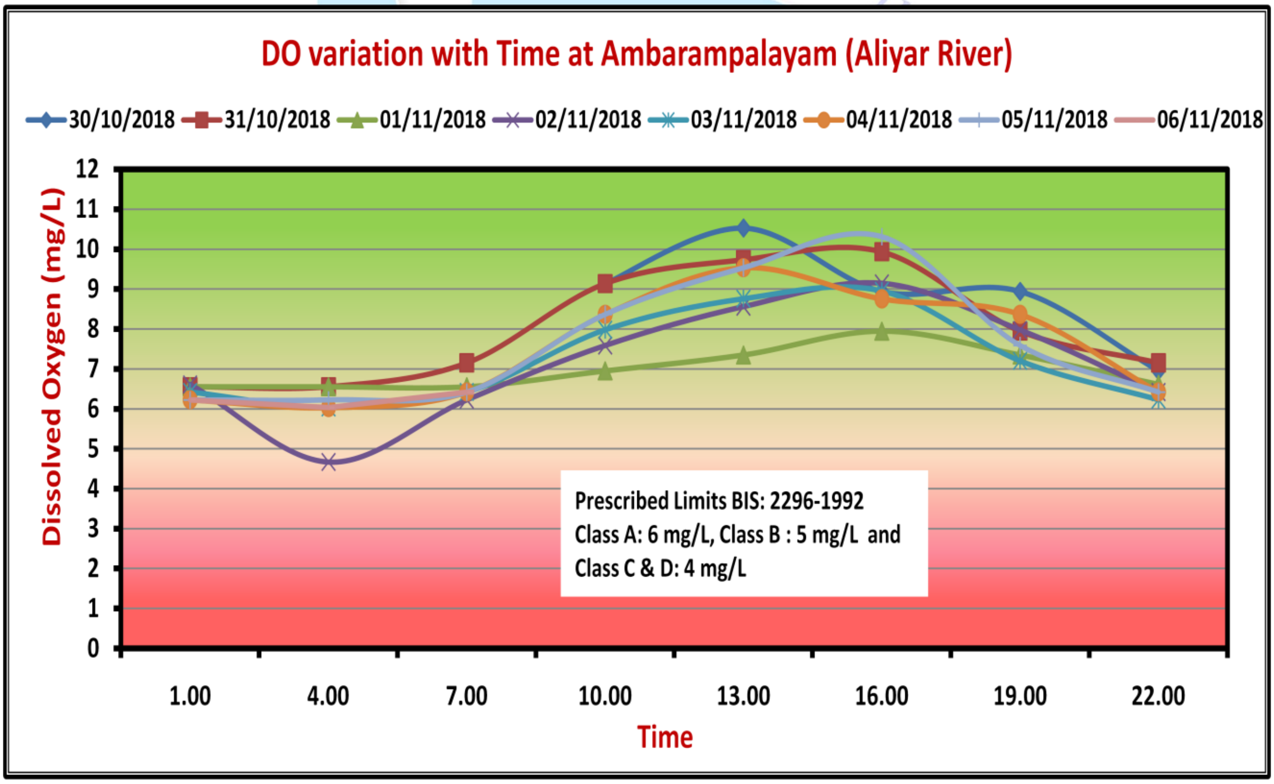


Figure 18: DO variation with Time at Ambarampalayam on Aliyar River

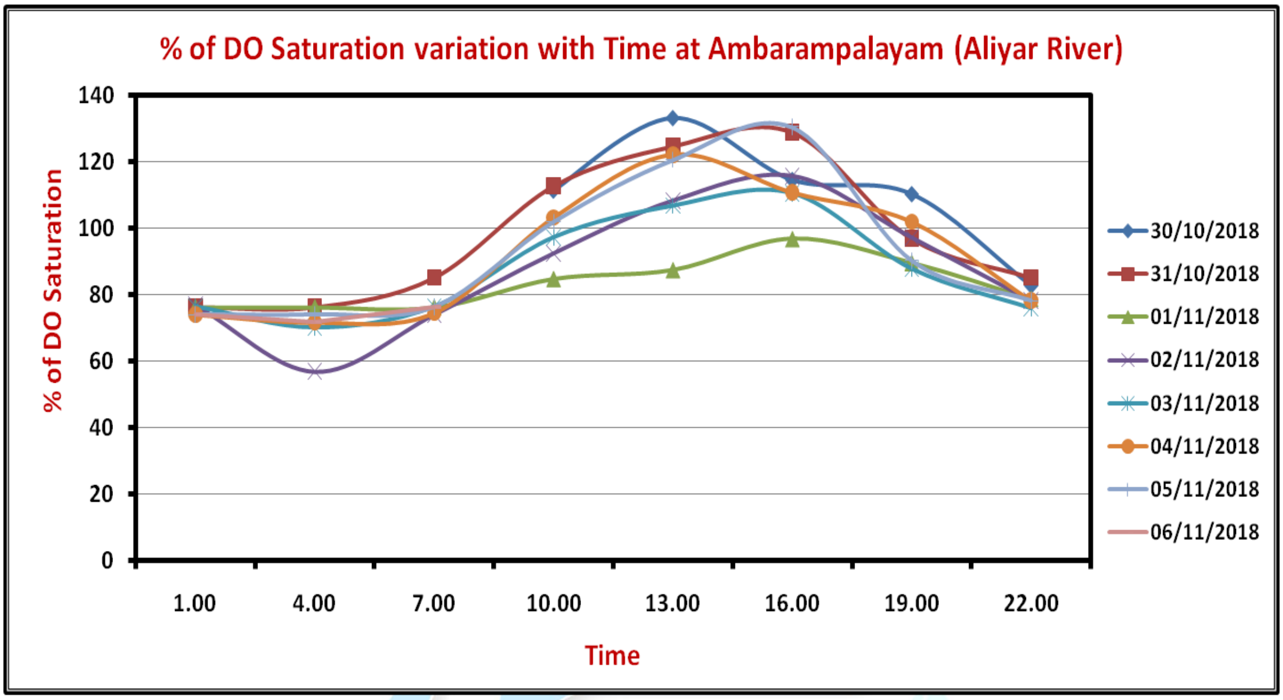


Figure 19: % of DO saturation variation with time at Ambarampalayam on Aliyar River

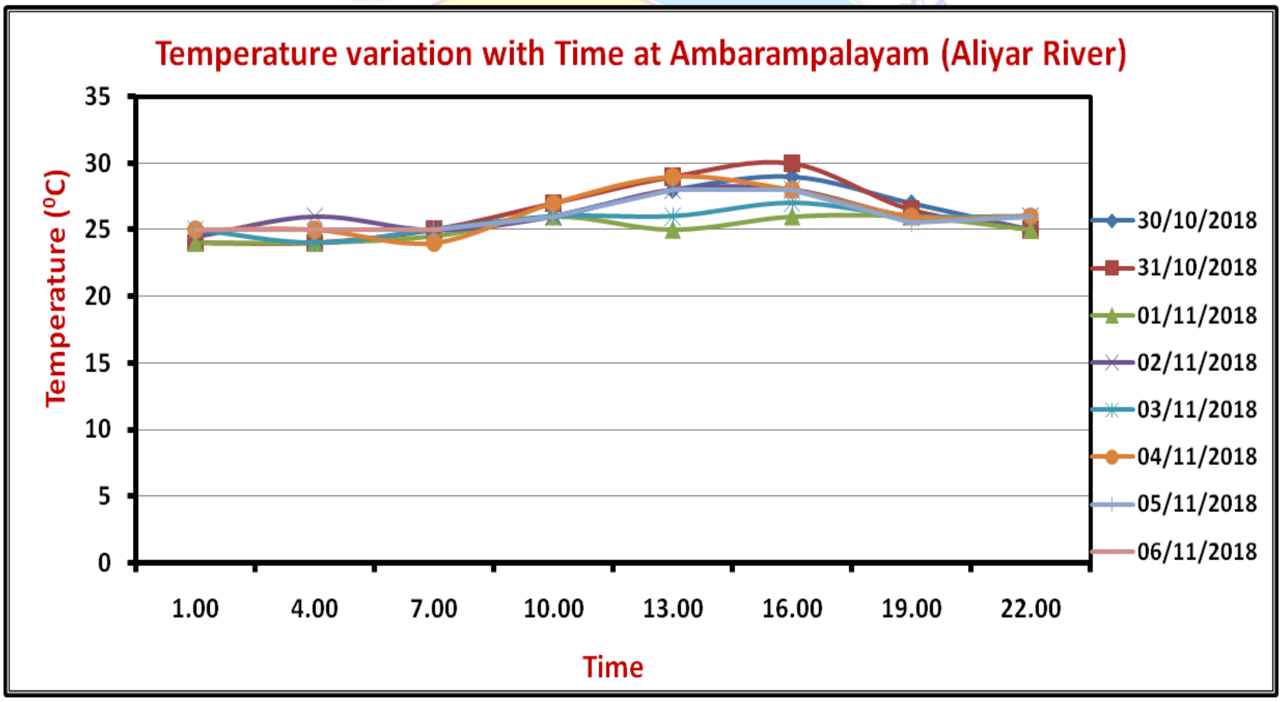


Figure 20: Temperature variation with time at Ambarampalayam on Aliyar River

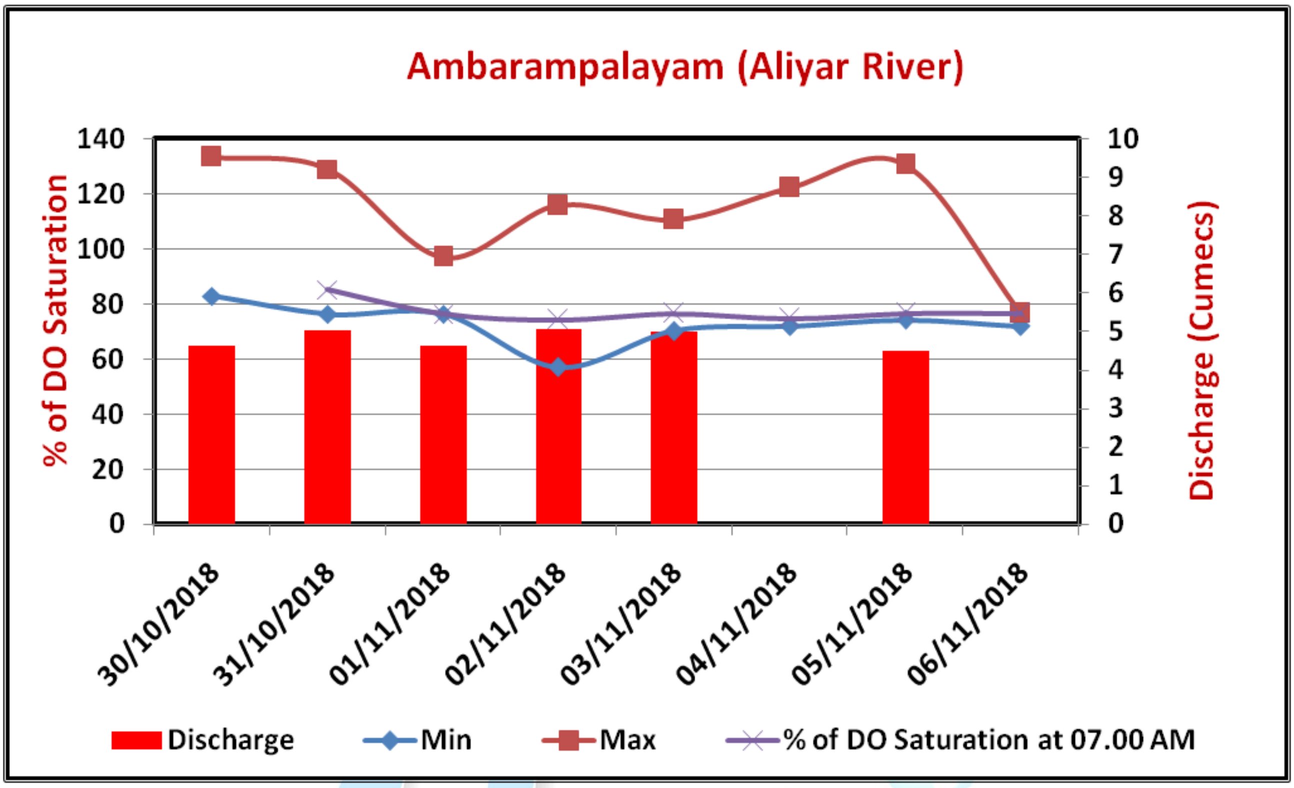


Figure 21: Relation between % of DO saturation and Discharge at Ambarampalayam on Aliyar River

GANGA RIVER:

The Ganga is the 20th longest river in the Asia and the 41st longest in the world (Source: Philips World Atlas). The headwaters region of Ganga is the Himalayas dotted by number of mighty tributaries. The Bhagirathi river that rises from the Gangotri glacier near Gomukh at an elevation of about 7,010 m above mean sea level in the Uttarkashi district of Uttarakhand is considered as the source of Ganga river. It descends down the valley up to Devprayag where after joining another hill stream Alaknanda, it is called Ganga. Flowing downhill, the river is joined by a number of streams, such as the Mandakini, the Dhuli Ganga and the Pindar. The principal tributaries joining the river from right are the Yamuna and the Son. The Ramganga, the Ghaghra, the Gandak, the Kosi and the Mahananda join the river from left. The total length of river Ganga (measured along the Bhagirathi and the Hooghly) up to its outfall into Bay of Bengal is 2,525 km with 631 km navigable length.

3.1.7 Varanasi on Ganga River:

Both DO and Temperature graphs following almost similar trends with respect to time during all the days of study period from 15/12/2018 to 22/12/2018. Temperature lies between 17.5 ^{0}C and 21 ^{0}C during the study period. Maximum DO value observed was 9.19 mg/L (DO saturation = 101.44%) on 21/12/2018 at 15:00 Hrs at temperature 20 ^{0}C and Minimum DO value observed was 6.18 mg/L (DO saturation = 64.38%) on 18/12/2018 at 03:00 Hrs at temperature 18.5 ^{0}C. From DO vs Time graphs, it can be explain that, DO concentrations found within the prescribed limits for all classes of water. From the DO saturation and Temperature graphs it can seen that DO saturation is increasing during day in all the days of study period. This relationship can be attributed to photosynthesis phenomenon in river water. However, no clear relationship was observed between quantity of flow and DO saturation.

