**Final Report**

# Conservation of Ponds in Ibrahimpur-Masahi Village and Performance Evaluation of Natural Treatment System


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# PREFACE

Water conservation and rejuvenation/ retrofitting of village ponds are essential for properly utilizing the water for beneficial use in society. The present study was taken for the Ibrahimpur Masahi Revenue village of the Haridwar District (Uttarakhand). A severely degraded village pond at Village Ibrahimpur Masahi has been rejuvenated and thereafter a phytoremediation-based natural treatment system was developed for wastewater treatment. Researchers from CEH-UK were also involved to study the effectiveness of the NTS at Village Ibrahimpur Masahi in comparison with the control pond at Masahi Kala under the SUNRISE program.

Constructed Wetland (CW) is an artificially constructed natural treatment system, using aquatic plants and microbes, for the treatment of wastewater laden with organics and nutrients. It is constructed with locally available materials like gravel, brick ballast, etc., and Reed grass and Canna plants are planted on the wetland bed. It is an eco-friendly, low-cost, and chemical-free technology. The system helps in maintaining a healthy aquatic ecosystem by reducing the oxygen need of the wastewater after treatment. Moreover, it also reduces the fecal coliforms present in the domestic wastewater harmful to human health. CW is highly suitable for treating the effluents generated from villages, especially septic tanks constructed under "Swachh Bharat Mission", to avoid the eutrophication of the ponds which are a source of sustainable water supply for the livelihood of the villagers. The water quality of the pond was also assessed before and after rejuvenation works and the results are discussed in the report.

The present report has been jointly prepared by NIH (Er. Omkar Singh, Scientist F; Dr. Rajesh Singh, Scientist D; Er. Digambar Singh, Scientist C) and UK-CEH (Prof. Laurence Carvalho; Er. Elliot Hurst; Ms. Anne Dovel) under supervision of Dr. V.C. Goyal, Scientist G & Head (RMOD). Shri Subhash Kichlu, PRA; Shri Rajesh Agarwal, SRA; Shri Rakesh Goel, Tech-I; and Shri N.R. Allaka, RA have contributed to various field and lab activities in this study. In addition, pond team members (Dr. N.G. Shrivastava; Er. Jhalesh Kumar; Dr. Nihal Singh; Dr. Kalzang Chhoden; and Er. Subhash Vyas) also assisted in various field/lab activities.

**DIRECTOR**

# ABSTRACT

Ponds are a common feature of many villages in rural India, and are widely used as important sources of water for agriculture, aquaculture and groundwater recharge. Water conservation and restoration of village ponds is, therefore, essential for delivering secure water supplies for beneficial use of society. Realizing the importance of village ponds for water conservation and sustainable development, the Institute (NIH) demonstrated a pilot project aimed at rejuvenating severely degraded pond in Ibrahimpur Masahi village (Dist. Haridwar, Uttarakhand) through the establishment of a Constructed Wetland based Natural Treatment System (CW-NTS). Constructed wetlands are a low-cost, low energy solution for treating wastewater to improve the water quality and also provide natural habitat. The treatment chain comprises of bar screen for removal of large objects like rags and plastics, followed by 3 numbers of grit chambers for removal of heavier inorganic particles (specific gravity: 2.4-2.65), 2 numbers of subsurface flow constructed wetland chambers, and pond.

For effective evaluation of the CW-NTS, and assessment of its potential replicability in other village ponds, NIH has collaborated with UK-Centre for Ecology and Hydrology (United Kingdom). The objectives of the present study were (i) Water quality investigations of identified ponds, village wastewater and adjacent groundwater sources (Handpumps); (ii) Performance evaluation of CW based natural treatment system and assessment of treated wastewater for beneficial uses; (iii) Societal impact assessment of NTS and mass awareness activities.

The water quality of the rejuvenated pond in Ibrahimpur Masahi village has been compared with a control pond (without any constructed wetland treatment) in a nearby village (Masahi Kala). Field investigations related to water quality, ecological quality, greenhouse gas emissions, groundwater quality and level, and social surveys of village attitudes to the constructed wetland and pond rejuvenation were carried out to evaluate the benefits of the constructed wetland treatment system.

The study has shown that the treatment of wastewater entering the pond through the constructed wetland has greatly improved water quality (reduced organic loads, coliform bacteria and nutrients and increased dissolved oxygen levels) compared with the control pond. The ecological quality of the pond with constructed wetland treatment is also much higher, with associated enhanced ambience for villagers. The treatment of domestic wastewater entering the pond also resulted in the reduction of GHGs emissions. Mean $CH_4$-C and $CO_2$-C concentrations measured in Masahi Kala pond were an order of magnitude greater than those measured in Ibrahimpur Masahi (7.66 mg $CH_4$-C $L^{-1}$ and 7.69 mg $CO_2$-C $L^{-1}$ in Masahi Kala compared to 0.237 ± 0.0550 mg $CH_4$-C $L^{-1}$ and 0.933 ± 0.720 mg $CO_2$-C $L^{-1}$ in Ibrahimpur Masahi).