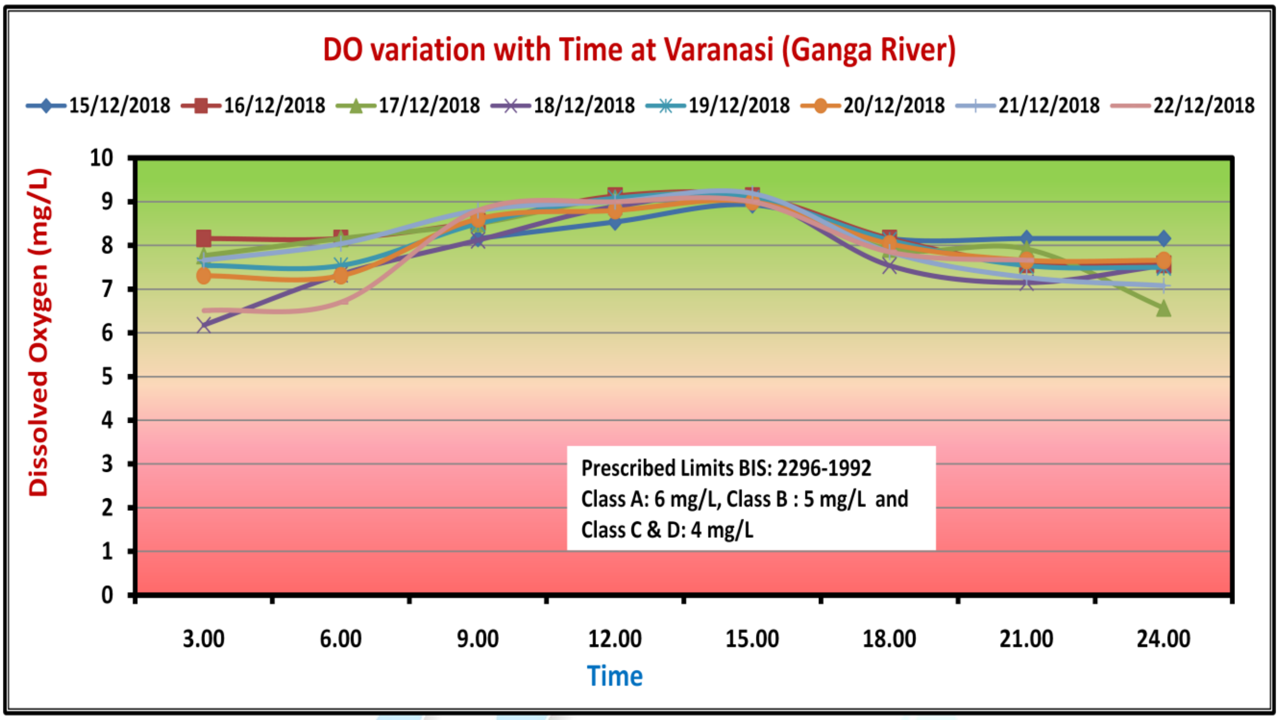


Figure 22: DO variation with Time at Varanasi on Ganga River

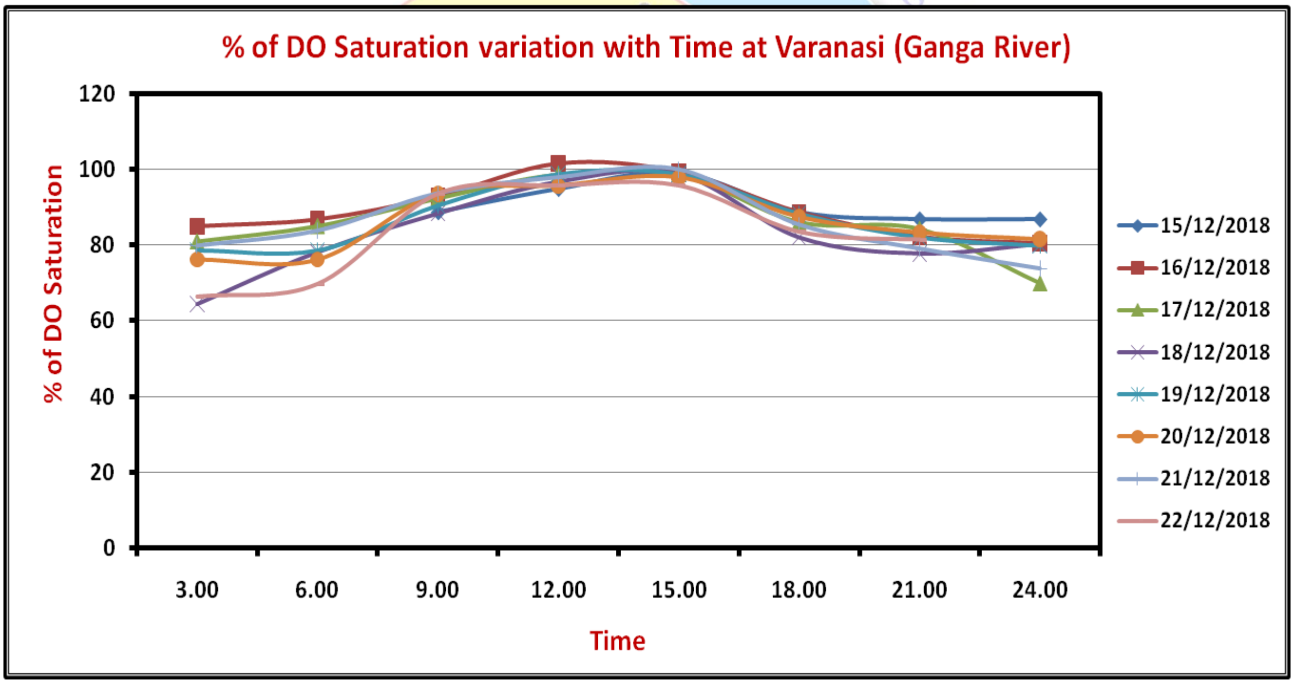


Figure 23: % of DO saturation variation with time at Varanasi on Ganga River

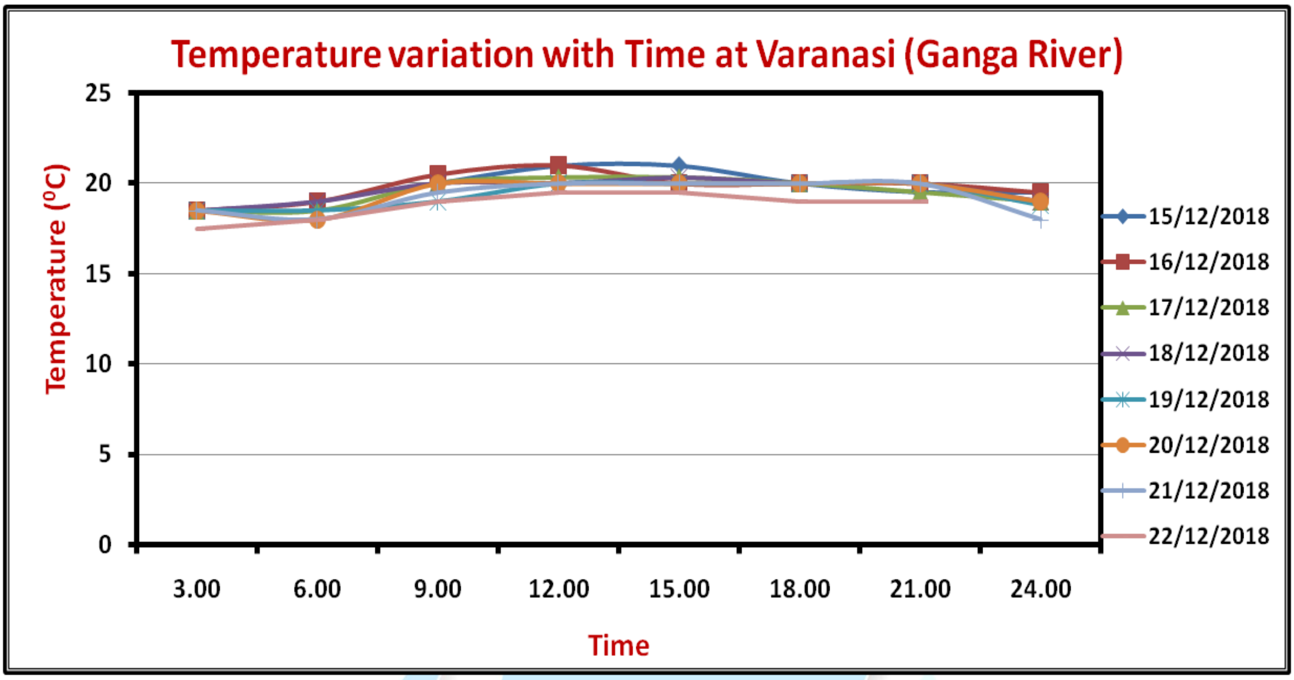


Figure 24: Temperature variation with time at Varanasi on Ganga River

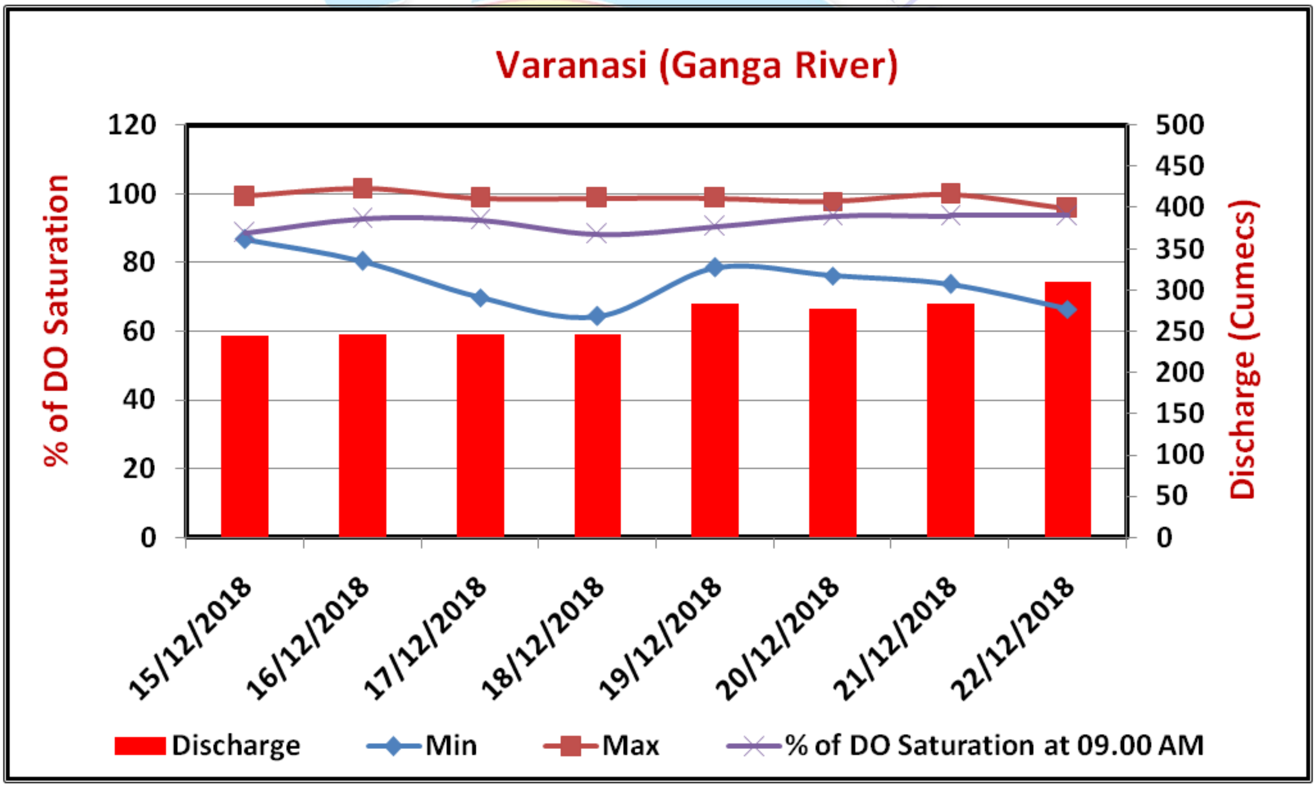


Figure 25: Relation between % of DO saturation and Discharge at Varanasi on Ganga River

3.1.8 Gandhighat on Ganga River:

Both DO and Temperature graphs showing almost similar trends with respect to time during all the days of study period from 29/10/2018 to 04/11/2018 except for temperature on 03/11/2018 which is showing decreasing trend approximately. Temperature lies between 26 ^{0}C and 29.5 ^{0}C during the study period. Maximum DO value observed was 7.95 mg/L (DO saturation = 100.63%) on 01/11/2018 at 08:00 Hrs at temperature 28.5 ^{0}C and Minimum DO value observed was 5.24 mg/L (DO saturation = 63.9%) on 04/11/2018 at 20:00 Hrs at temperature 27 ^{0}C. Majorly, from DO saturation and temperature graphs it can be explain that, from 08:00 Hrs to 17:00 Hrs, maximum DO saturation values were observed where there is a possibility to obtain higher temperatures and DO values corresponds to it found within permissible limit for all classes of water. And in early morning and night times where probability to obtain lesser temperatures is more, minimum DO saturation values found and its corresponding DO values observed below the permissible limit for Class A water which are within to Class B, C and D waters. However, no clear relationship was extracted between quantity of flow and DO saturation.

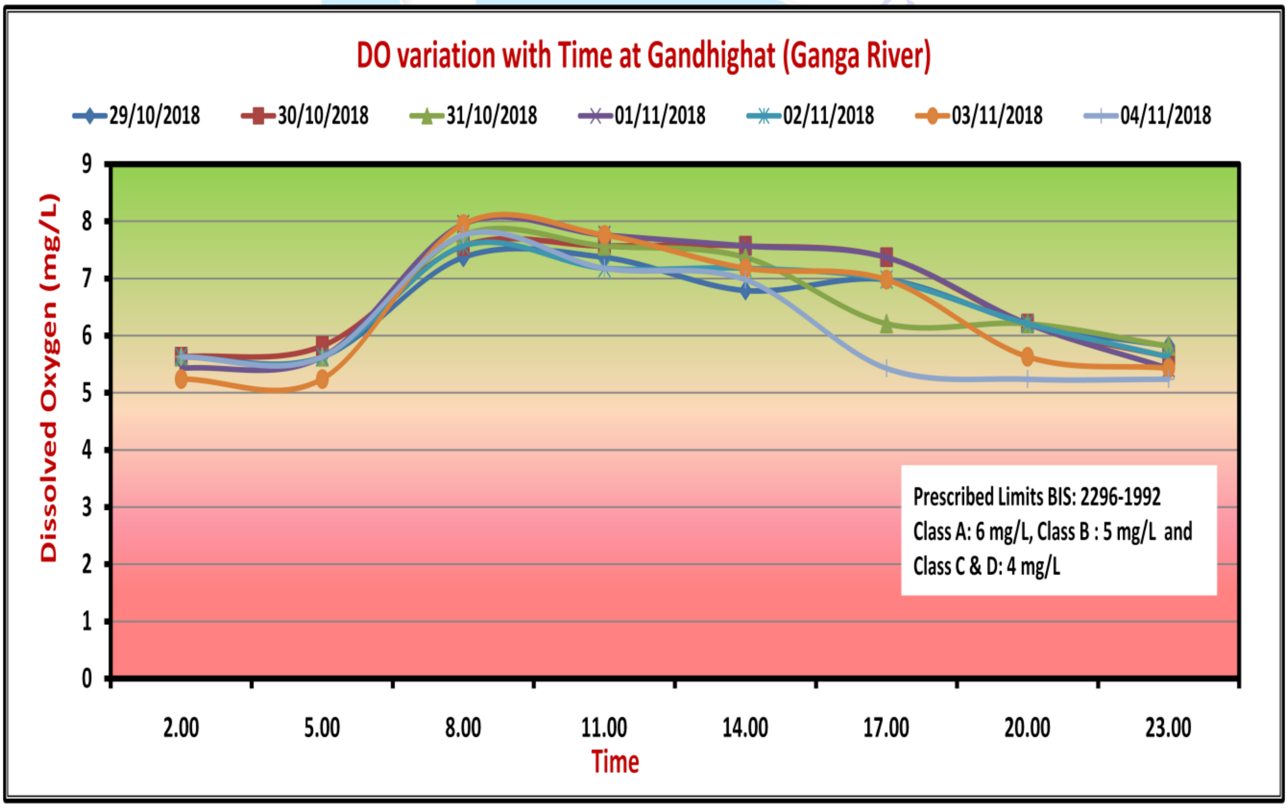


Figure 26: DO variation with Time at Gandhighat on Ganga River

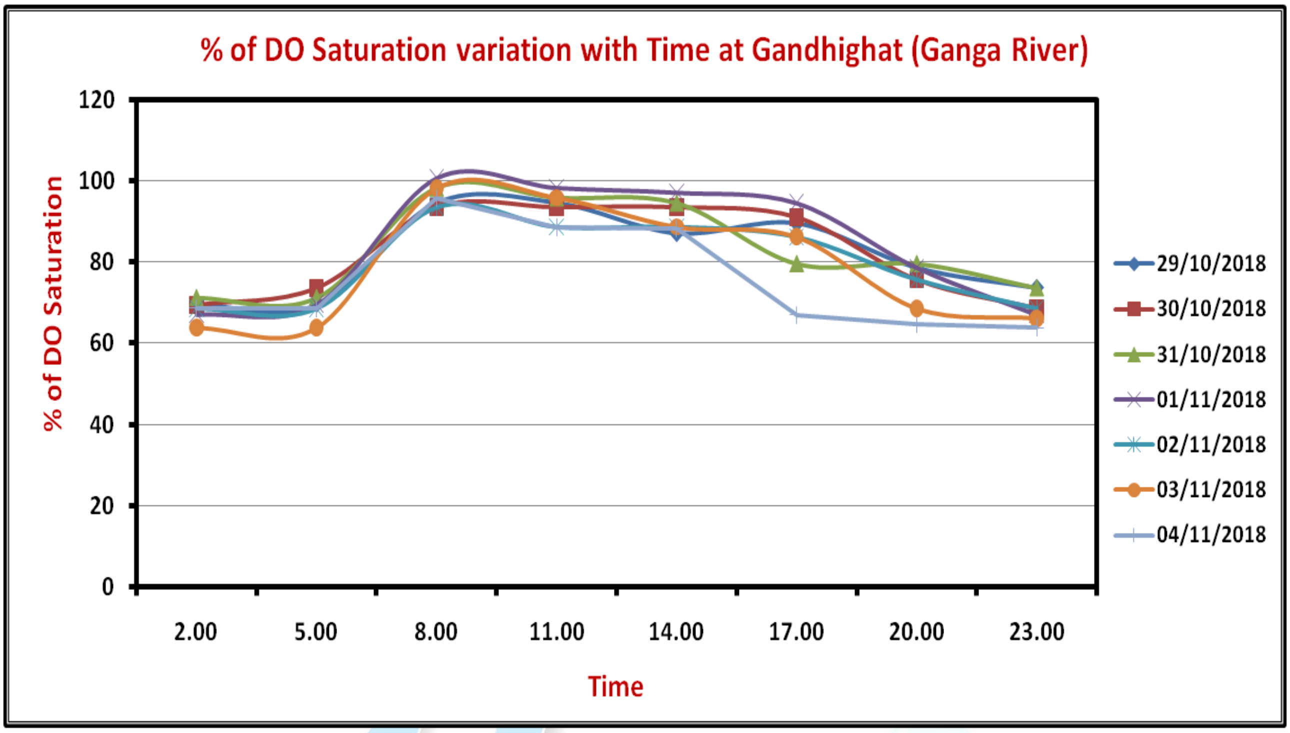


Figure 27: % of DO saturation variation with time at Gandhighat on Ganga River

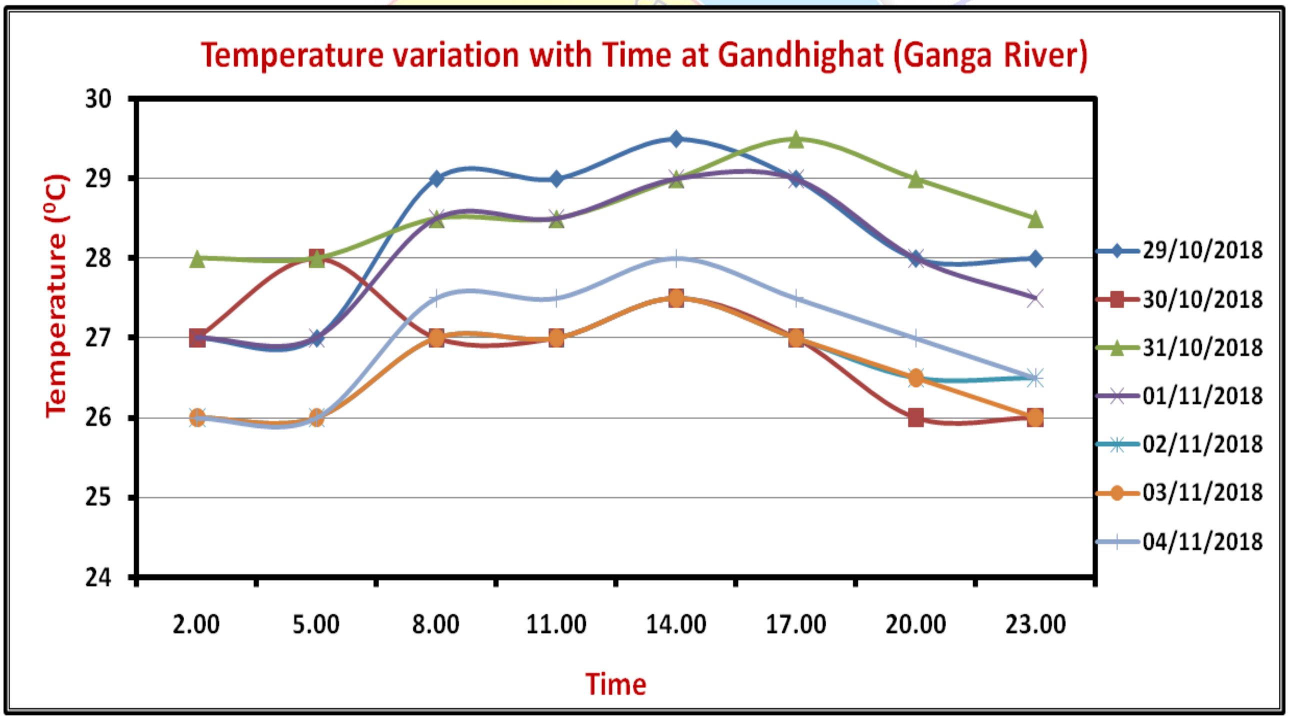


Figure 28: Temperature variation with time at Gandhighat on Ganga River

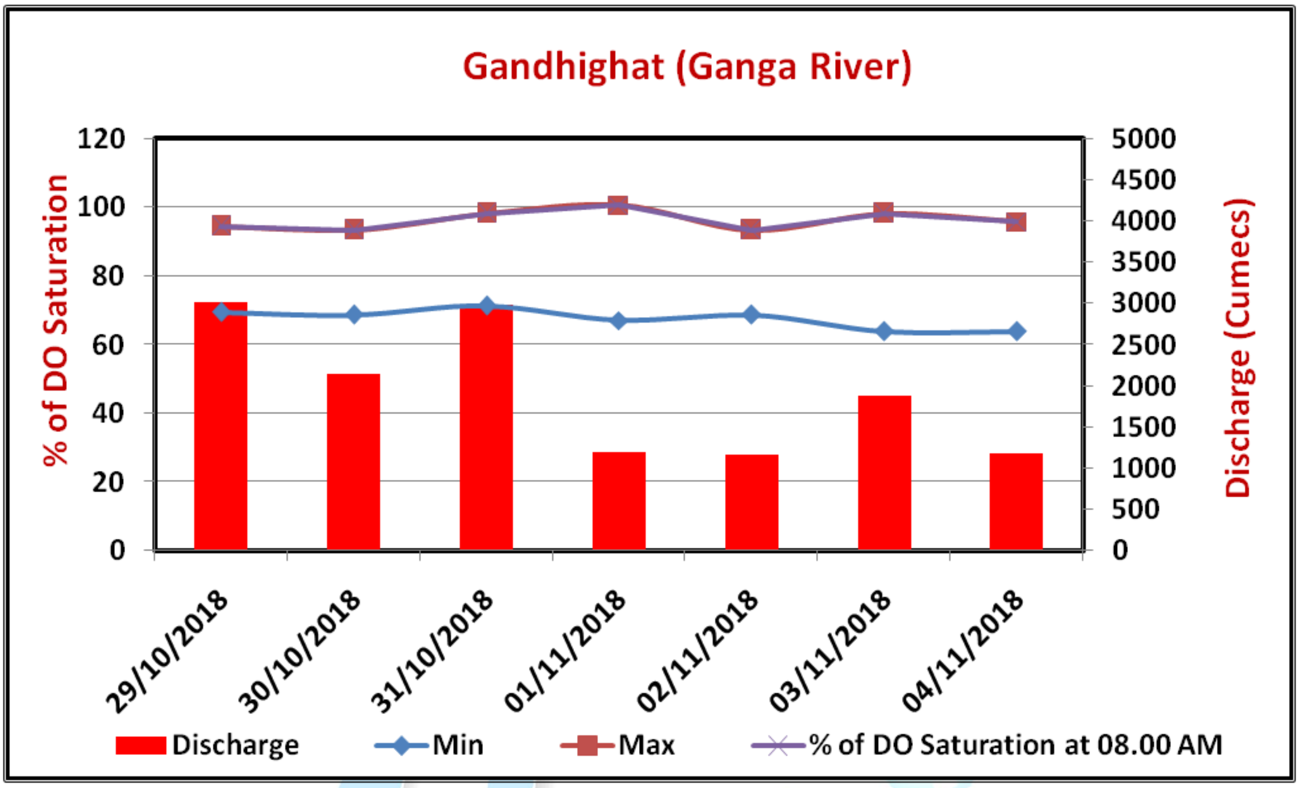


Figure 29: Relation between % of DO saturation and Discharge at Gandhighat on Ganga River

BRAHMANI RIVER:

The Brahmani River is the second largest river in the state of Odisha. In fact, two headwater streams, namely Sankh River and South Koel River originates in Chhattisgarh and Jharkhand states, respectively. After the confluence of Sankh River and South Koel River at Vedvyas, the combined river is known by the name Brahmani. The Brahmani River flows through the heart of Odisha till it joins the Bay of Bengal at Dhamara mouth. After the confluence at Vedvyas, the Brahmani River heads towards the southeast direction and traverses a total length 461 km before it joins the Bay of Bengal. It drains a total catchment area 39,269km^2.

3.1.9 Jenapur on Brahmani River:

DO graph showing almost similar trends with respect to time during all the days of study period from 18/12/2018 to 24/12/2018 except for 19/12/2018 and 23/12/2018. Maximum DO value observed was 9.8 mg/L on 23/12/2018 at 15:00 Hrs and Minimum DO value observed was 7.2 mg/L on 18/12/2018 at 18:00 Hrs. From the DO vs Time graphs it can be explain that, DO value found within permissible limits for all classes of water.

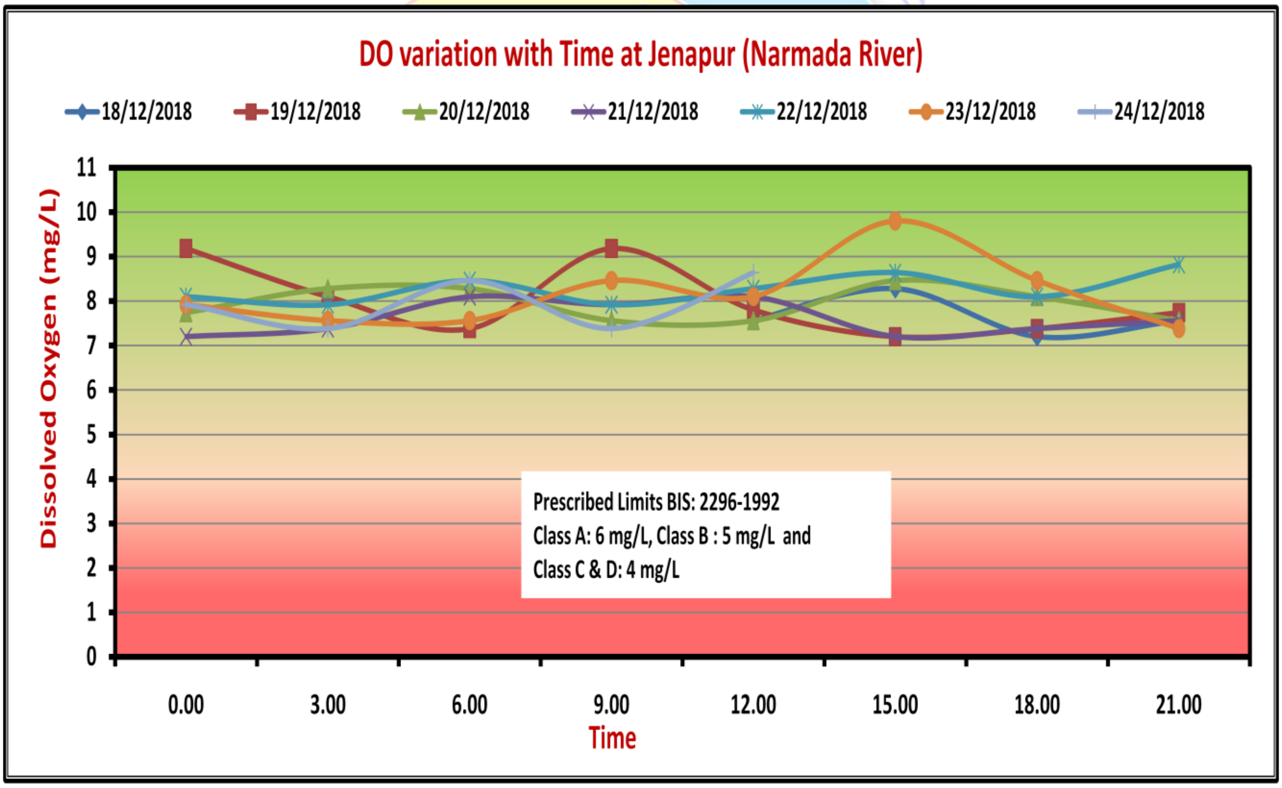


Figure 30: DO variation with Time at Jenapur on Brahmani River

MAHI RIVER

Mahi River originates on the northern slope of Vindhyas at latitude 22°- 35 N and longitude 74°-58 E near the village of Sardarpur in the Dhar district of Madhya Pradesh at an elevation of 500 m above MSL. Its length is 583 kms and traverses through the states of Madhya Pradesh, Rajasthan and Gujarat. The Mahi River drains an area of 34,842 km^2. Initially the River flows towards north passing through Dhar and Jhabua districts of Madhya Pradesh State, and then turns left and passes through the Ratlam district of Madhya Pradesh State. There after the river turns to north-west and enters in the Banswara district of Rajasthan and flows in south-western direction and finally enters in the Panchmahal district of the Gujarat State. The River continuously flows in the same direction through Kheda district of Gujarat and finally falls into the Mahi Sagar in the Gulf of Khambhat in the Arabian Sea.

3.1.10 Khanpur on Mahi River:

Both DO and Temperature graphs showing almost similar trends with respect to time during all the days of study period from 03/12/2018 to 09/12/2018. Temperature lies between 20 ^{0}C and 24 ^{0}C during the study period. Maximum DO value observed was 9.2 mg/L (DO saturation = 106.98%) on 03/12/2018 at 13:00 Hrs at temperature 24 ^{0}C and Minimum DO value observed was 7.0 mg/L (DO saturation = 77.78%) on 03/12/2018 at 19:00 Hrs at temperature 21 ^{0}C. From the DO vs Time graphs it can be explain that, DO values found within permissible limits for all classes of water. By comparing DO saturation and temperature graphs it can be seen that DO saturation is increasing with temperature during day time. This relationship can be attributed to photosynthesis activities in river water.

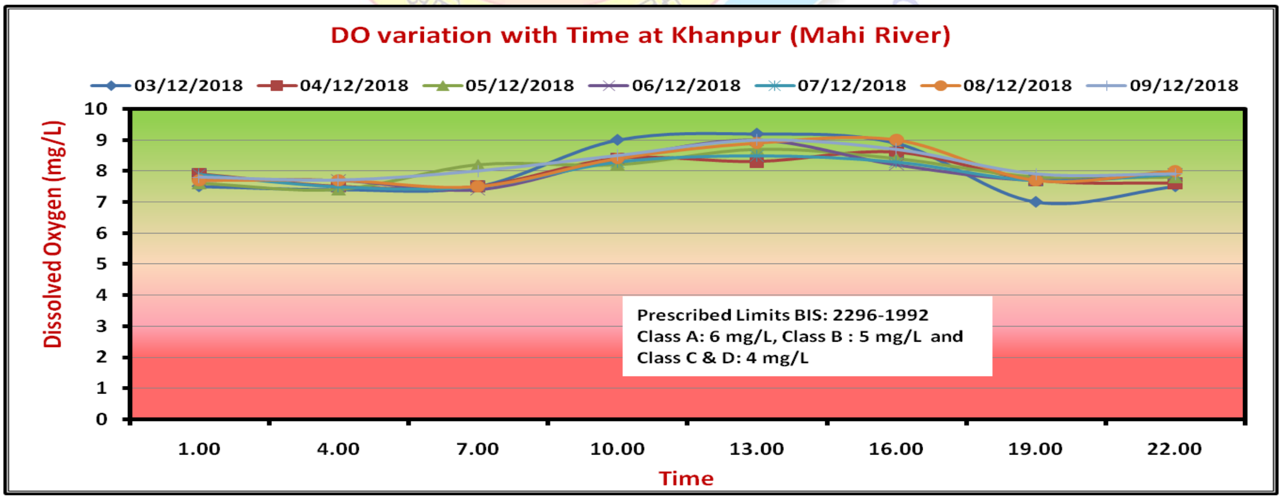


Figure 31: DO variation with Time at Khanpur on Mahi River

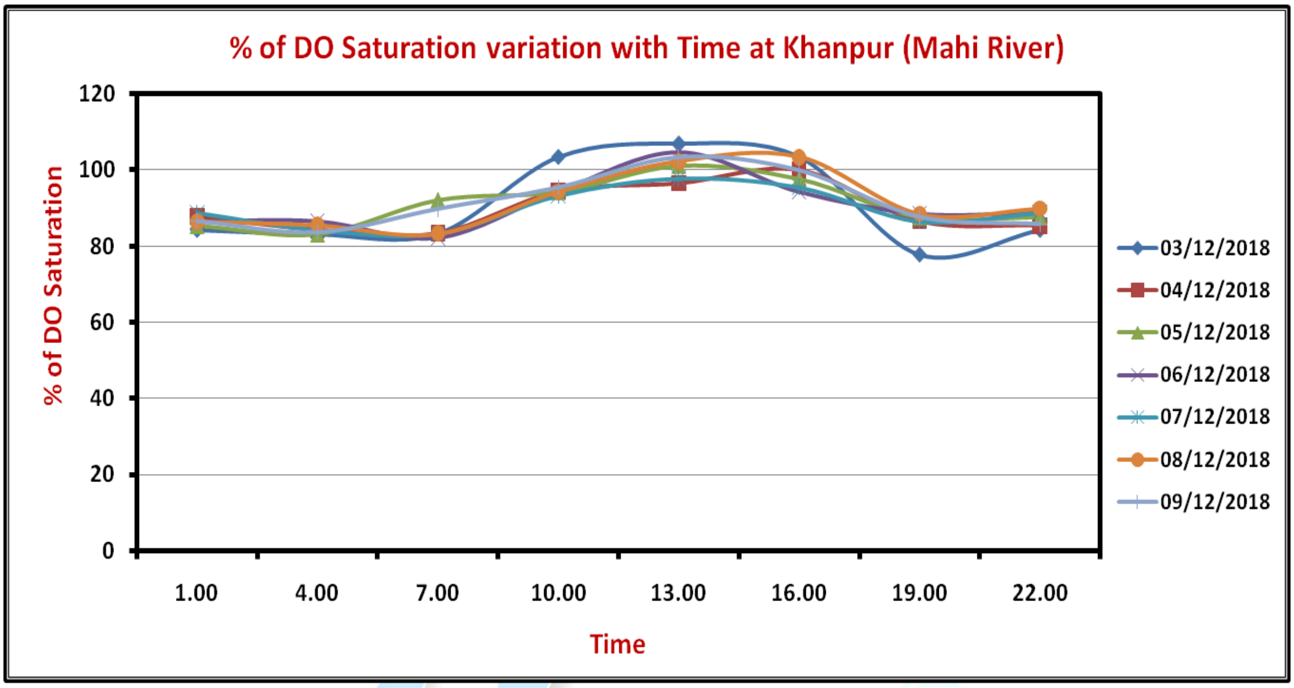


Figure 32: % of DO saturation variation with time at Khanpur on Mahi River

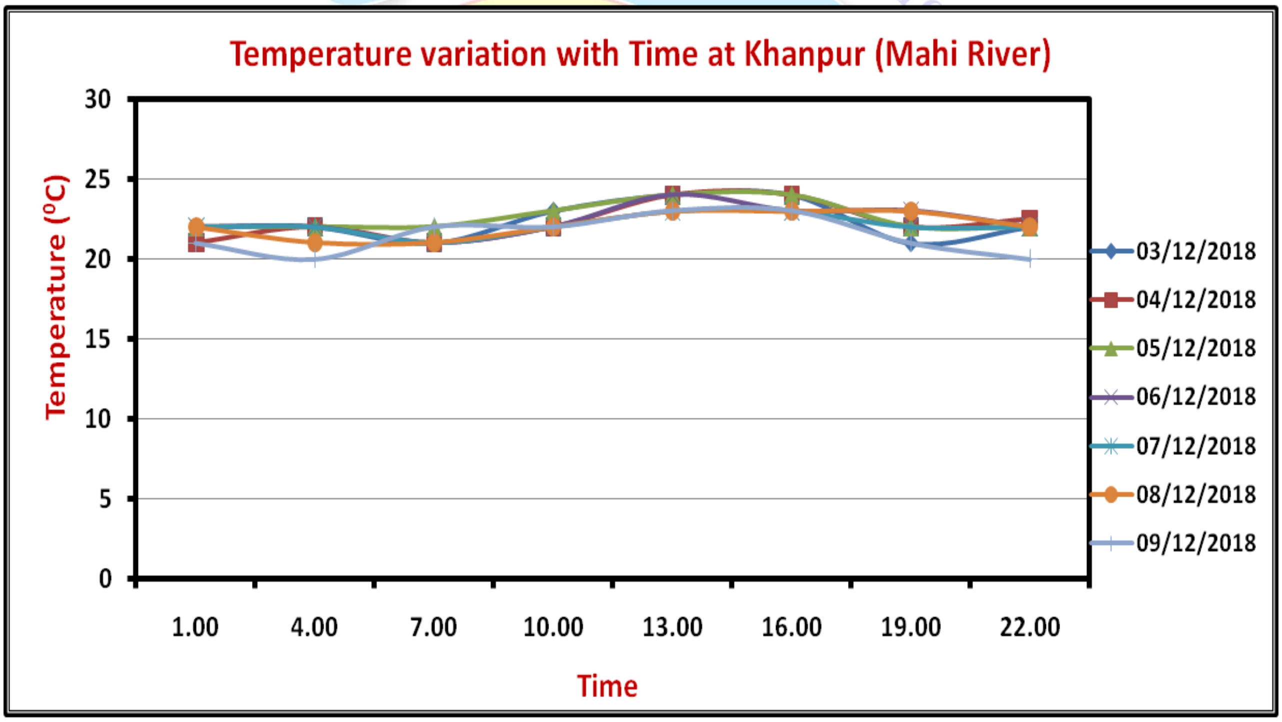


Figure 33: Temperature variation with time at Khanpur on Mahi River

BHAGIRATH RIVER

The Bhagirath is a turbulent Himalayan river in the state of Uttarakhand and one of the two headstreams of the Ganges, the major river of Northern India and the holy river of Hinduism. In Hindu mythology and culture, the Bhagirath is considered the source stream of the Ganges. However, in hydrology, the other headstream, Alaknanda, is considered the source stream on account of its great length and discharge.

The headwaters of the Bhagirath are formed at Gaumukh (elevation 3,892 metres (12,769 ft)), at the foot of the Gangotri glacier and Khatling glaciers in the Garhwal Himalaya. It is then joined by its tributaries; these are, in order from the source:

- Kedar Ganga at Gangotri (elevation 3,049 m (10,003 ft)),
- Jadh Ganga at Bhaironghati (elevation 2,650 m (8,690 ft)),
- Kakora Gad and Jalandhari Gad near Harsil (elevation 2,745 m (9,006 ft)),
- Siyan Gad near Jhala (elevation 2,575 m (8,448 ft)),
- Asi Ganganear Uttarkashi (elevation 1,158 m (3,799 ft)),
- Bhilangna River near Old Tehri (elevation 755 m (2,477 ft)).

The Bhilangna itself rises at the foot of the Khatling Glacier (elevation 3,717 m (12,195 ft)) approximately 50 km (31 mi) south of Gaumukh. The river flows from its source for 205 km (127 mi) before meeting the Alaknanda River at an elevation of 475 m (1,558 ft) in the town of Deoprayag. Downstream of this confluence, considered holy by Hindus, the river is known as the Ganga Ji, or Ganges River by westerners.

3.1.11 Koteswar on Bhagirath River:

Both DO and Temperature graphs showing almost similar trends with respect to time during all the days of study period from 01/11/2018 to 08/11/2018. Temperature lies between 16 ^{0}C and 17.8 ^{0}C during the study period. From the Temperature vs Time graphs, it can understand that, there is no notable change in temperatures observed in all the times. Maximum DO value observed was 8.55 mg/L (DO saturation = 87.24%) on 05/11/2018 at 06:00 Hrs at temperature 16.1 ^{0}C and Minimum DO value observed was 6.84 mg/L (DO saturation = 69.8%) on 02/11/2018 at 15:00 Hrs at temperature 17.8 ^{0}C. It can be explained from DO vs Time graphs that, DO values found within permissible limits for all classes of water. Further, no clear relationship was attained between quantity of flow and DO saturation.

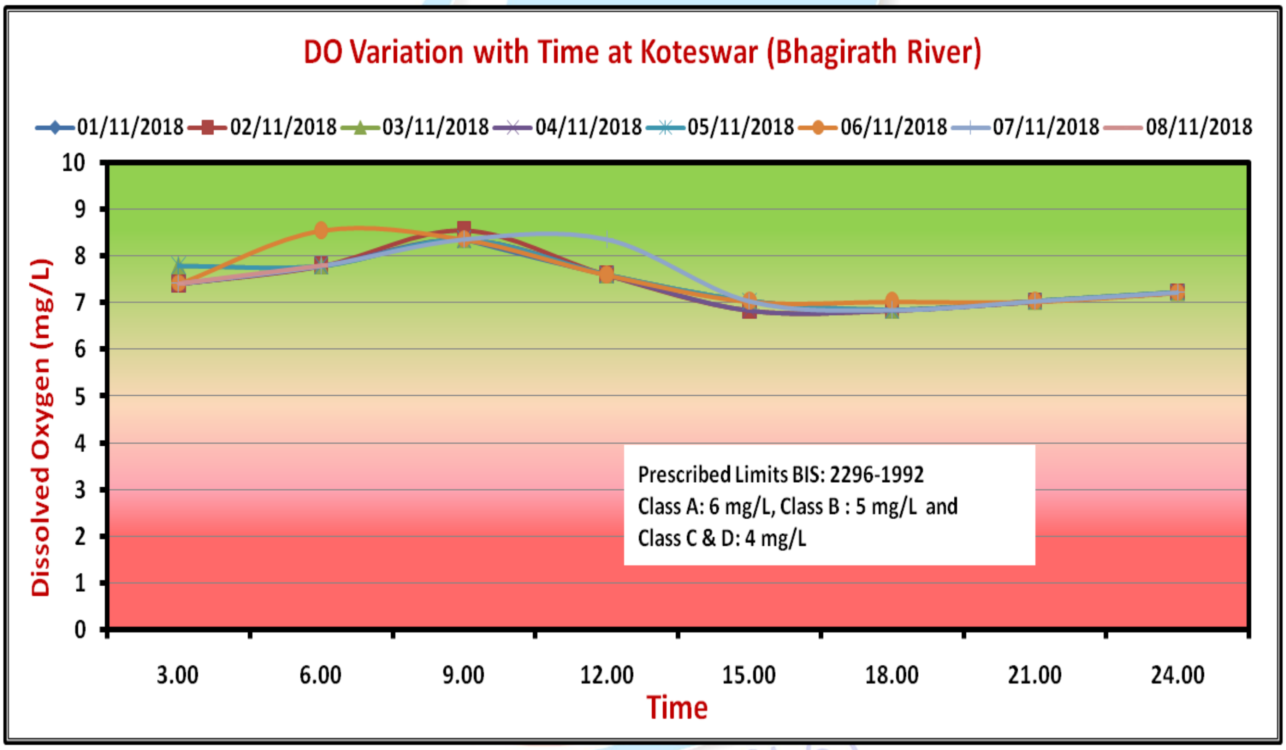


Figure 34: DO variation with Time at Koteswar on Bhagirath River

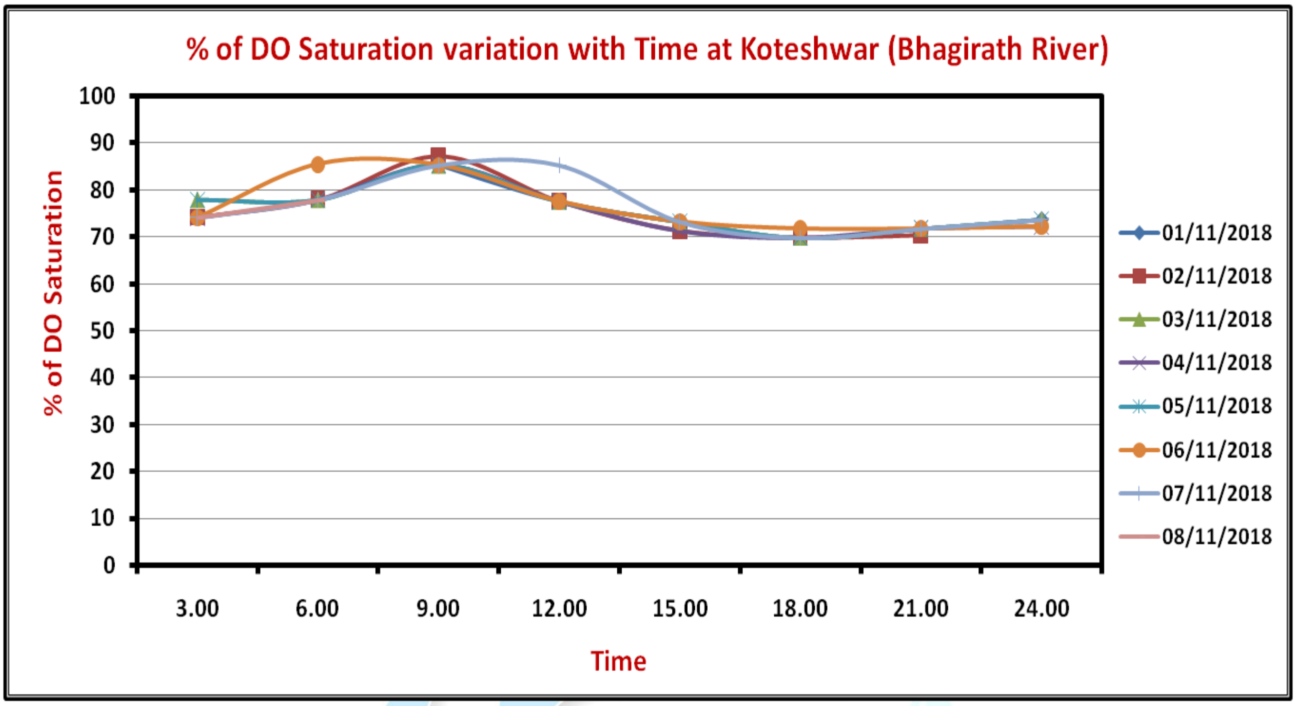


Figure 35: % of DO saturation variation with time at Koteswar on Bhagirath River

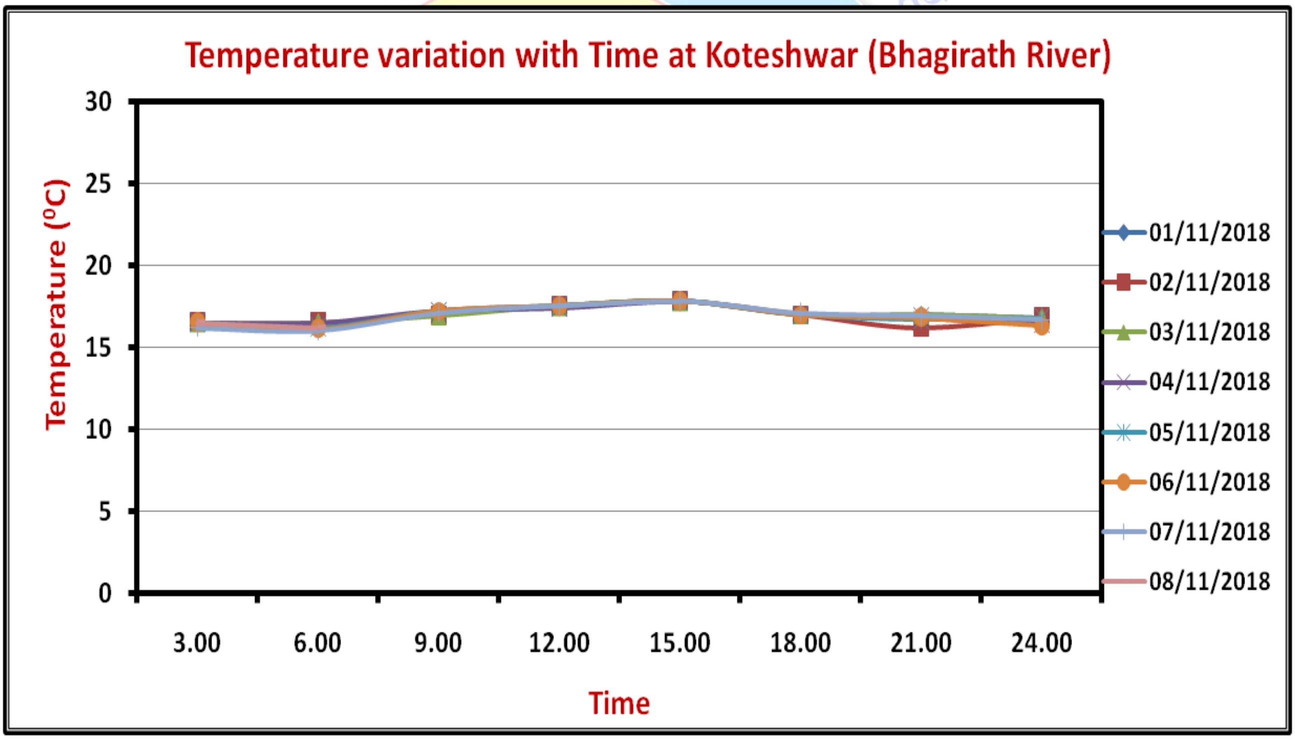


Figure 36: Temperature variation with time at Koteswar on Bhagirath River

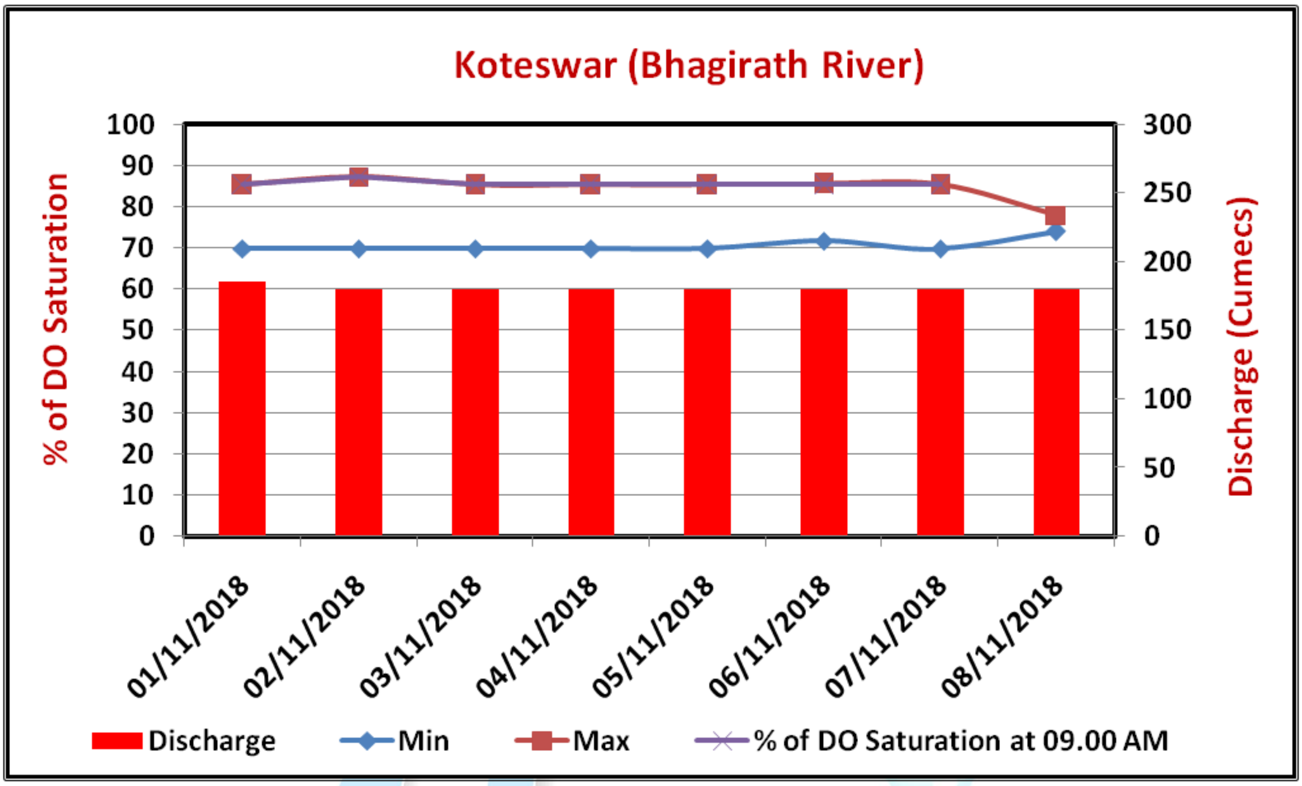


Figure 37: Relation between % of DO saturation and Discharge at Koteswar on Bhagirath River

TUNGABHADRA RIVER:

Tungabhadra River is formed from the union of the two rivers, namely Tunga and Bhadra, which together rise in Varahagiri in the Western Ghats of Karnataka State at an altitude of about 1,196m. The two rivers confluence at a village called Kudali near Shimoga. The united Tungabhadra River flows for about 531 km in a generally northeasterly direction, through Mysore and Andhra Pradesh and joins the Krishna at an elevation of about 264 m beyond Kurnool. The length of the river is 786 km. The important tributaries of the Tungabhadra River are the Varada, the Hagari, the Vedavati, and the Kumudvati. The total drainage area of the Tungabhadra is 71,417 km^2.

3.1.12 Mantrayalayam on Tungabhadra River:

Mantrayalayam is a pilgrim village located in Kurnool district in Andhra Pradesh. It lies on the banks of the Tungabhadra River on the border with neighboring Karnataka state. The village is known for the brindavan of Raghavendra Swami, a saint who lived in 17^{th} Century and who entered into a samadhi alive in front of his disciples. Thousands of people visit the Raghavendra Matth and temples which are located on the banks of Tungabhadra River.

The DO monitoring was done during the festival season of Karthika month when large people gather on the banks of Tungabhadra river to take dip in holy water.

Both DO and Temperature graphs showing almost similar trends with respect to time during all the days of study period from 17/11/2018 to 24/11/2018. Temperature lies between 25 ^{0}C and 30 ^{0}C during the study period. Maximum DO value observed was 9.6 mg/L (DO saturation = 121.82%) on 18/11/2018 at 14:00 Hrs at temperature 28 ^{0}C and Minimum DO value 5.2 mg/L (DO saturation = 66.67%) on 20/11/2018 at 14:00 Hrs at temperature 29 ^{0}C. From DO saturation vs Time graphs it can be explain that, DO concentration in the early morning times between 02:00 Hrs and 08:00 Hrs found lesser values when comparing with other times in the day. Maximum DO saturation was observed at 14:00 Hrs in all the days except for 18/11/2018 and 19/11/2018. During the time where there is a probability to obtain high temperatures is more i.e. between 11:00 Hrs and 17:00 Hrs showing increasing trend in DO saturation and followed by decreasing trend. This might be explained by photosynthesis phenomenon occurs in river water. However, no clear relationship was seen between quantity of flow and DO saturation.

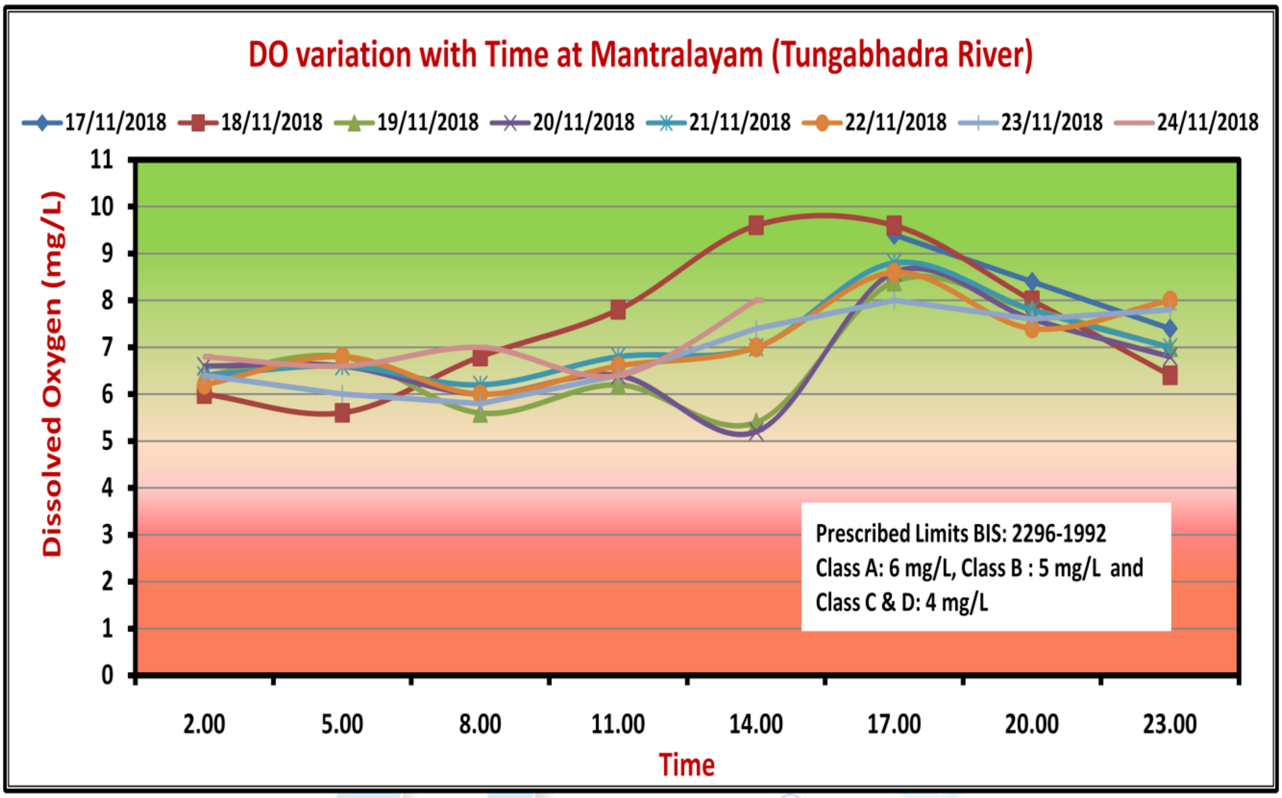


Figure 38: DO variation with Time at Mantralayam on Tungabhadra River

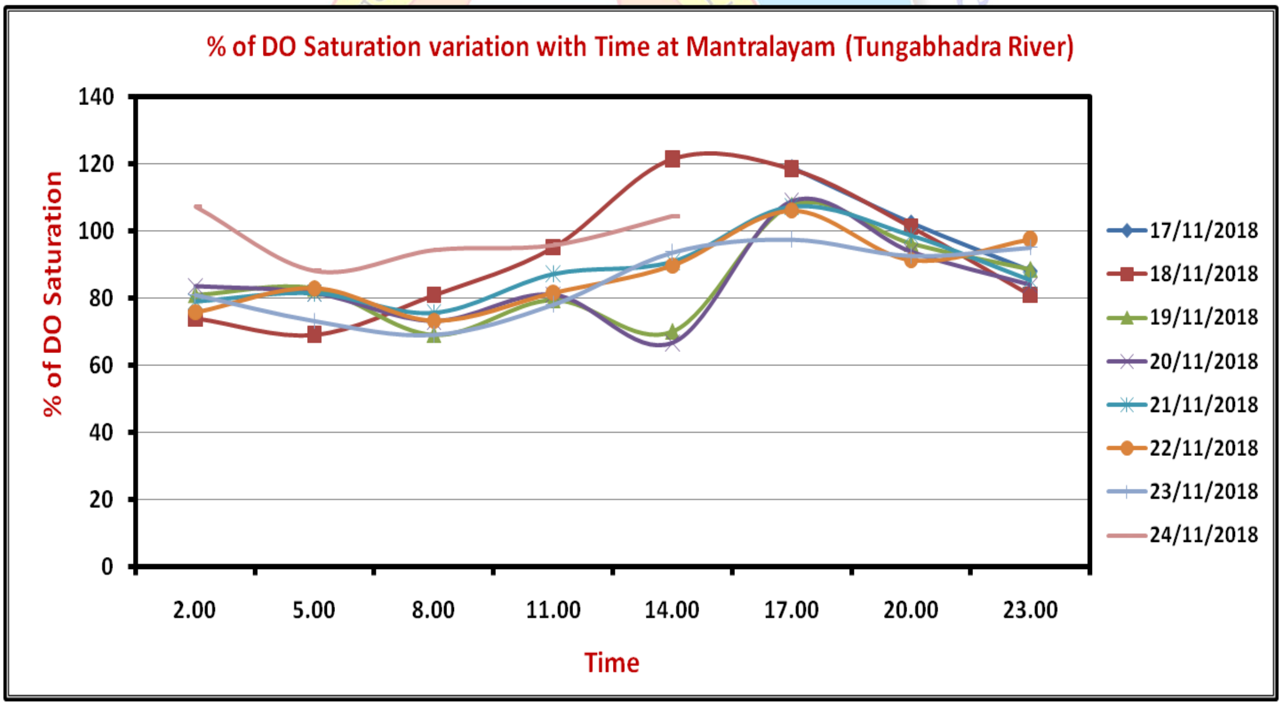


Figure 39: % of DO saturation variation with time at Mantralayam on Tungabhadra River

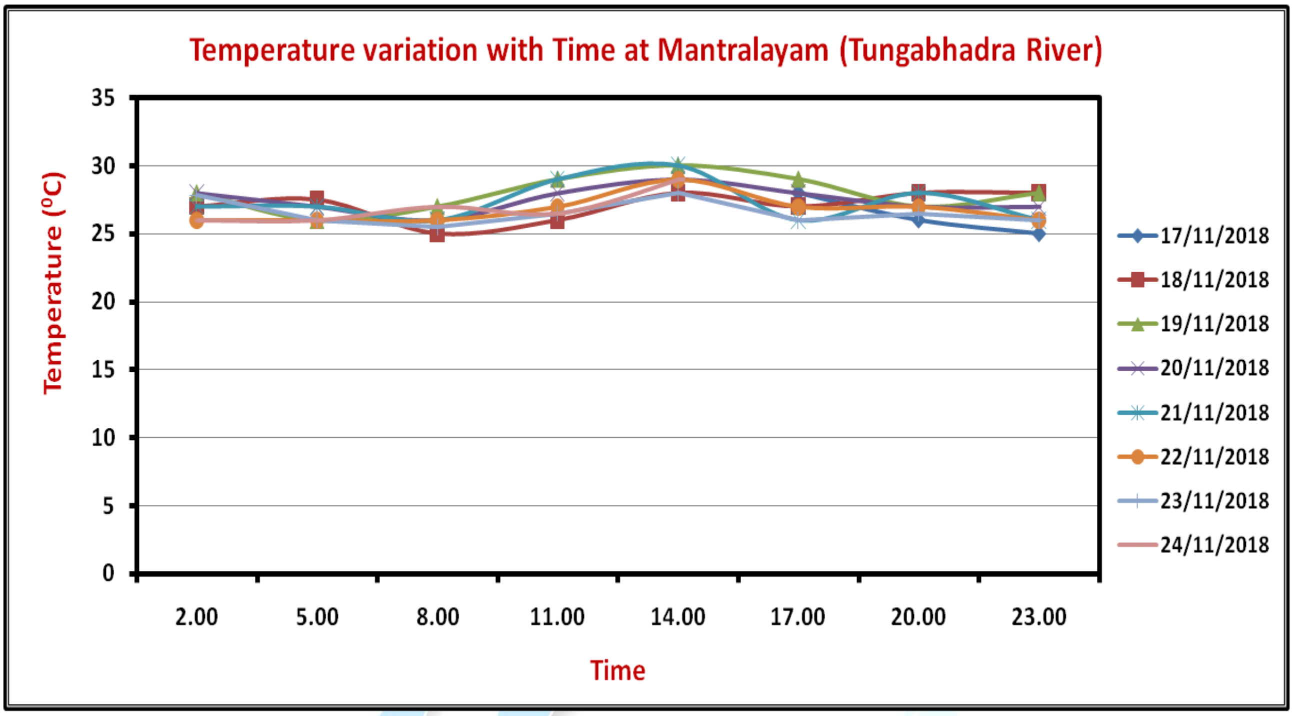


Figure 40: Temperature variation with time at Mantralayam on Tungabhadra River

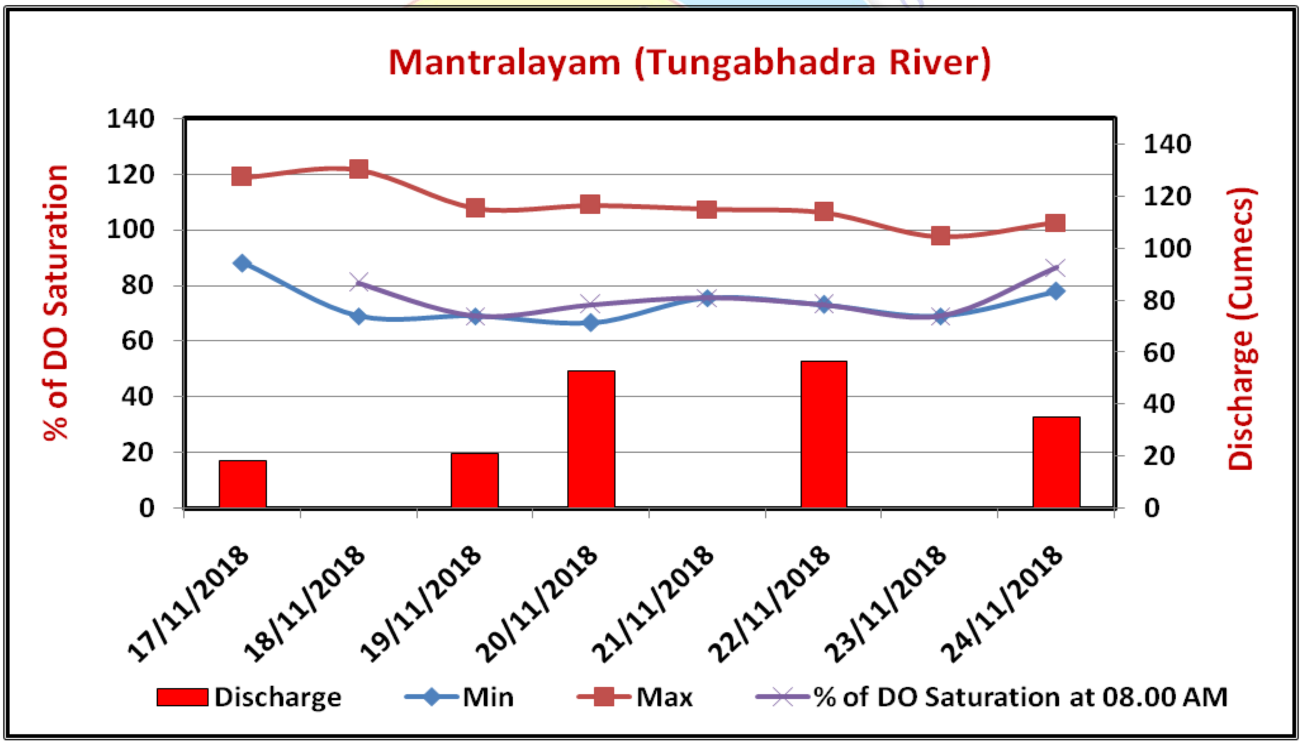


Figure 41: Relation between % of DO saturation and Discharge at Mantralayam on Tungabhadra River

BRAHMAPUTRA RIVER

The Brahmaputra River originates in the north from Kailash ranges of Himalayas at an elevation of 5,150 m just south of the lake called Konggyu Tsho and flows for about a total length of 2,900 km. In India, it flows for 916 km. The principal tributaries of the river joining from right are the Lohit, the Dibang, the Subansiri, the Jiabharali, the Dhansiri, the Manas, the Torsa, the Sankosh and the Teesta whereas the Buridehing, the Desang, the Dikhow, the Dhansiri and the Kopili joins it from left.

3.1.13 Pandu on Brahmaputra River:

Both DO and Temperature graphs following almost similar trends with respect to time during all the days of study period from 22/10/2018 to 29/10/2018. Temperature lies between 23.1 ^{0}C and 27.2 ^{0}C during the study period. Maximum DO value observed was 10.92 mg/L (DO saturation = 130.98%) on 23/10/2018 at 05:30 Hrs at temperature 24.1 ^{0}C and Minimum DO value observed was 7.23 mg/L (DO saturation = 86.07%) on 22/10/2018 at 20:30 Hrs at temperature 25.5 ^{0}C. From DO vs Time graphs it can be explain that, DO concentrations found within prescribed limits for all classes of water. It can be seen from Temperature vs time graphs, there is no considerable change in temperatures observed in all the times during study period.

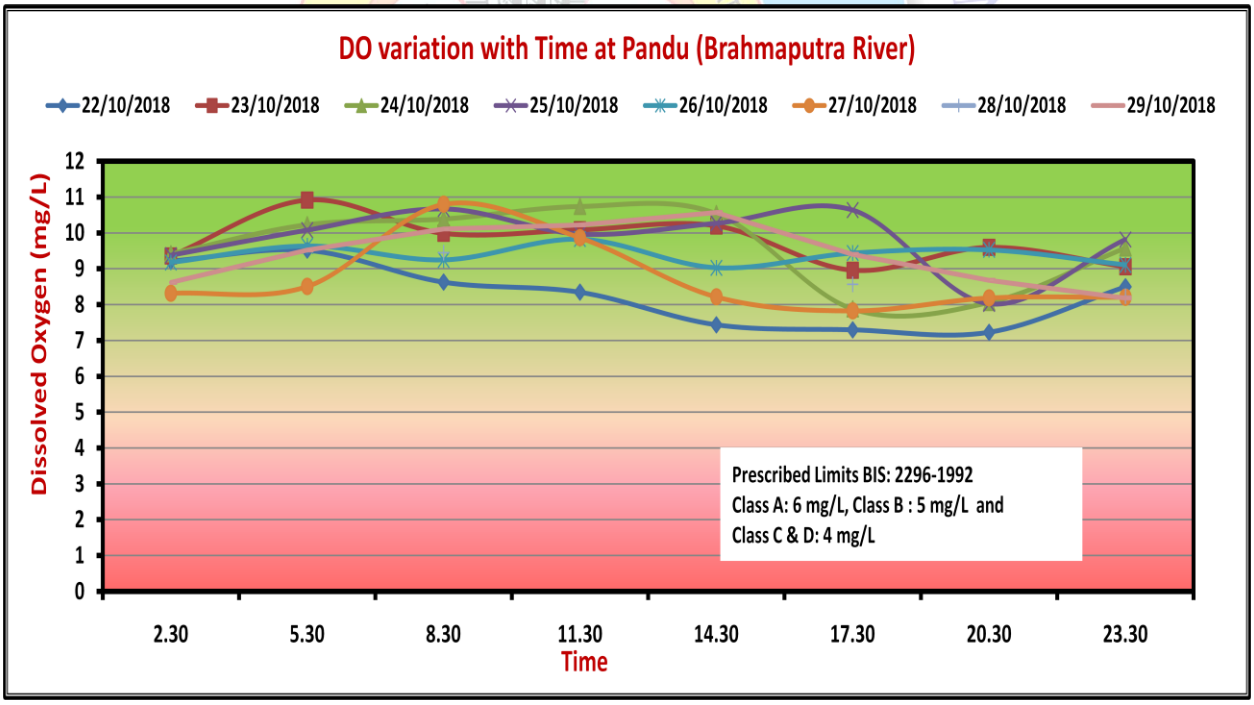


Figure 42: DO variation with Time at Pandu on Brahmaputra River

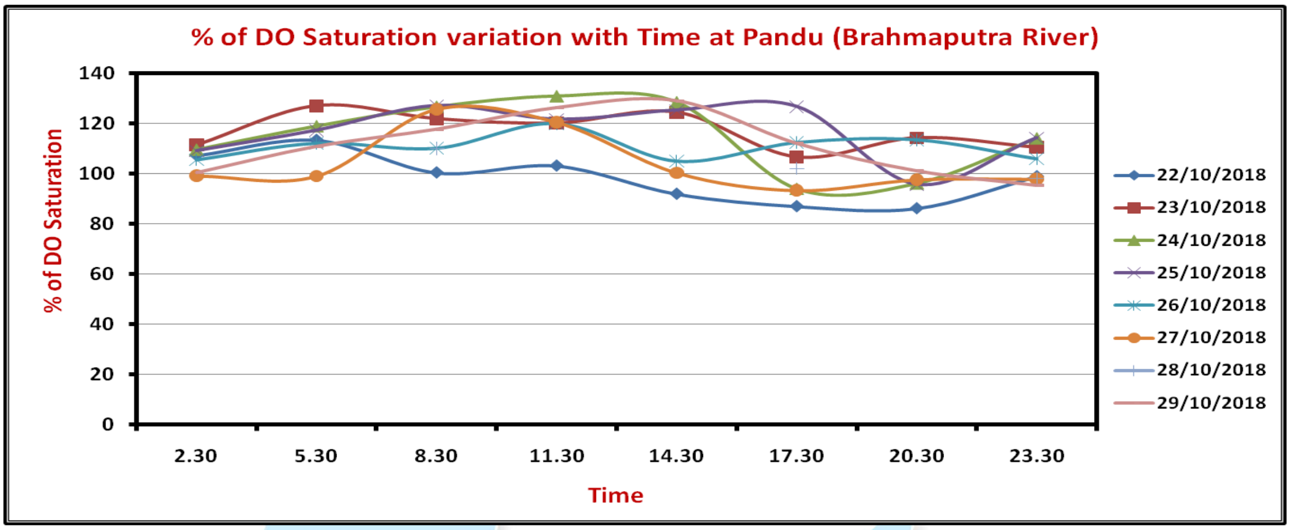


Figure 43: % of DO saturation variation with time at Pandu on Brahmaputra River

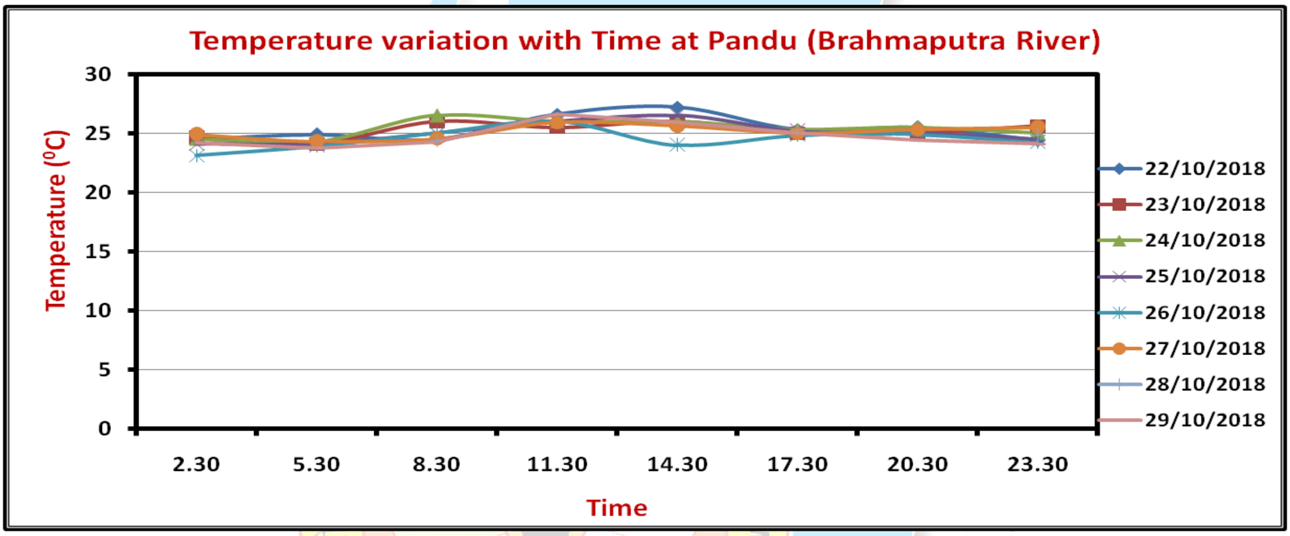


Figure 44: Temperature variation with time at Pandu on Brahmaputra River

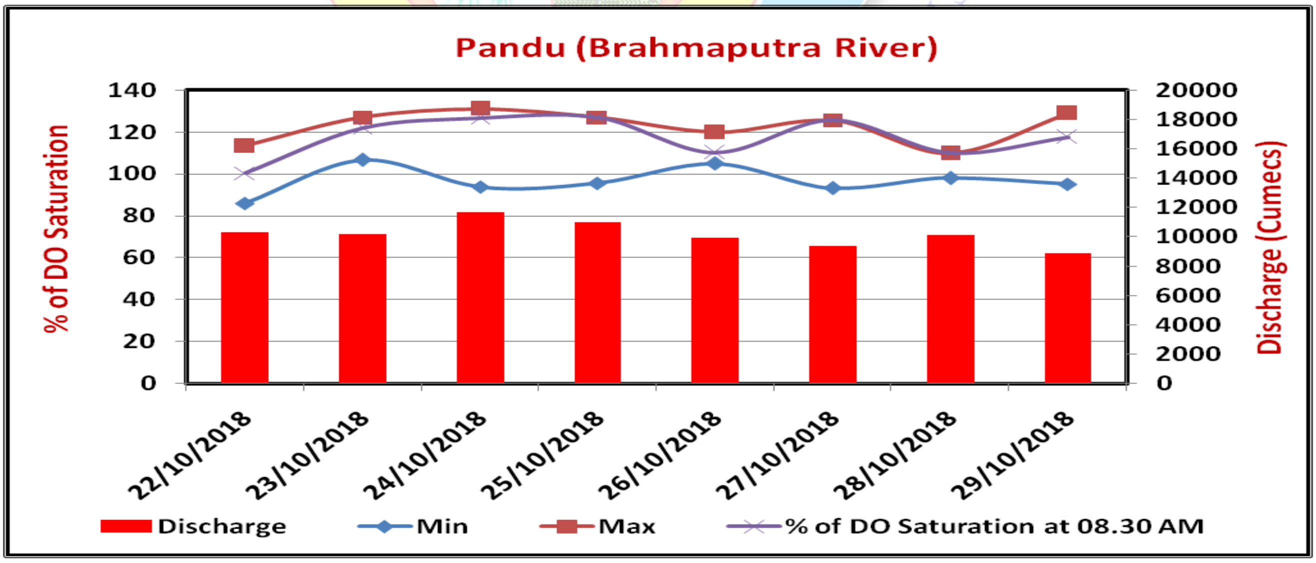


Figure 45: Relation between % of DO saturation and Discharge at Pandu on Brahmaputra River

BHIMA RIVER

The Bhima River is a major left bank tributary of the Krishna River. It originates in Bhimashankar hills near Karjat on the western side of Western Ghats, known as Sahyadri, in Maharashtra state in India. Bhima flows southeast for 725 km through Maharashtra, Karnataka and Andhra Pradesh states. Bhima is the most important tributary of the Krishna river, which is one of the two major rivers in Maharashtra, the other being Godavari River. During this long journey many smaller rivers confluence in it. Kundali River, Kumandala River, Ghod river, Bhama, Indrayani, Mula River, Mutha River and Pavna River are the major tributaries of this river around Pune. Indrayani, Mula, Mutha and Pawana flow through Pune and Pimpri Chinchwad city limits. Chandani, Kamini, Moshi, Bori, Sina, Man, Bhogwati and Nira are the major tributaries of the river in Solapur. Nira river confluences with Bhima river at Narsingpur, in Malshiras taluka in Solapur district. The total basin area is 48,631 km^2.

3.1.14 Phulgaon on Bhima River:

Both DO and Temperature graphs following almost similar trends with respect to time during all the days of study period from 27/10/2018 to 02/11/2018. Temperature lies between 18 ^{0}C and 32 ^{0}C during the study period. Maximum DO value observed was 10.9 mg/L (DO saturation = 140.54%) on 27/10/2018 at 17:00 Hrs at temperature 28 ^{0}C and Minimum DO value observed was 6.2 mg/L (DO saturation = 72.09%) on 31/10/2018 at 08:00 Hrs at temperature 24 ^{0}C. From DO vs Time graphs it can be explain that, DO concentrations found within prescribed limits for all classes of water. By comparing temperature graph and DO saturation graph it can be seen that DO concentration is increasing with temperature i.e during the day time. This relationship can be attributed to photosynthesis activities in river water.

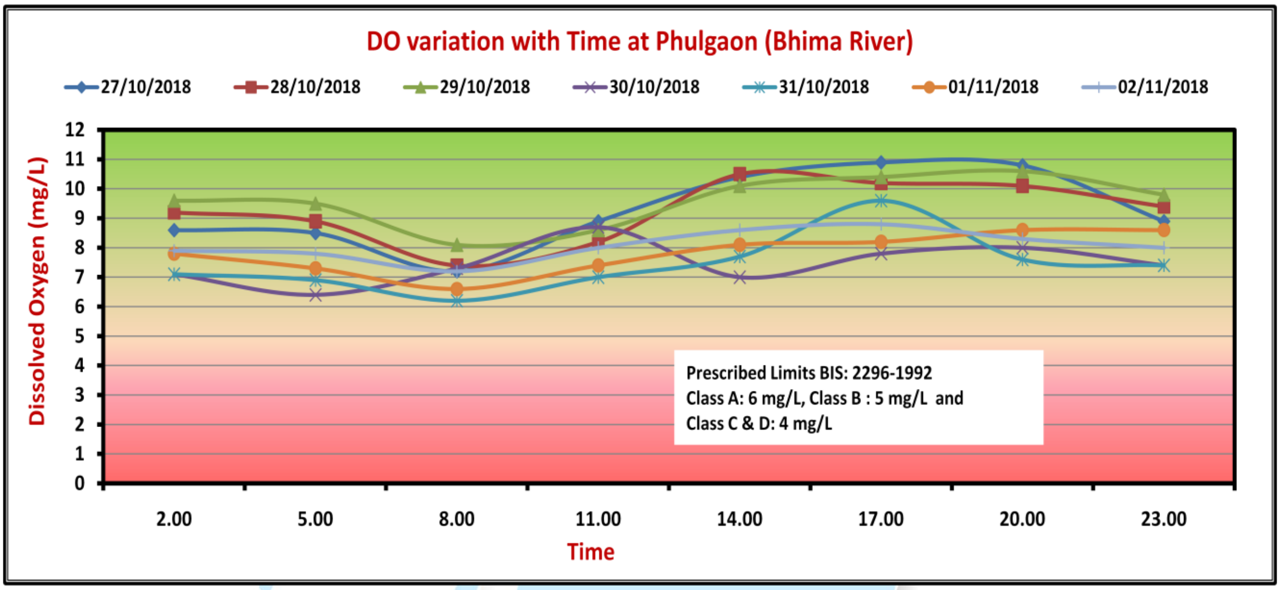


Figure 46: DO variation with Time at Phulgaon on Bhima River

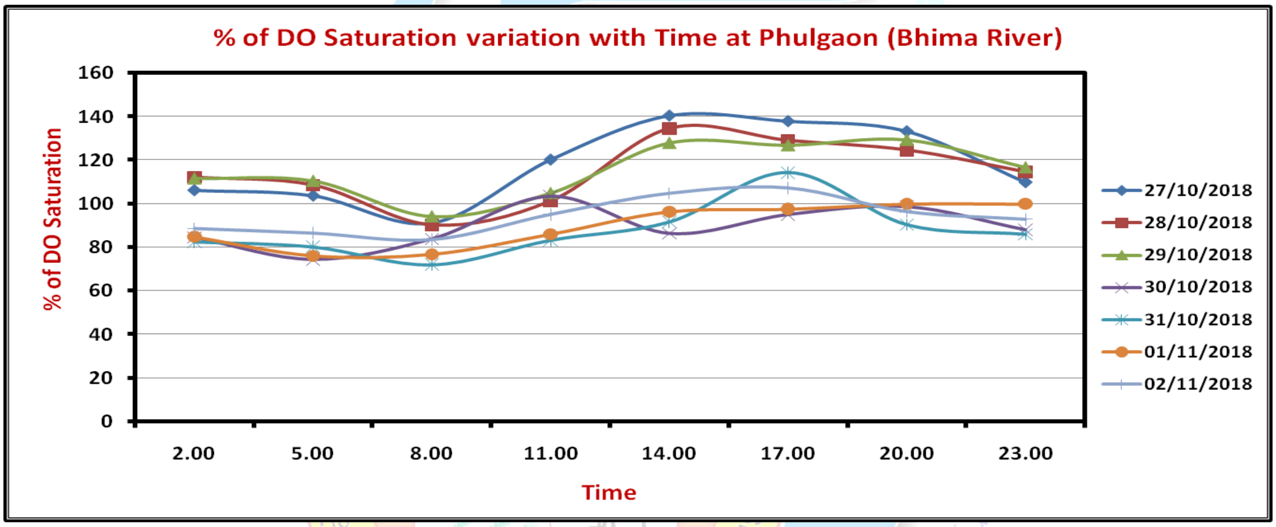


Figure 47: % of DO saturation variation with time at Phulgaon on Bhima River

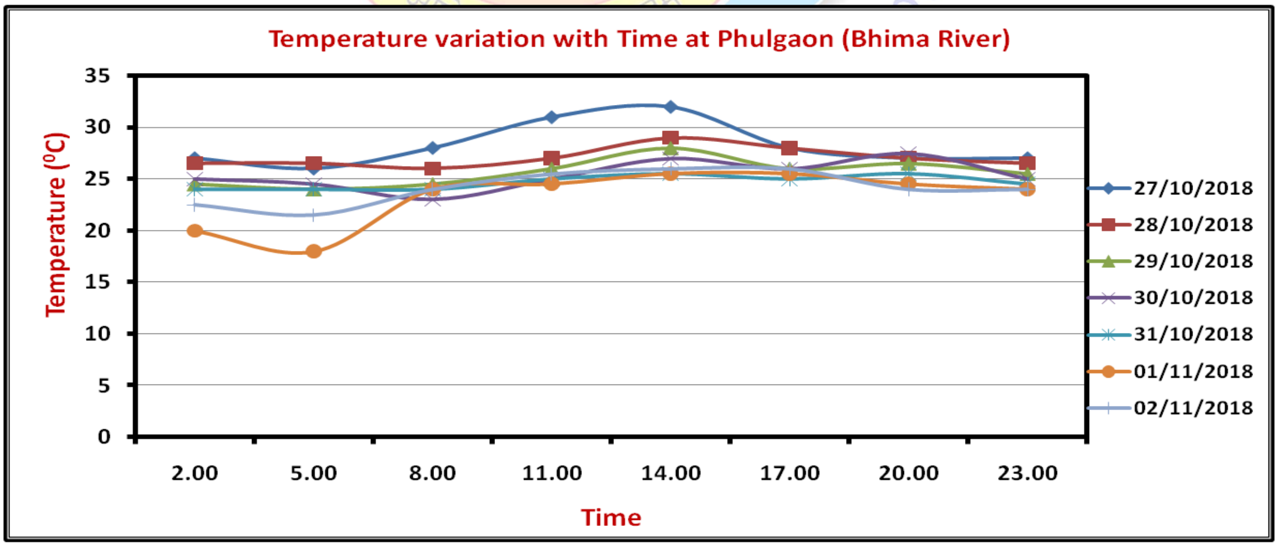


Figure 48: Temperature variation with time at Phulgaon on Bhima River

KALIYAR RIVER:

The Kaliyar is one of the tributaries of river Muvattupuzha which has its origin at East of Erattupetta village in the district of Kottayam in Kerala state at 76^0 53' East longitude and 9^0 43' North latitude at an elevation of 1,200 m. The Kaliyar is formed by the confluence of the Kamb Aar and the Toni Aar. The Kannadipuzha flowing from Valiya Parantan Hills joins the Kaliyar at Kannadi. Another stream originating from Venniyar Mudi also joins the main Kaliyar River. The Kaliyar flowing in a westerly direction for about 42 km. joins the Kothamangalam River near Perumattom and the combined river flows for about 2 km before joining the Thodupuzha River.

3.1.15 Ramamangalam on Kaliyar River:

Both DO and Temperature graphs following almost similar trends with respect to time during all the days of study period from 13/11/2018 to 20/11/2018. Temperature lies between 23 ^{0}C and 30^{0}C during the study period. Maximum DO value observed was 8.1 mg/L (DO saturation = 96.30%) on 16/11/2018 at 21:00 Hrs at temperature 23.5 ^{0}C and Minimum DO value observed was 6.1 mg/L (DO saturation = 72.62%) on 18/11/2018 at 24:00 Hrs at temperature 25 ^{0}C. From DO vs Time graphs it can be explain that, DO concentrations found within prescribed limits for all classes of water.

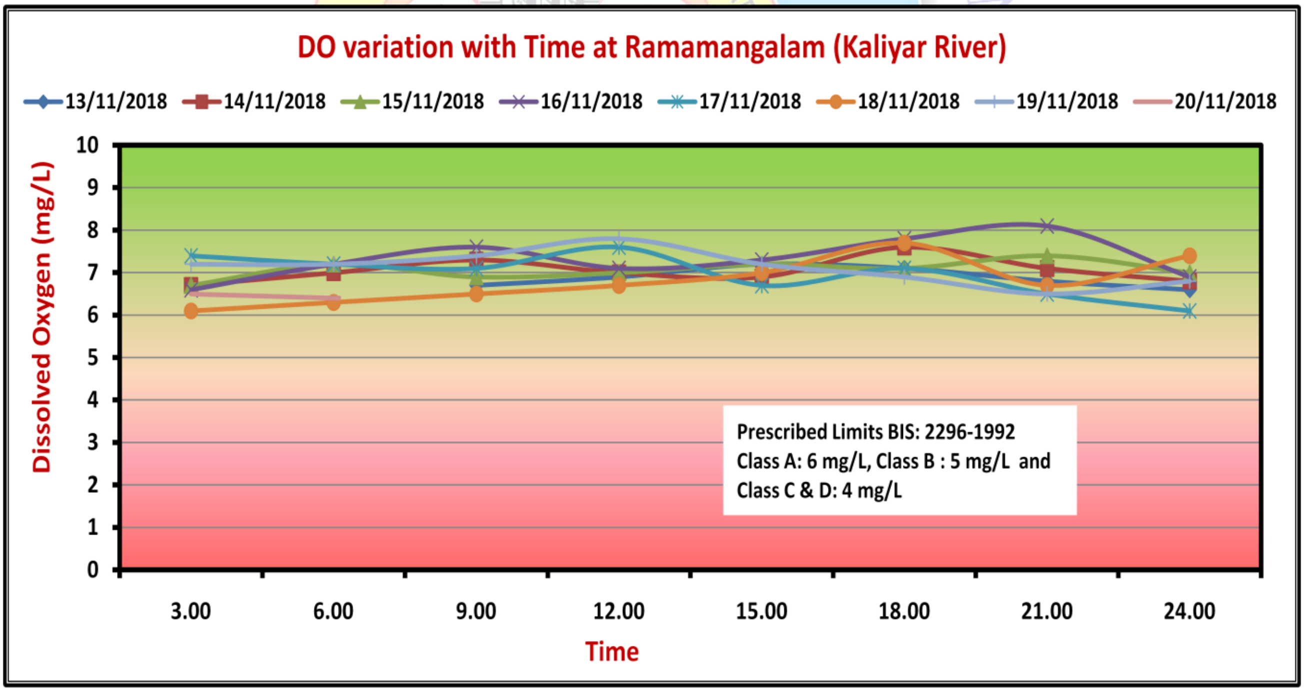


Figure 49: DO variation with Time at Ramamangalam on Kaliyar River

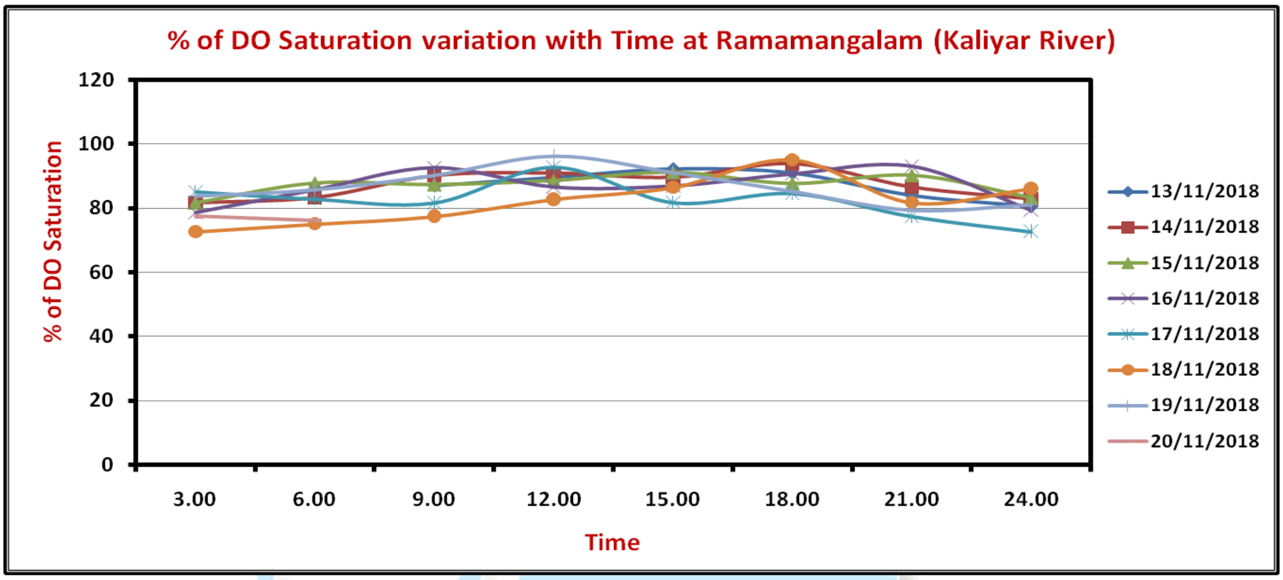


Figure 50: % of DO saturation variation with time at Ramamangalam on Kaliyar River

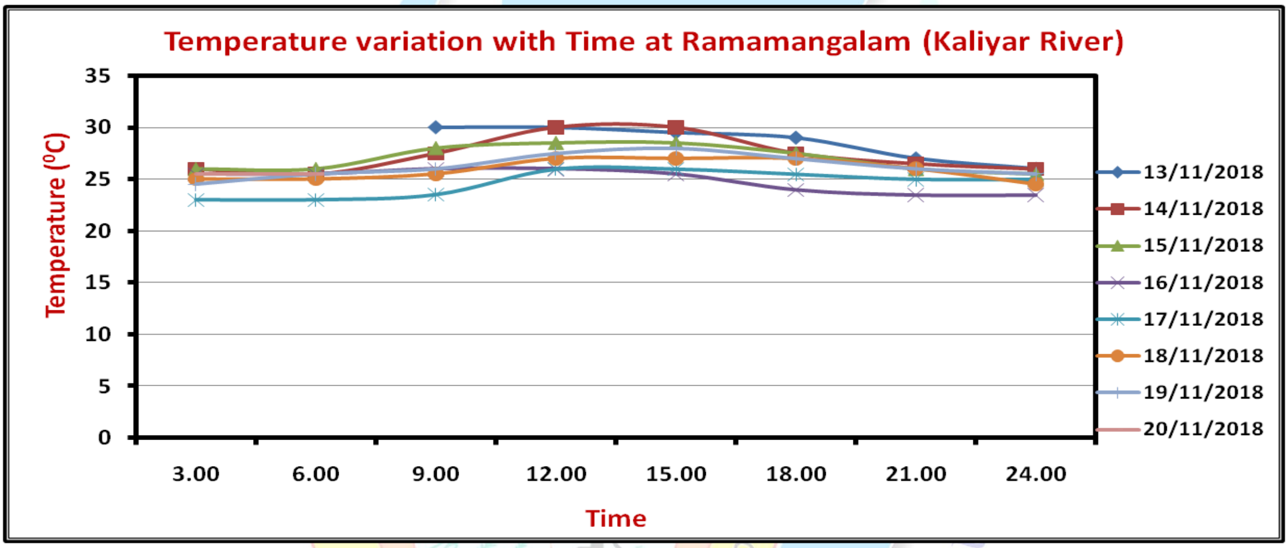


Figure 51: Temperature variation with time at Ramamangalam on Kaliyar River

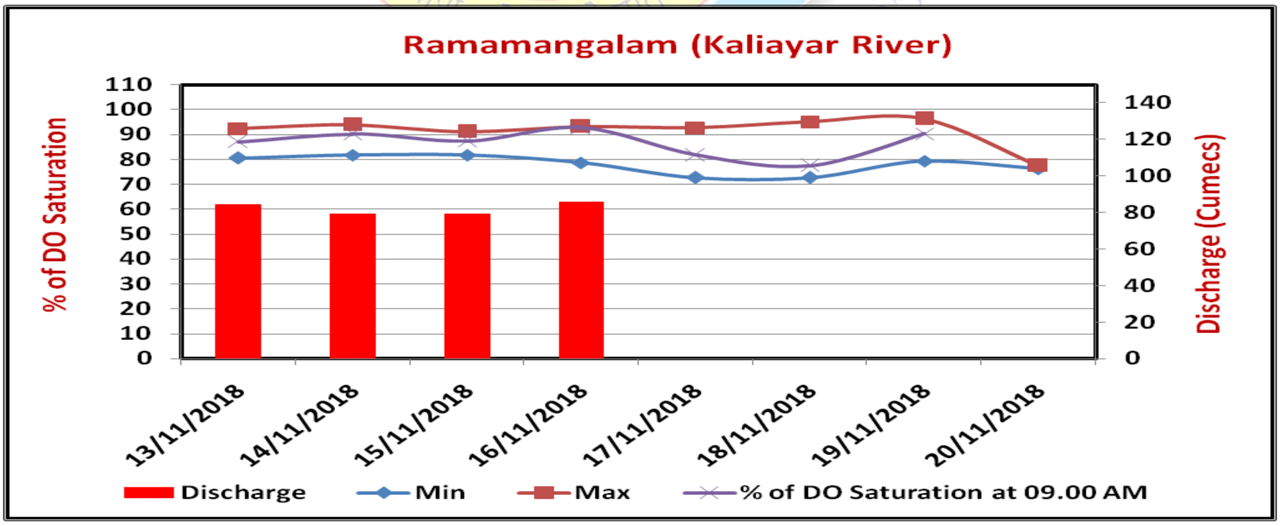


Figure 52: Relation between % of DO saturation and Discharge at Ramamangalam on Kaliyar River

KANHAN RIVER

The Kanhan River is a tributary of the Wainganga River of central India. Kanhan River is known for sand mining. Coal mining activies are also in large amount on the river basin. Kanhan River starts on the southern down side of Panchmarhi hill near Damua in Madhya Pradesh, India. The Kanhan is the Wainganga's longest tributary, at 275 km. It rises in the Satpura Range of Betul and flowing south and east, joins the Wainganga at the village of Ambora in Nagpur District.

3.1.16 Satrapur on Kanhan River:

Both DO and Temperature graphs following almost similar trends with respect to time during all the days of study period from 10/12/2018 to 16/12/2018. Temperature lies between 16.5 ^{0}C and 28.3 ^{0}C during the study period. Maximum DO value observed was 11.9 mg/L (DO saturation = 150.63%) on 10/12/2018 at 15:00 Hrs at temperature 28.3 ^{0}C and Minimum DO value 6.4 mg/L (DO saturation = 69.57%) on 11/12/2018 at 06:00 Hrs at temperature 20.5 ^{0}C have been observed. From DO vs Time graphs can be explain that, DO concentrations found within prescribed limits for all classes of water.

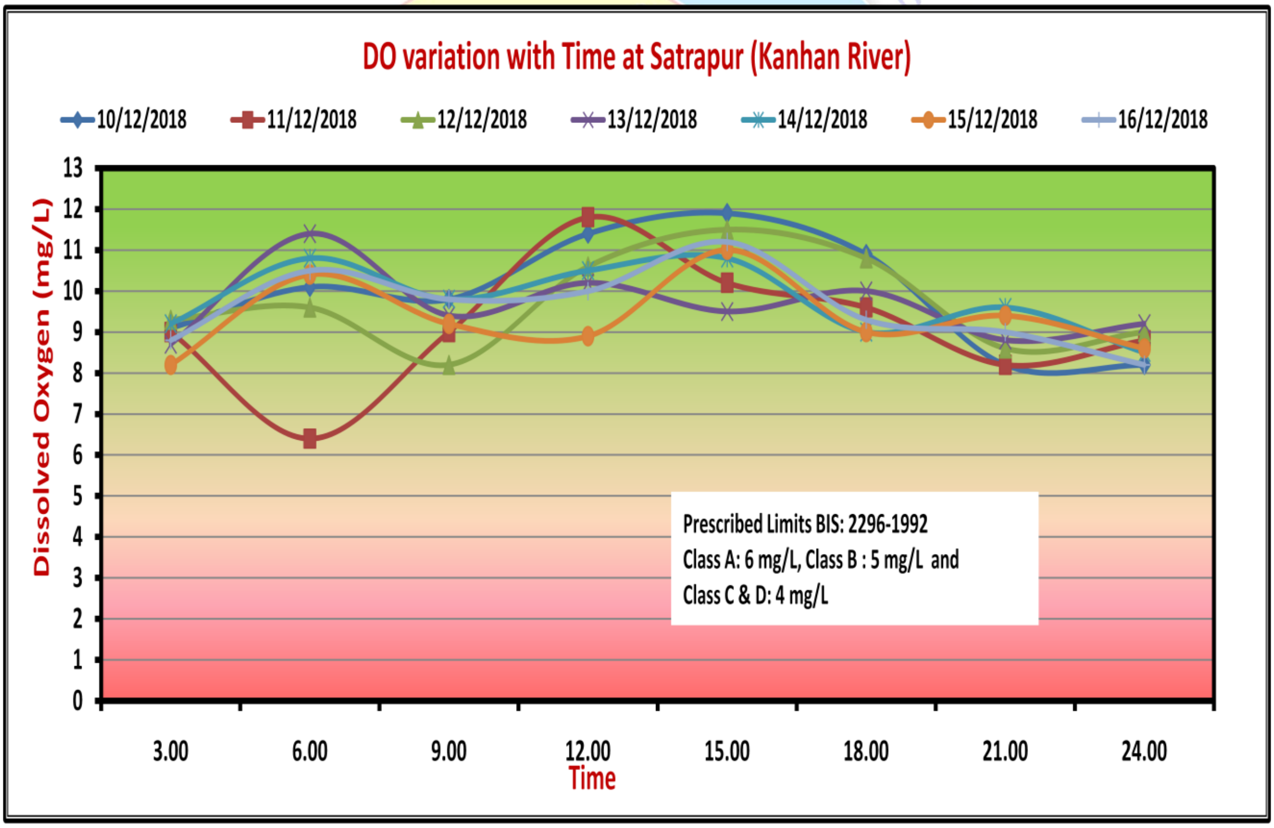


Figure 53: DO variation with Time at Satrapur on Kanhan River

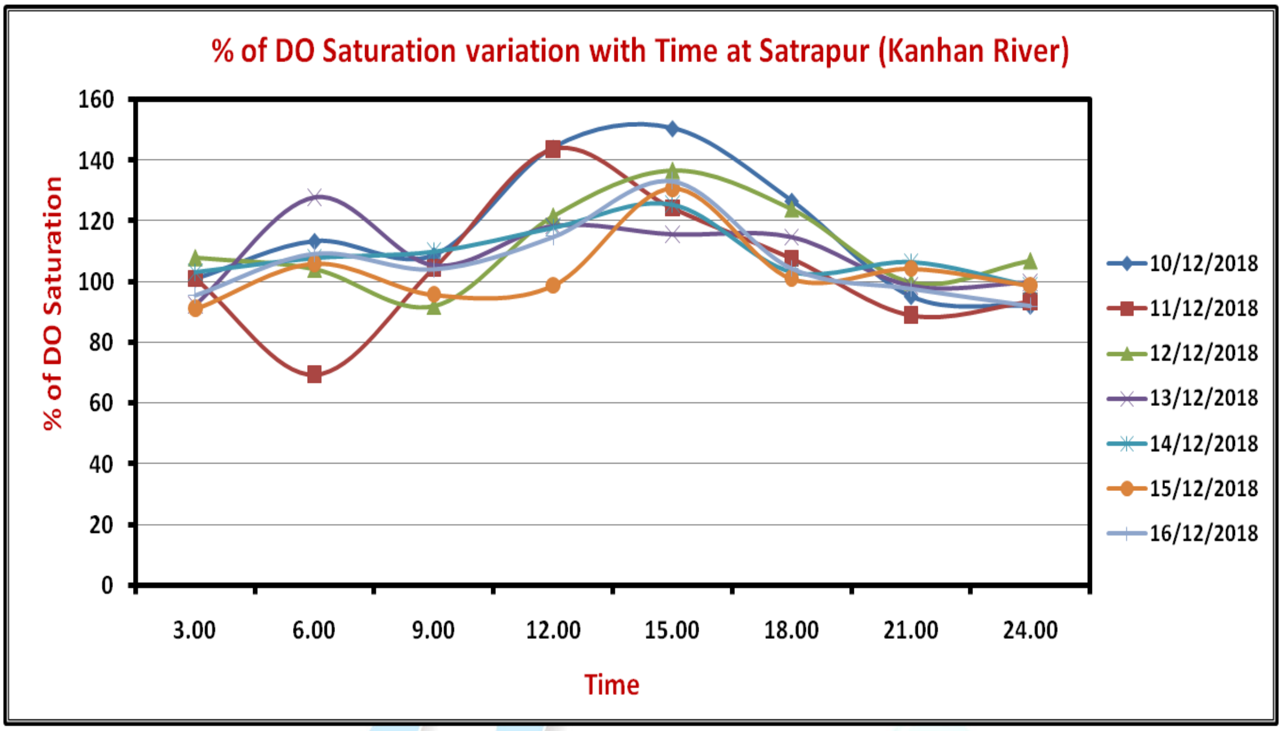


Figure 54: % of DO saturation variation with time at Satrapur on Kanhan River

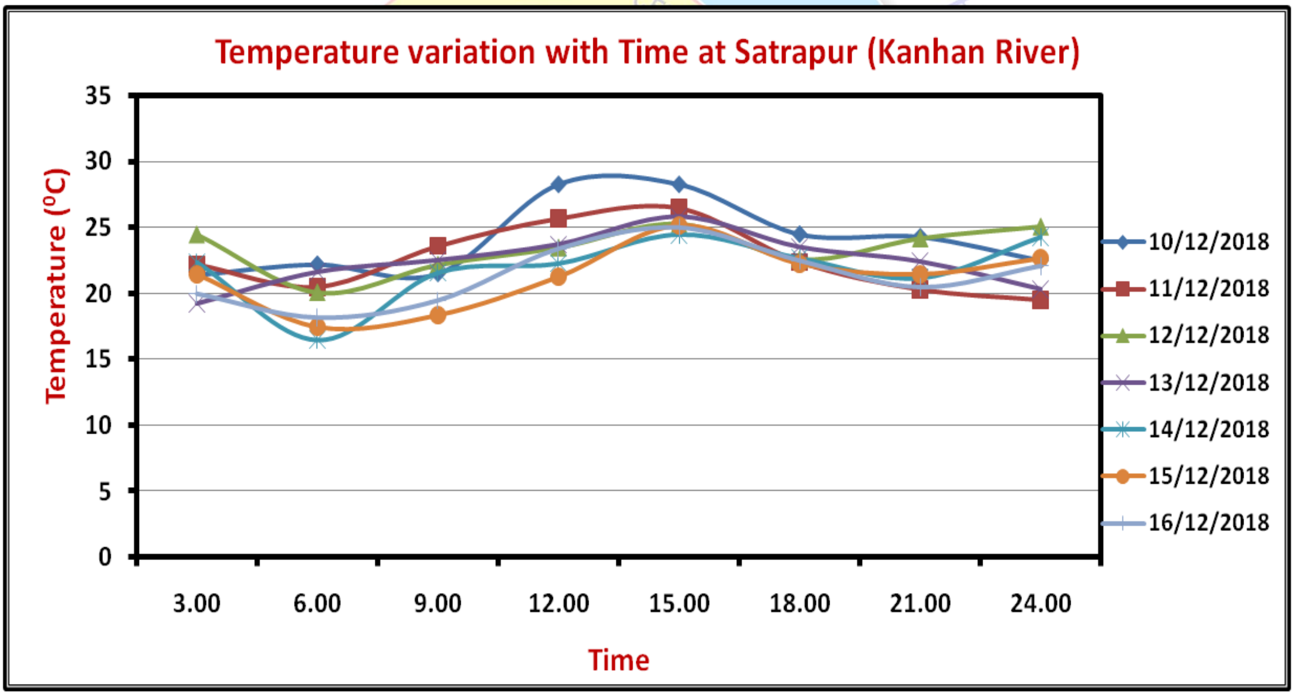


Figure 55: Temperature variation with time at Satrapur on Kanhan River

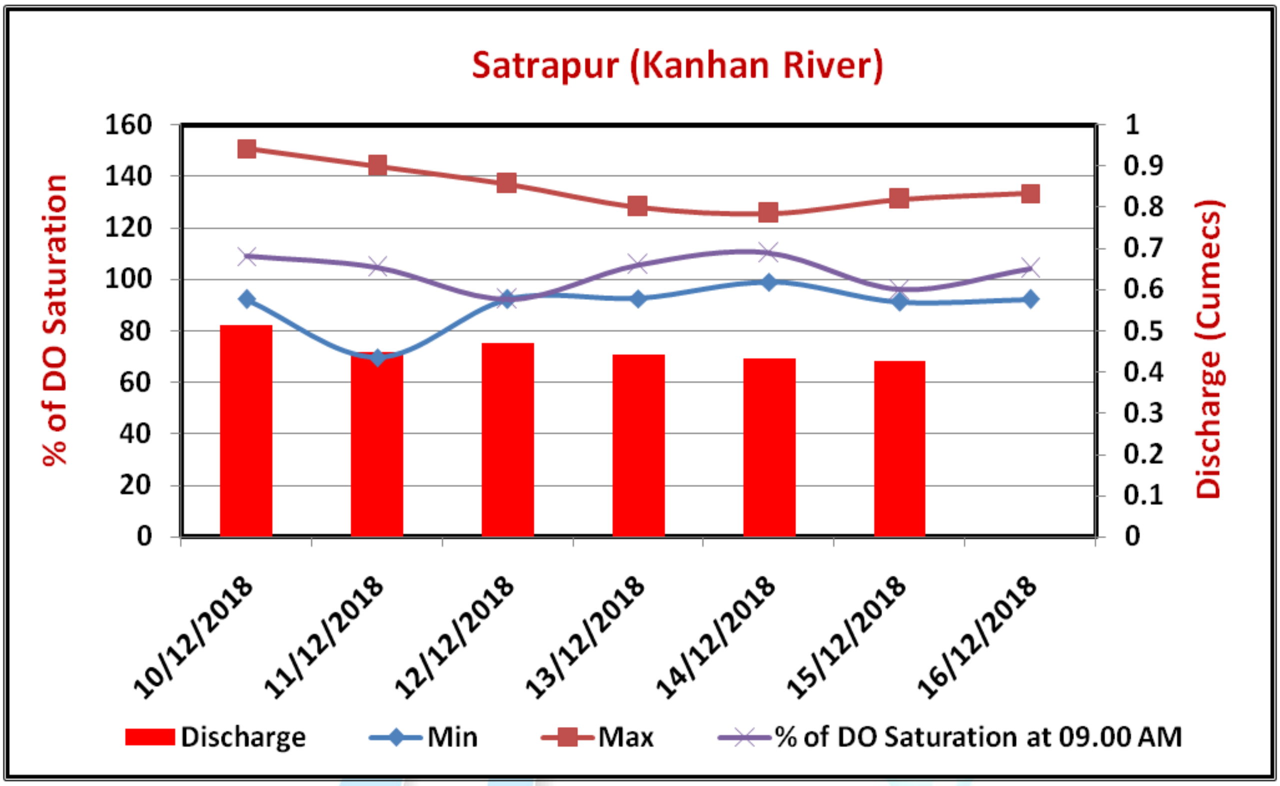


Figure 56: Relation between % of DO saturation and Discharge at Satrapur on Kanhan River

ARKAVATHI RIVER

The Arkavathi River is one of the important tributaries of the Cauvery River. It rises at Nandidurga hills in Chikballpur Taluk of Kolar district. After flowing in the southwest direction in the initial stage, it receives flow of Kumudvathi River. From this point, the Arkavathi River flows in a southerly direction up to Ramanagaram and turns towards southeast. It then flows in the same direction up to the confluence of its tributary Suvarnamukhi on the left bank. Thereafter, it flows in southerly direction and receives the water of Kuttlehole from the left near Kanakapura town. Further, it flows down and receives the waters of Doddahalla from the left and then finally joins Cauvery at Kungedoddi. The total length of the Arkavathi River is about 150 km from its origin to its confluence with Cauvery.

3.1.17 T. Bekuppe on Arkavathi River:

Both DO and Temperature graphs following almost similar trends with respect to time during all the days of study period from 14/11/2018 to 21/11/2018. Temperature lies between 22 ^{0}C and 27 ^{0}C during the study period. Maximum DO value observed was 5.4 mg/L (DO saturation = 64.29%) on 14/11/2018 at 13:00 Hrs at temperature 25 ^{0}C and Minimum DO value observed was 2.5 mg/L (DO saturation = 29.76%) on 16/11/2018 at 04:00 Hrs at temperature 25 ^{0}C. From DO vs Time graphs can be explain that, DO concentrations found below prescribed limits for class A water. Majorly, from 01:00 Hrs. to 10:00 Hrs. and 19:00 Hrs. to 22:00 Hrs., obtained DO values found below the permissible limits for Class C and D also. Although, during 13:00 Hrs and 16:00 Hrs, it shows within permissible limit for Class C & D and lies outside for Class B permissible limits. It can be understand that from DO saturation and temperature graphs, DO concentration increasing from early morning and reaches peak concentration at 13:00 Hrs. followed by decreasing trend. This kind of behavior can be due to photosynthesis phenomenon in river water. However, no clear relationship was seen between quantity of flow and DO saturation.

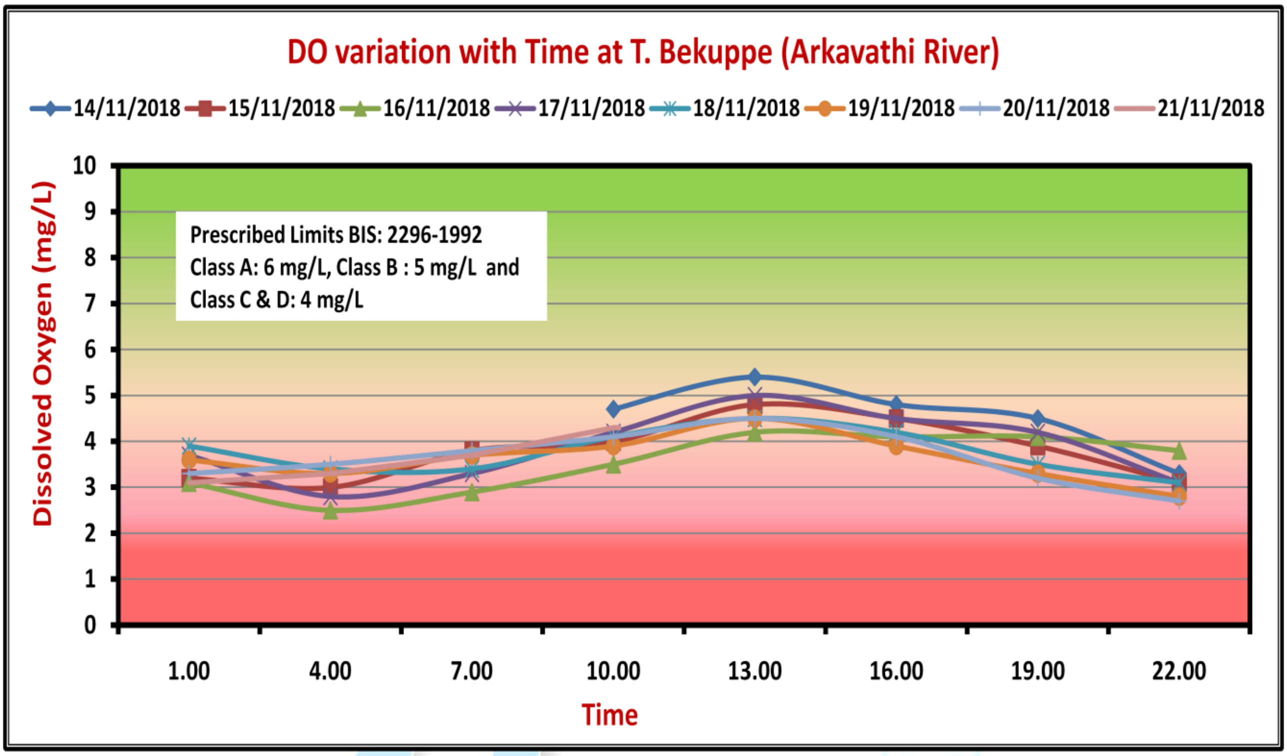


Figure 57: DO variation with Time at T. Bekuppe on Arkavathi River

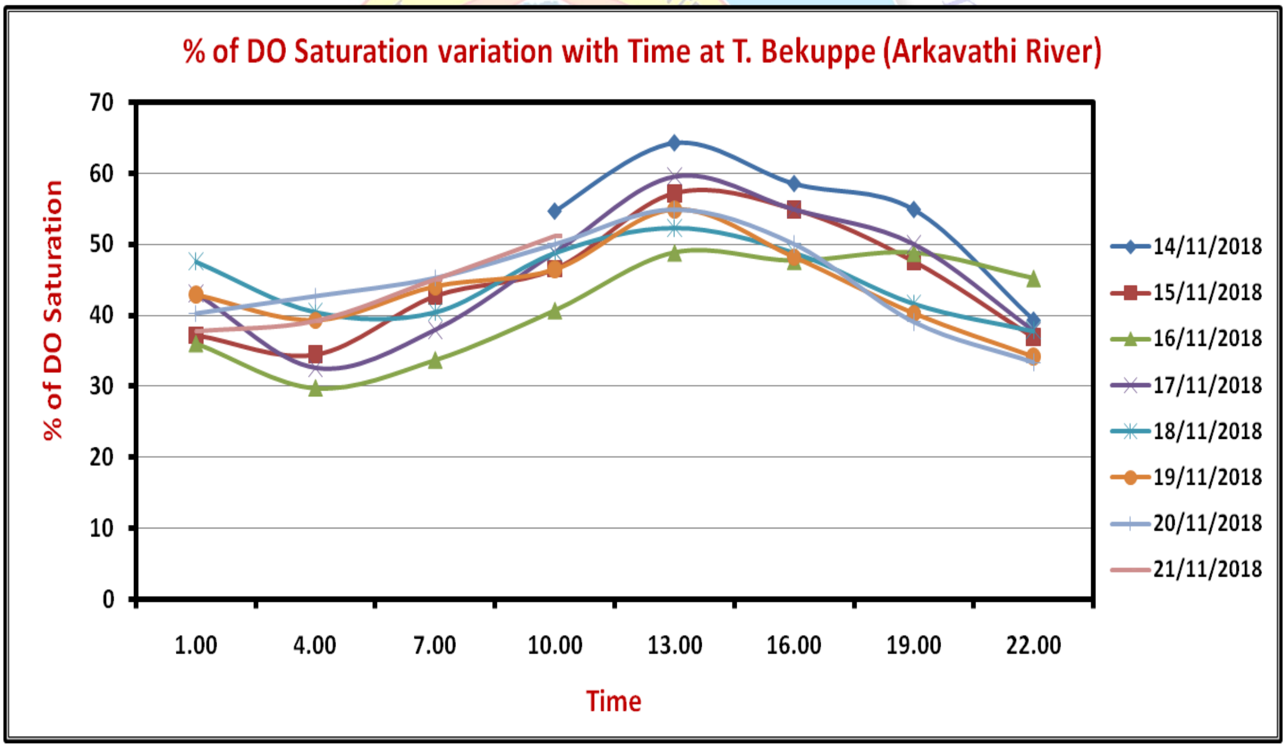


Figure 58: % of DO saturation variation with time at T. Bekuppe on Arkavathi River

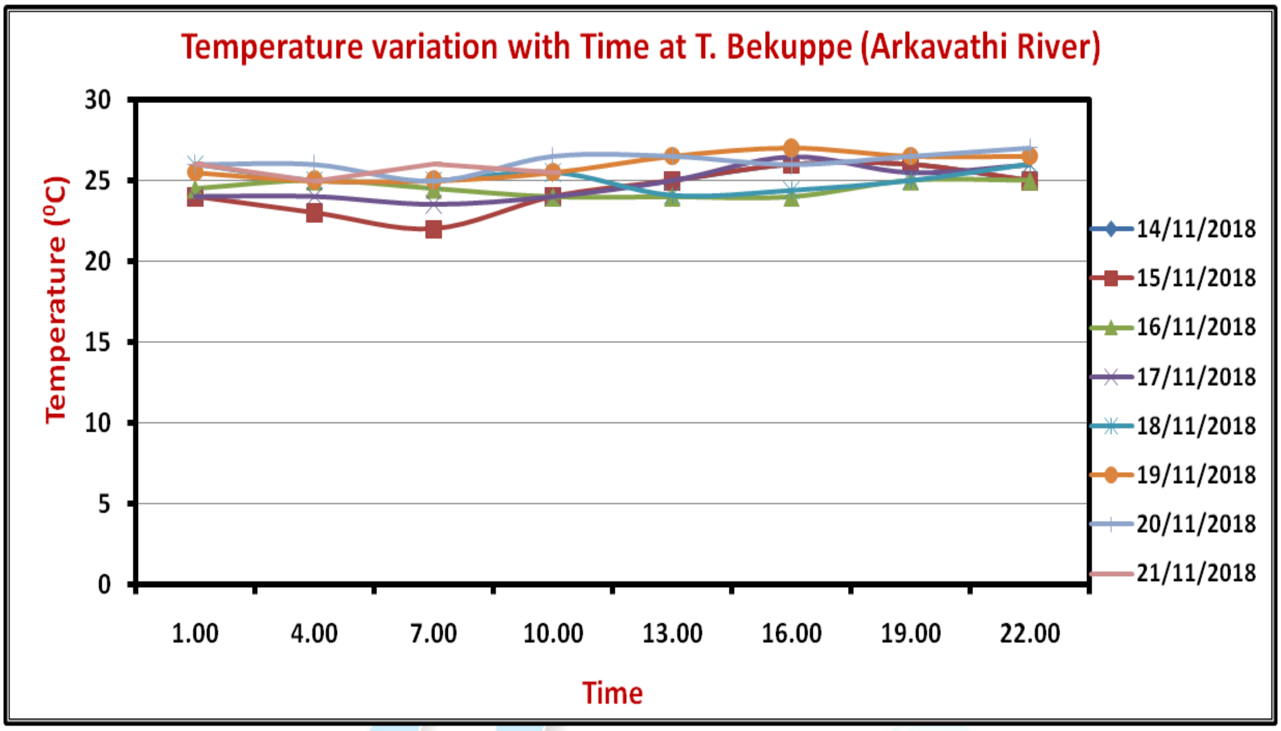


Figure 59: Temperature variation with time at T. Bekuppe on Arkavathi River

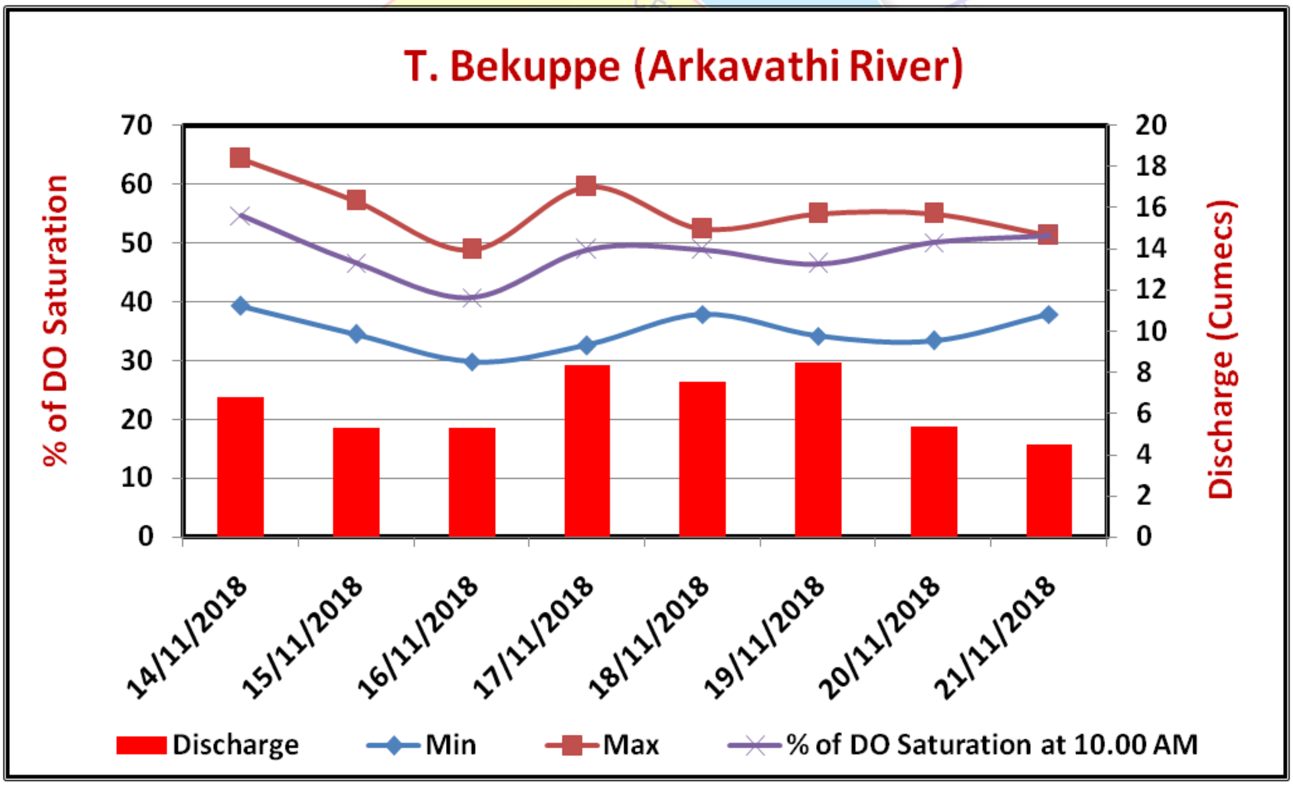


Figure 60: Relation between % of DO saturation and Discharge at T. Bekuppe on Arkavathi River

3.1.18 Thengudi on Thirumalairajanaar:

Both DO and Temperature graphs following almost similar trends with respect to time during all the days of study period from 27/01/2019 to 02/02/2019. Temperature lies between 23 ^{0}C and 30 ^{0}C during the study period. Maximum DO value observed was 8.96 mg/L (Do saturation = 117.31%) on 27/01/2019 at 15:00 Hrs at temperature 30 ^{0}C and Minimum DO value observed was 5.57 mg/L (DO saturation = 64.02%) on 31/01/2019 at 06:00 Hrs at temperature 23 ^{0}C. During early morning time (03:00 Hrs. to 09:00 Hrs), DO concentrations found below the prescribed limit for Class A category. And, remaining time (from 12:00 Hrs to 00:00 Hrs.) it found within permissible limits for classes of water. From DO saturation and Temperature graphs it can be explain that, from 00:00 Hrs. to 06:00 Hrs. DO concentration values found decreasing trend and then increased, reaches higher maximum value at 15:00 Hrs. followed by decreasing trend. This relationship can be attributed to photosynthesis activities in river water. However, no clear relationship was seen between quantity of flow and DO saturation.

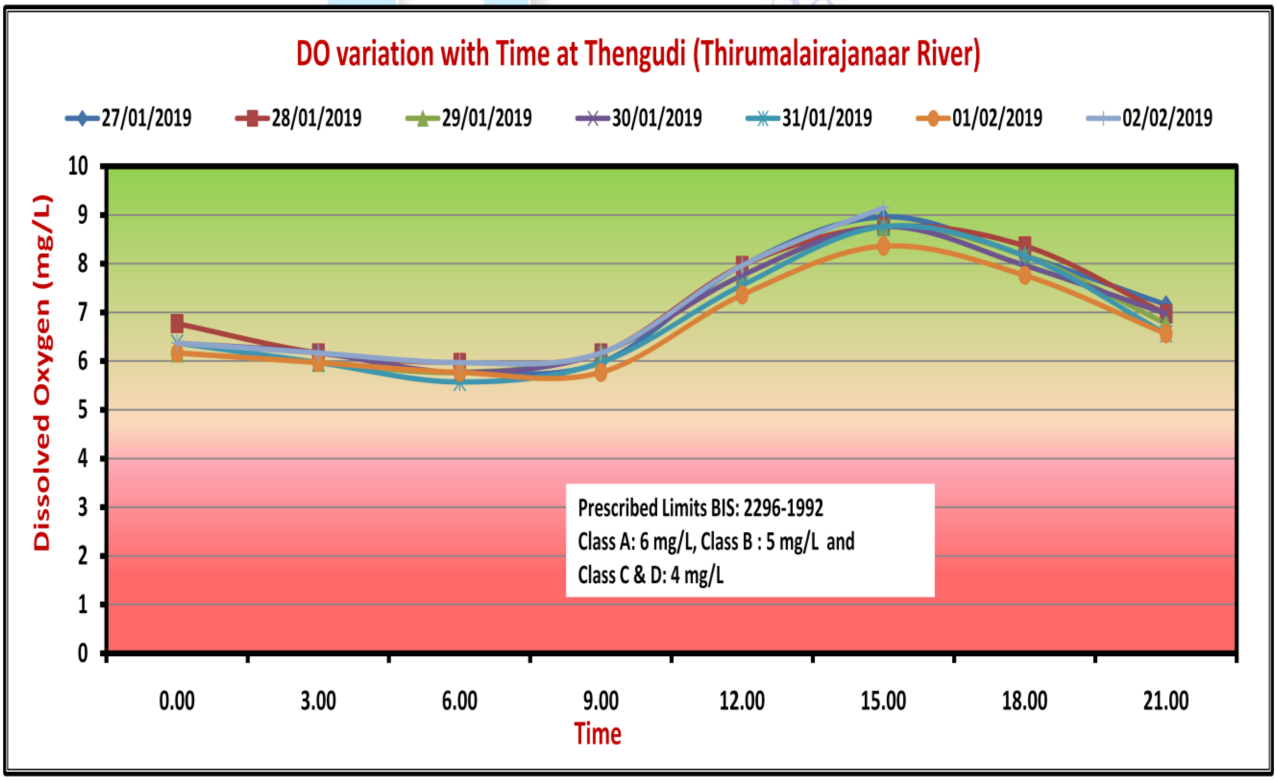


Figure 61: DO variation with Time at Thengudi on Thirumalairajanaar

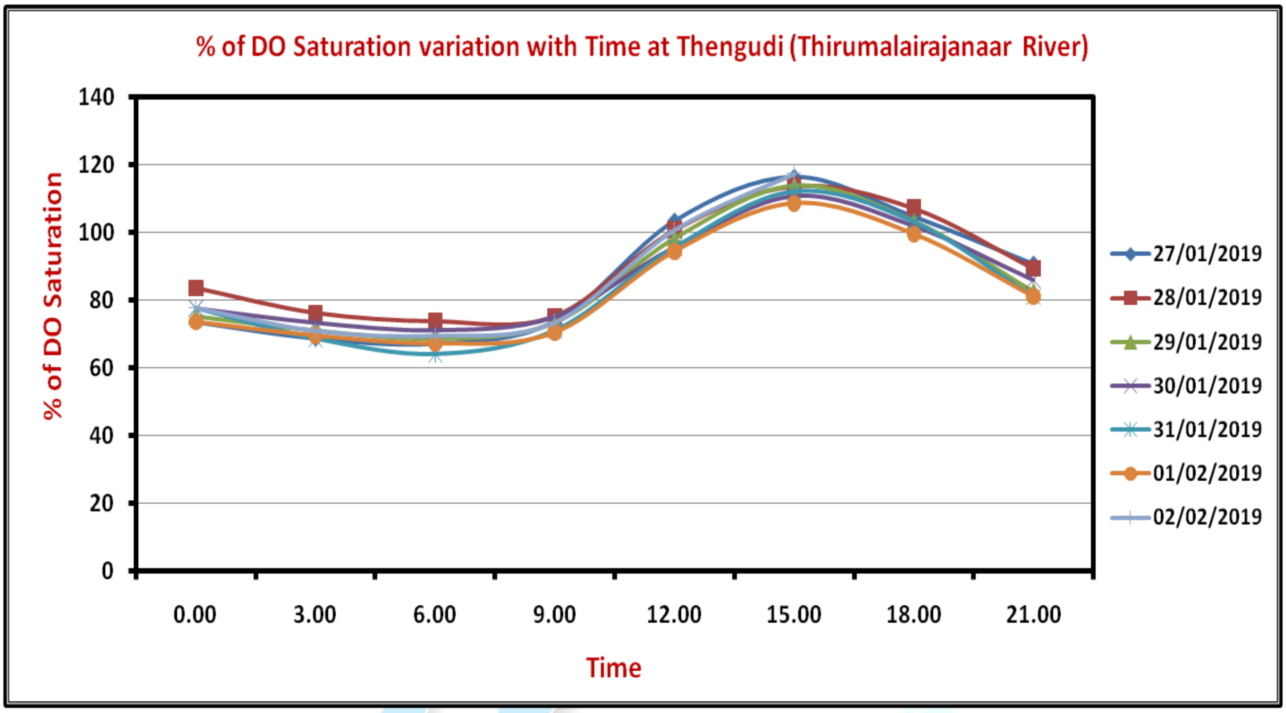


Figure 62: % of DO saturation variation with time at Thengudi on Thirumalairajanaar

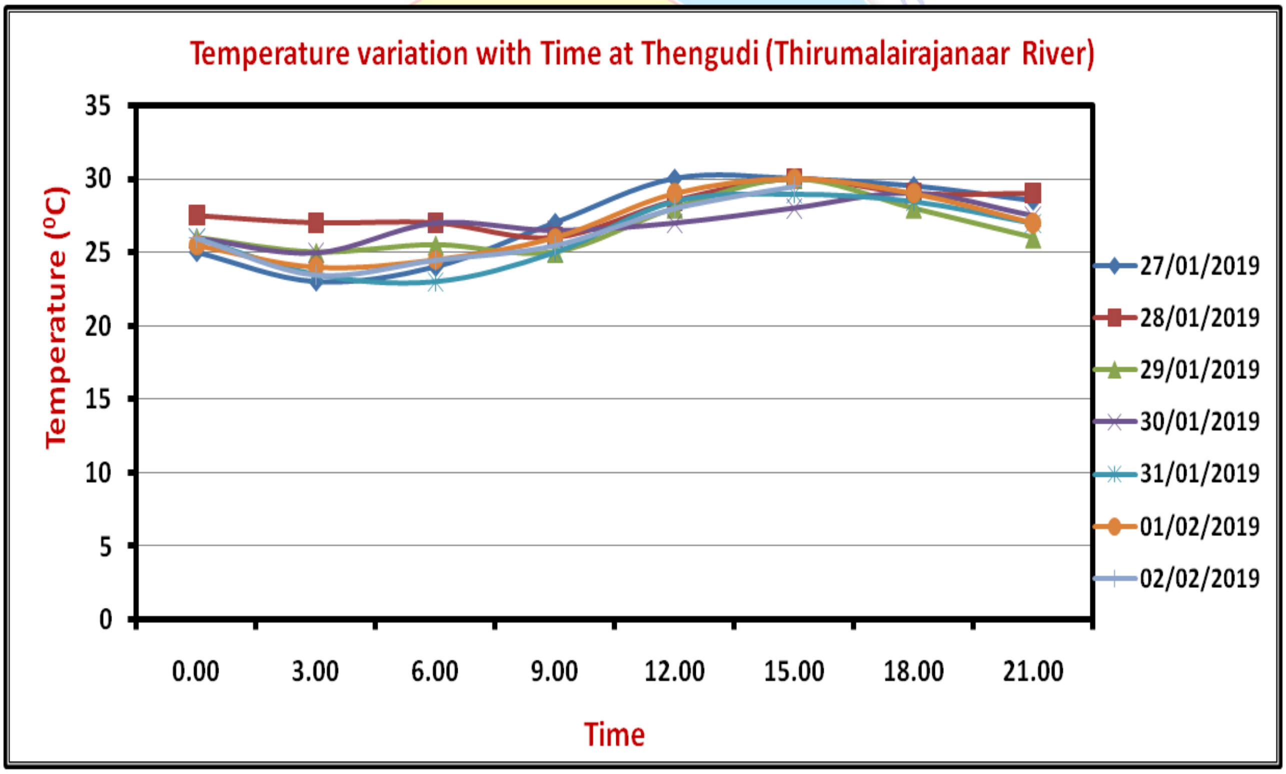


Figure 63: Temperature variation with time at Thengudi on Thirumalairajanaar

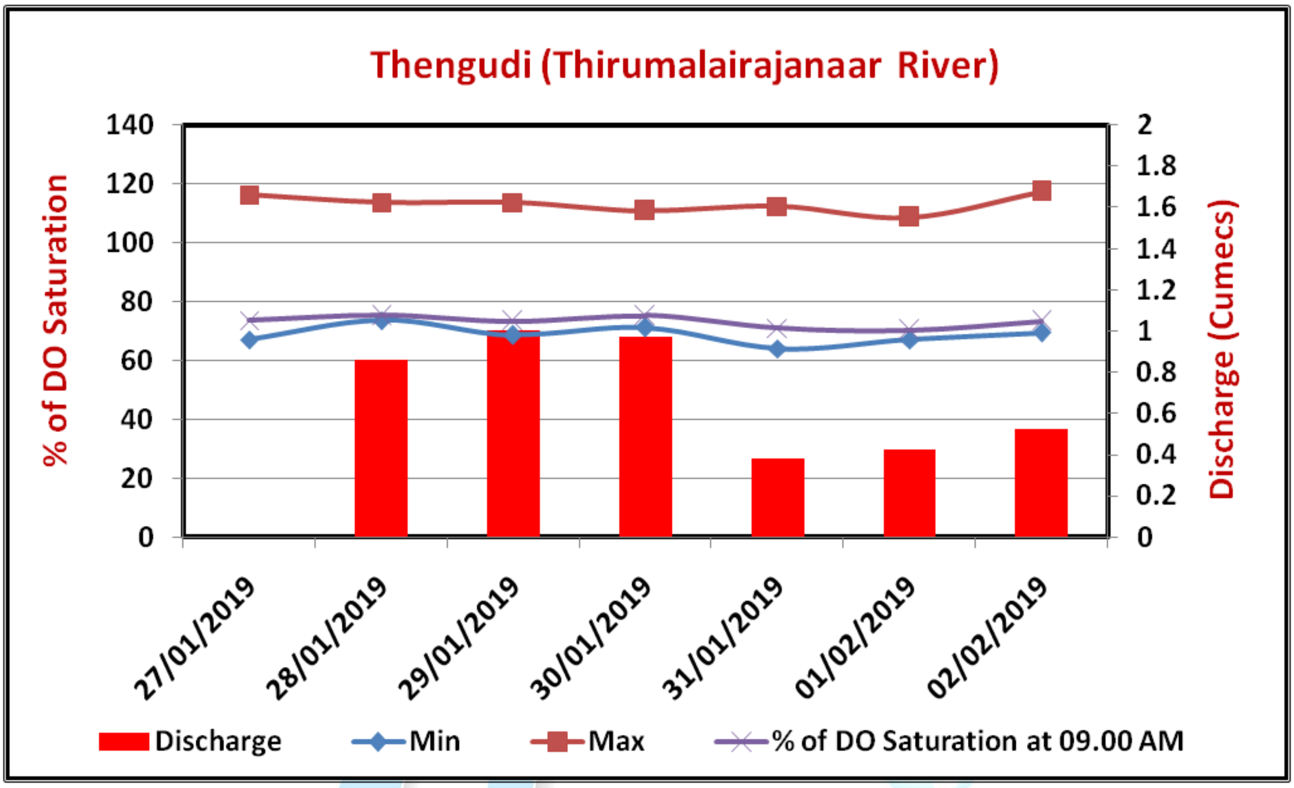


Figure 64: Relation between % of DO saturation and Discharge at Thengudi on Thirumalairajanaar

TAWI RIVER

The Tawi River is a major left bank tributary of the Chenab. It originates from outer Himalaya ranges in Udhampur district at an elevation of about 1220 m. Initially it flows in western direction for about 16 km and then takes a turn towards North West direction and flows for a distance of 27 km upto Sudhmahadev. There after it flows in westerly direction for about 5 km upto Chenani and further down in a westerly course upto Udhampur after which it takes a southerly course for about 24 km. The river finally joins the Chenab a little downstream of the international border in Pakistan. The total length of the river is about 141 km. The river generally flows through steep hills on either side except the lower reach of about 35 km.

3.1.19 Vikram Chowk on Tawi River:

It can be seen from the graphs, Both DO and Temperature graphs following some irregular trend with respect to time during all the days of study period from 11/02/2019 to 15/02/2019. Temperature lies between 8 ^{0}C and 17.5 ^{0}C during the study period. Maximum DO value observed was 8.8 mg/L (DO saturation = 80.73%) on 14/02/2019 at 05:30 Hrs at temperature 12.5 ^{0}C and Minimum DO value observed was 6.21 mg/L (DO saturation = 53.88%) on 11/02/2019 at 11:30 Hrs at temperature is 13 ^{0}C. It can be understand from DO Vs Time graphs, DO values found within permissible limit during entire study period.

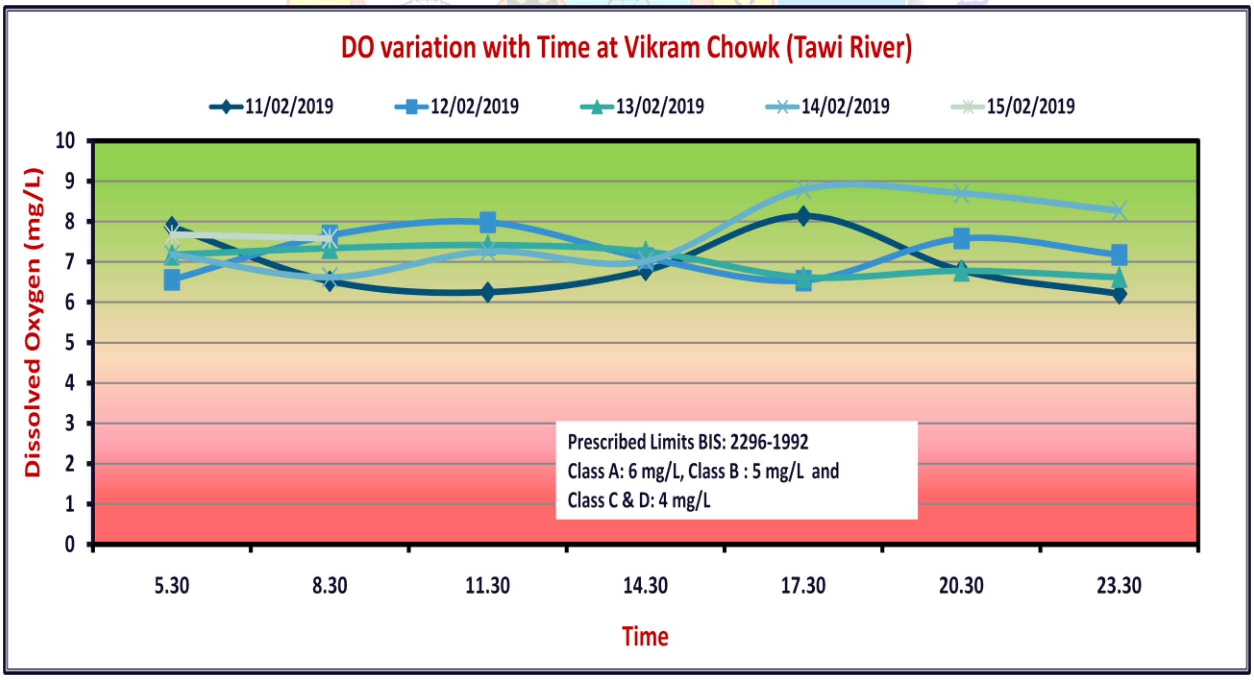


Figure 65: DO variation with Time at Vikram Chowk on Tawi River

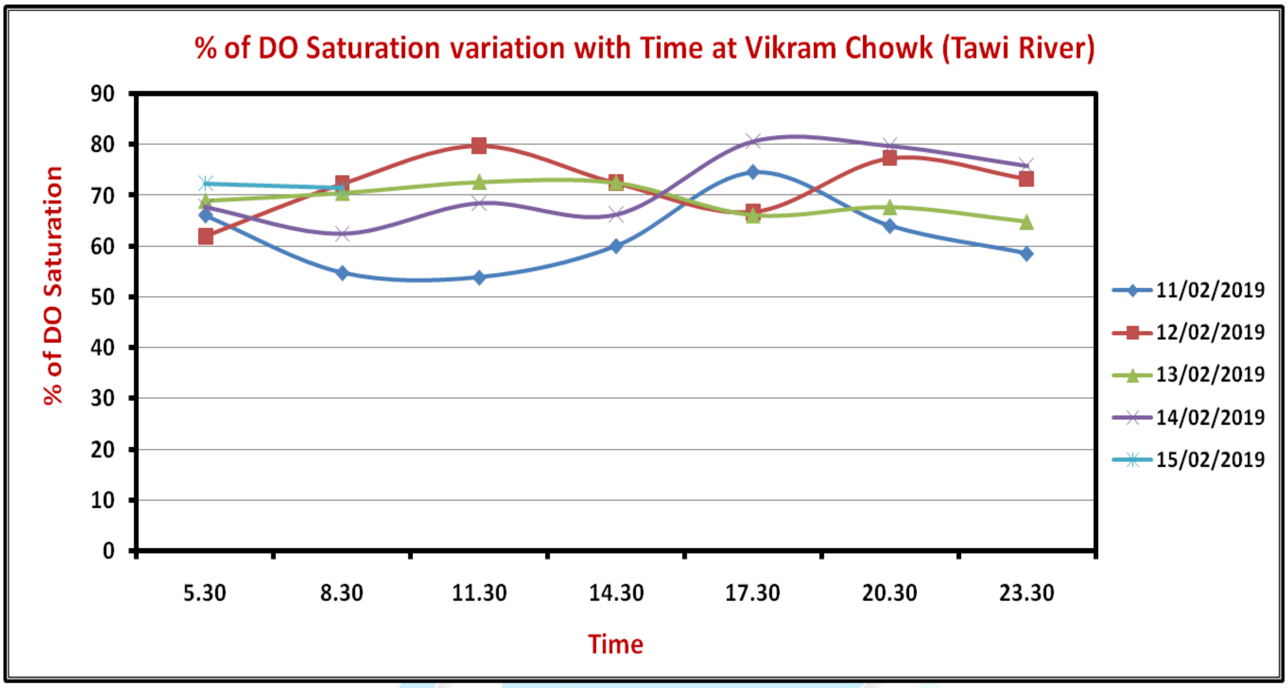


Figure 66: % of DO saturation variation with time at Vikram Chowk on Tawi River

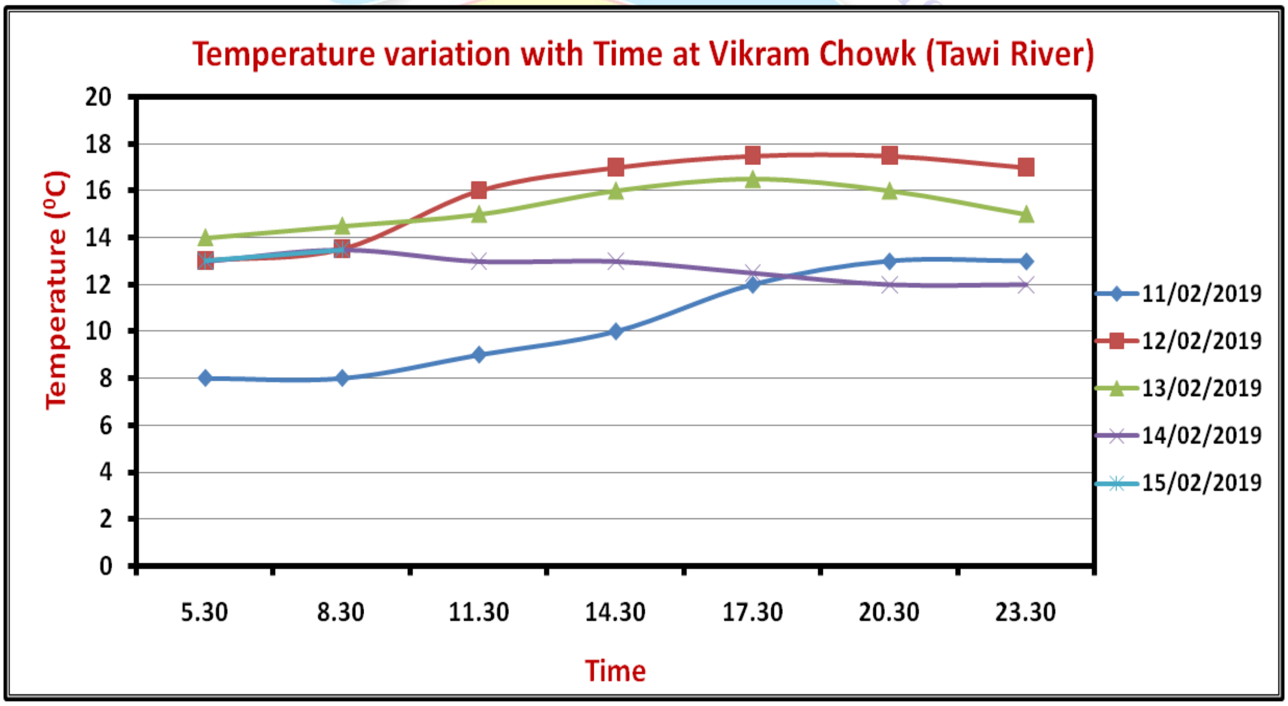


Figure 67: Temperature variation with time at Vikram Chowk on Tawi River

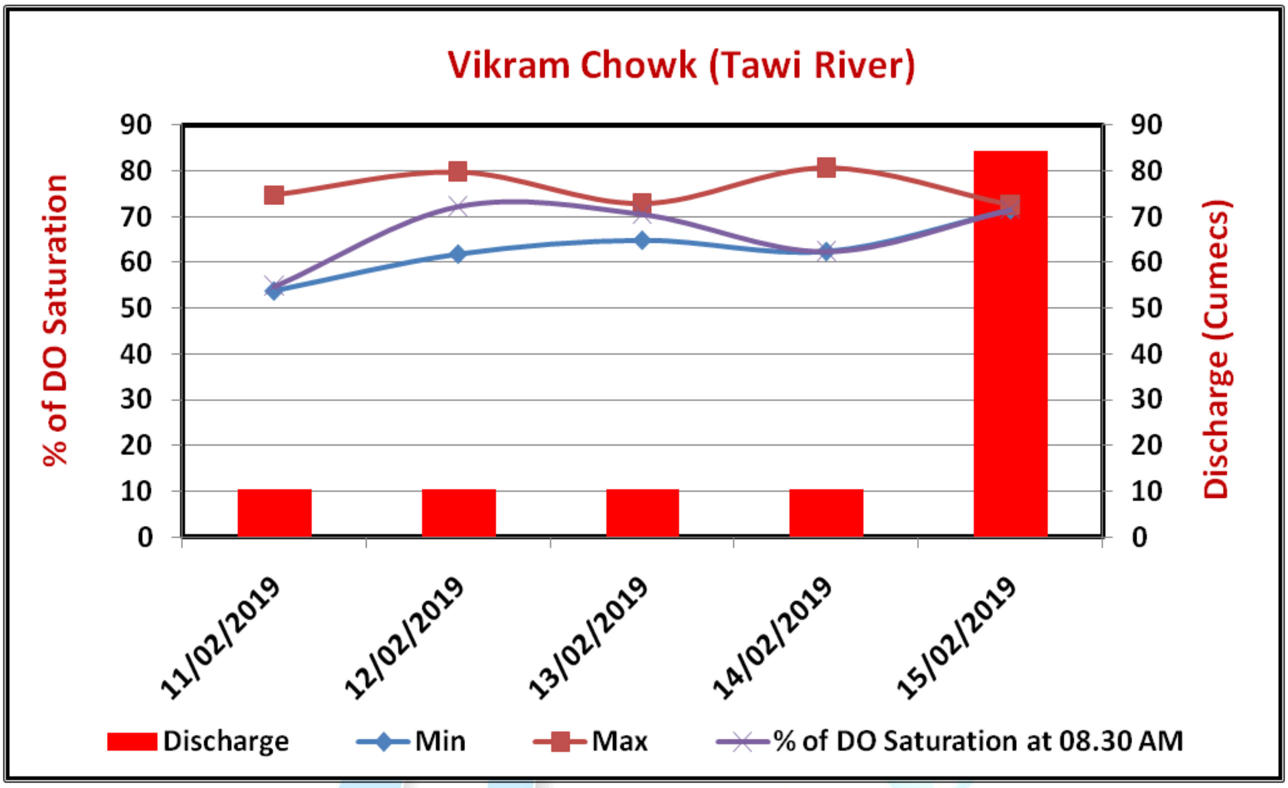


Figure 68: Relation between % of DO saturation and Discharge at Vikram Chowk on Tawi River

CONCLUSIONS

From the Dissolved Oxygen vs Time graphs, it can be seen that, in almost all the WQ stations, Minimum DO values were observed in night and early morning time because during night there is an absence of sunlight which minimized the photosynthesis activities. This resulted in depletion of DO content in water by consuming it in respiration process of aquatic organisms and plants. It can be further explained that, maximum DO values have been found during day times is caused by the oxygen production as a by-product in photosynthesis process of aquatic plants. Here it may be noted that turbulence of flowing water and aeration from air remains same during day and night.

Majorly, maximum DO values have been obtained when the temperatures are in high during day time, which is quite contrary to the general relation between soluble DO and temperature. The reason behind it is that the rate of oxygen diffusion to surface water from atmosphere is comparatively lesser than the rate of oxygen solubility in water as a by-product in photosynthesis process. During day time, oxygen enters into the water body by photosynthesis process and which is primary source of oxygen in all-natural water bodies. It is evident that, temperature is not only parameter which affects in varying DO but there are few more parameters which affect DO variation i.e atmospheric pressure, climatic conditions, salinity, aqua plants and organisms, organic load present in water systems and surface runoff to streams from farm lands [19].

Dissolved oxygen and water temperature exhibited considerable diurnal variations at almost all the WQ stations. Herein, out of 19 WQ stations monitored for DO, 11 WQ stations (Pandu, Ramamangalam, Vikram Chowk, Phulgaon, Satrapur, Jenapur, Khanpur, Garudeswar, Koteshwar, Varanasi and Poanta) were found within prescribed limits for all classes of water, 4 WQ stations (Thengudi, Mantralayam, Gandhighat and Hoshangabad) were found within prescribed limits for Class B, C & D water, 1 WQ station i.e Amabarampalayam was found within prescribed limit for Class C & D water, 2 WQ stations (T. Bekuppe and Agra (P.G)) were found below the limits prescribed for all classes of water. At Delhi Railway Bridge WQ station, DO levels have been observed Zero in all the times during study period from 14/01/2019 to 16/01/2019 irrespective of variation in temperature.

Furthermore, DO results obtained for T. Bekuppe WQ station on Arkavathi River observed below 4 mg/L in early morning and night time (1:00 Hrs to 07:00 Hrs and 22:00 Hrs) and between 4 to 5 mg/L observed during day time i.e from 10:00 Hrs to 16:00 Hrs. DO results obtained for Agra (P.G) WQ station on Yamuna River shows between 2 to 4 mg/L in majority of times and 1.81 mg/L observed during night time i.e at 21:00 Hrs and 24:00 Hrs.

The main conclusions from the study are as under:-

- The DO is reduced in the night but the maximum reduction in DO was observed from 20.00 Hrs to 04.00 Hrs. However, generally DO levels were not found at such low level where aquatic life is in distress. Mostly, less DO concentrations observed during the night times, may be caused by the absence of photosynthesis as well as DO consumption by aquatic plants and decomposition of organic matter by microorganisms.
- The % of DO saturation at the various sites has been found to be between 16.31% and 150.63%.
- The Difference in % of DO saturation in the morning to night is attributed to the effect of photosynthesis.
- During daylight hours due to photosynthesis high DO concentrations were observed. The daily DO maximum commonly occurs in mid - afternoon during which photosynthesis is the dominant phenomenon.
- The relation between flow and DO could not be established due to the limited data.

Further Studies Proposed

- The change of DO with level of BOD needs to be studied.
- Variation of DO with time and its relationship with flora, fauna and nutrients discharged in river from various sources.
- The relationship between discharge and DO in different rivers of India.
- The variation of DO in reservoirs along its length, width and depth needs to be studied for its economic utilization.
- Effect of barrages on DO, both up-stream and down-stream may be studied.
- Effect of Nitrification and sediment oxygen demand might be considered for further study.

REFERENCES

1. Ji, Z., (2008). Hydrodynamics and Water Quality, Modelling Rivers, Lakes and Estuaries. John Wiley & Sons, Honoken, New Jersey.

2. EPA. (2000). Ambient Aquatic Life Water Quality Criteria for Dissolved Oxygen (Saltwater): Cape Cod to Cape Hatteras. Washington DC: Office of Water: Office of Science and Technology.

3. Fondriest Environmental (2013). Inc. "Dissolved Oxygen." Fundamentals of Environmental Measurements. 19 Nov. 2013. Web. < https://www.fondriest.com/environmental-measurements/parameters/water-quality/dissolved-oxygen/ >.

4. USEPA (2000) Nutrient Criteria Technical Guidance Manual: Lakes and Reservoirs, First Edition. EPA - 822 - B00 - 001. Office of Water, Office of Science and Technology, Washington, DC .

5. Wetzel, R. G. (2001). Limnology: Lake and River Ecosystems (3rd ed.). San Diego, CA: Academic Press.

6. Rabalais, N. N., W. J. J. Wiseman, and R. E. Turner. (1994). Comparison of continuous records of near-bottom dissolved oxygen from the hypoxia zone along the Louisiana coast. Estuaries 17(4): 850-861.

7. American Public Health Assoc., American Water Works Assoc. & Water Environment Federation. (1999). Standard Methods for the Examination of Water and Wastewater (20th ed.). Baltimore, MD: American Public Health Association).

8. Dissolved Gases – Oxygen. (n.d.). In Lecture – Water Chemistry. Retrieved from http://www.esf.edu/efb/ schulz/Limnology/Oxygen.html).

9. YSI. (2005). Environmental DO Values Above 100% Air Saturation. In YSI Environmental Tech Note. Retrieved from http://www.ysi.com/media/pdfs /T602-Environmental-Dissolved-Oxygen-Values-Above-100-percent-Air-Saturation.pdf).

10. Oxygen (Dissolved Oxygen, DO). (n.d.). In Water Chemistry. Retrieved from http://academic.keystone.edu/jskinner/Limnology/Water_Chemistry_LectureNotes.html).

11. D. L. Breitburgl, Nancy steinberg, Sarah DuBeau, Cynthia Cooksey, Edwar D Houde, Effects of low dissolved oxygen on predation on estuarine fish larvae. Marine ecology progress series 104, 235-246, 1994.

12. EPA. (1986) Quality Criteria for Water. Washington DC: Office of Water Regulations and Standards).

13. Caduto, M.J. 1990. Pond and Brook: a guide to nature in freshwater environments. Prentice-Hall, Inc. Englewood Cliffs, NJ.

14. Simpson, J.T. 1991. Volunteer Lake Monitoring: A Methods Manual. EPA 440/4-91-002. pp. 16-21,70-72.

15. https://gato-docs.its.txstate.edu/the-riversinstitute/MCWE_NEW_SITE/TST/curriculum/WQMonitoring Manual/curriculumlesson1.pdf)

16. Zhen Xu, Y. Jun Xu (2016). A Deterministic Model for Predicting Hourly Dissolved Oxygen Change: Development and Application to a Shallow Eutrophic Lake. Water 8, 41.

17. Carpenter, J. (1965). The Accuracy of the Winkler Method for Dissolved Oxygen Analysis. In Association for the Sciences of Limnology and Oceanography. Retrieved from http://aslo.org/lo/toc/vol_10/issue_1/0135.pdf

18. APHA, (2017). Standard methods for the examination of water and wastewater (23rd Ed.). Washington, DC: American Public Health Association.

19. Campbell, G. and S. Wildberger. 1992. The Monitor's Handbook . #1507. LaMotte Company, Chestertown, MD, pp. 30-32, 36-39. Phone # 1-800-344-3100.

GUIDANCE

Shri S. Masood Husain, Chairman, CWC, New Delhi

Shri R.K. Sinha, Member (River Management), CWC, New Delhi

Shri Ravi Shanker, Chief Engineer (Planning & Development), CWC, New Delhi

Shri Pankaj Kumar Sharma, Director (RDC -2 Directorate), CWC, New Delhi

Shri Rakesh Kumar, Deputy Director (RDC -2 Directorate), CWC, New Delhi

DATA COMPILATION AND REPORT PREPARATION DONE BY

Dr. Jakir Hussain, Research Officer, RDC-2 Directorate & In-charge & Quality Manager, NRWQL, YBO, CWC, New Delhi

Shri. N. Prabhakarrao, Senior Research Assistant, RDC-2 Directorate, CWC, New Delhi

STAFF INVOLVED IN WATER SAMPLE COLLECTION AND ANALYSIS FROM THE FIELD LABORATORIES

S. No.	Name	Designation	Laboratory / Site Location	
1	Shri. Chandra Pal	Assistant Research Officer	Agra	
2	Shri. Shashi Kant Meena	Senior Research Assistant	Agra	
3	Shri. Vasu Dhanavath	Senior Research Assistant	Agra	
4	Shri. Bhagirathi	Junior Engineer	Agra	
5	Shri. Narayana Swamy	Senior Research Assistant	Bangalore	
6	Shri. V. Ajay Kumar	Senior Research Assistant	Bangalore	
7	Shri. Vijay Kumar	Senior Research Assistant	Bangalore	
8	Shri. N. K. Rohit	Junior Engineer	Hoshangabad Site	
9	Shri. Rahuk Kumar sharma	Junior Engineer	Jenapur Site	
10	Shri. P. Rajan	Assistant Research Officer	Chennai	
11	Shri. Ch. Ajay Kumar	Senior Research Assistant	Chennai	
12	Shri. J. Krishna Pratap V	Senior Research Assistant	Chennai	
13	Shri. K. T. Raman	Work Sarkar (Gr.II)	Chennai	

S. No.	Name	Designation	Laboratory / Site Location	
14	Shri. K. Bal Krishna Chettri	Skilled Work Assistant	Chennai	
15	Shri. Tanmoy Kar	Assistant Research Officer	Coimbatore	
16	Shri. Maneesh T. P	Senior Research Assistant	Coimbatore	
17	Shri. Srikanth Reddy Alla	Senior Research Assistant	Coimbatore	
18	Shri. Mukesh Kumar Yadav	Assistant Research Officer	Hyderabad	
19	Shri. Prasanth Yentapalli	Senior Research Assistant	Hyderabad	
20	Shri. Ankur Patel	Junior Engineer	Mantralayam site	
21	Shri. Angad Kumar	Senior Research Assistant	Jammu	
22	Monika Sharma	Junior Research Fellow /Laboratory Assistant (Contractual)	Jammu	
23	Shri.Mohit Sawhney	Junior Research Fellow /Laboratory Assistant (Contractual)	Jammu	
24	Shri. K. Sasidhar	Senior Research Assistant	Kochi	
25	Shri. Janardhan A	Senior Research Assistant	Kochi	
26	Miss. Malika Kumar	Senior Research Assistant	Surat	
27	Shri. Devnarayan Mali	Junior Engineer	Garudeswar Site	

S. No.	Name	Designation	Laboratory / Site Location	
28	Shri. Barigedi Satheesh Kumar	Skilled Work Assistant	Surat	
29	Shri. Poojari Damodhara Rao	Skilled Work Assistant	Surat	
30	Shri. A. K. Trivedi	Assistant Research Officer	Varanasi	
31	Shri. Ajay Kumar Singh	Senior Research Assistant	Varanasi	
32	Shri. Abhishek Kumar	Senior Research Assistant	Varanasi	
33	Madhuri Saroj	Senior Research Assistant	Varanasi	
34	Shri.Neeraj Kumar	Senior Research Assistant	Dehradun	
35	Shri. Vikrant Babu	Senior Research Assistant	Dehradun	
36	Shri. Jitendra Karva	Junior Engineer	Khanpur Site	
37	Shri. Kalu Ram Bhil	Skilled Work Assistant	Khanpur Site	
38	Shri. V.L. Chauhan	Skilled Work Assistant	Khanpur Site	
39	Shri. R.U. Chauhan	Skilled Work Assistant	Khanpur Site	
40	Shri. Chirag Kumar M.Tank	Skilled Work Assistant	Rangeli Site	
41	Shri. Amit Barud	Senior Research Assistant	Pune	

S. No.	Name	Designation	Laboratory / Site Location	
42	Shri. Brijesh Meena	Junior Engineer	Pune	
43	Shri. Prashant Kamble	Skilled Work Assistant	Pune	
44	Amar Ghaderao	Skilled Work Assistant	Pune	

CENTRAL WATER COMMISSION

Department of Water Resources,
River Development & Ganga Rejuvenation,
Ministry of Jal Shakti
R.K. Puram, Sector 1, New Delhi