The wastewater generated from the Ibrahimpur Masahi village habitation is contaminated with organics (BOD: 245±71 mg/l; COD: 506±37 mg/l), nitrogen (NO3-N: 2.68±0.29 mg/l; NH4-

N: 9.42±1.77 mg/l), and phosphorus (3.02±0.38 mg/l). The treatment chain comprises of settling chamber (≈2.5 hr HRT), constructed wetland (≈4.5 days HRT), and pond (≈160 days HRT) resulted in a reduction of 45.9% electrical conductivity, 83.2% BOD, 80.9% COD, 29.9% $NO_3$-N, 81.85% $NH_4$-N, and 75% $PO_4$ concentration. An increase of around 824.4% in the DO levels was observed. Further, a 99.6% reduction in average annual total coliform counts and a 99.9% reduction in E. coliform counts were observed. The results indicate a positive impact on the pond water quality and avoided algal blooms at Ibrahimpur Masahi pond.

Comparison of water quality of pond equipped with natural treatment system with the pond without any intervention indicates the improved water quality and pond ecosystem. Treatment of influent of the pond reduces organics, phosphate & nitrate concentrations causing in reduction of eutrophication status of the pond helping to maintain higher DO levels, which is beneficial for fish survival. The average annual DO in the pond without any intervention (Masahi Kala) was 0.35±0.58 and in the pond with the treatment system (Ibrahimpur Masahi) was 5.92±1.68. Ibrahimpur Masahi pond was dominated by Chlorophyta algae (on average 57% of biovolume) and Euglenophyta (on average 32% of biovolume), however, Masahi Kala pond was always dominated by Euglenophyta (on an average 70% of biovolume). Mosquito larva do not appear to be a particular issue in the Ibrahimpur Masahi village pond, as this taxa was only recorded once and in very low numbers, however, mosquito larvae were recorded on both sampling occasions from Masahi Kala village pond.

The rejuvenation of the Ibrahimpur Masahi pond resulted in enhanced groundwater recharge and was evident from the improved groundwater levels. The household survey of villagers indicated a positive impact of the CW-NTS benefits. The residents appreciated the reduction in bad odor and change in the villager's behavior towards the rejuvenated pond. Overall, the study concludes that the Settling chambers followed by Root zone wastewater treatment (CW-NTS) is a sustainable and effective treatment method for rural areas.

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# 1.0 INTRODUCTION

## 1.1 Scope of the Study

In our country, most of the traditional sources of water in villages are on the verge of disappearing/shrinking due to encroachment, siltation, and water quality deterioration, and witnessing severe eutrophication. The ponds located in the Haridwar District are also suffering from various hydrological problems and are at the verge of extinction, requiring immediate intervention to restore for various uses. Surface water resources (Pond) can be used to provide water for livestock, domestic use, and irrigation purposes. Water conservation and rain harvesting may help improve the livelihood of the people by reducing the uncertainty of human life. The purpose of rainwater harvesting is to either augment existing water supplies or to provide water where other sources are not available. It also aims to provide water in sufficient quantity and of suitable quality for the intended use. Therefore, water conservation and management of village ponds are essential for properly utilizing the water for beneficial use in society. The present study was taken for the Ibrahimpur Masahi Revenue village of the Haridwar District.

## 1.2 Statement of the Problem

Realizing the need and importance of the ponds for the society for sustainable development and utilization of available resources, the Institute (NIH) has rejuvenated a pond (Village: Ibrahimpur Masahi, Tehsil-Bhagwanpur, Dist. Haridwar) and established CW based Natural Treatment System (NTS) as a pilot study (Omkar & Goyal, 2017-18) . The rejuvenated ponds with treated wastewater will be used for agricultural use and other livelihood activities such as fishery. The performance evaluation of this system is necessary to establish its feasibility and replicability in other village ponds receiving continuous input of domestic wastewater into the village ponds. Therefore, it was proposed to monitor important water/wastewater quality parameters at two ponds, namely Ibrahimpur Masahi (receives village wastewater through constructed wetland) and Masahi Kala (control pond/reference pond: pond without any treatment system).

## 1.3 Objectives

The main objectives of the study are given as below:

- Water quality investigations of identified ponds, village wastewater, and adjacent groundwater sources (hand pumps)
- Performance evaluation of CW based NTS and assessment of treated wastewater for some uses
- Societal impact assessment of NTS and Mass Awareness Activities

## 2.0 REVIEW OF THE LITERATURE

'Phytoremediation' word is a combination of two different words in which the first word is taken from the Greek word 'Phyto' means plant, and the second word is the Latin word 'remedium' means to reduce or remove an evil (Cunningham et al., 1996). Phytoremediation is defined as the use of plants and their associated micro-organisms for the reduction of contaminants in wastewater and contaminated soil. Phytoremediation technique is also called "Green remediation" and "Botanical bioremediation". This plant-based wastewater treatment technology has widely been used for the enhancement of environmental clean-up by removing pollutants and heavy metals present in wastewater (Pilon-Smiths, 2005; Cook and Hesterberg, 2013). The mechanized or conventional treatment technologies require high financial cost, energy, and skilled labor for the treatment of wastewater. The phytoremediation technology is used as an alternative or complimentary for wastewater treatment. It is an in-situ wastewater treatment/remediation technology in which living plants are used to reduce pollutants for removing contaminations. It is also an eco-friendly, solar-energy-driven clean-up technology because solar radiation is used by plants for the photosynthesis process and uses nutrients. It is based on the concept of nature to cleanse nature.

In the 1950s, German Scientist Kathe Siedel made the first constructed wetland (CWs) for wastewater treatment. In the late 1960s, the first full-scale CW was made and at present in Europe, more than 50,000 and in North America more than 10,000 CWs are operating for wastewater treatment (Kadlec and Wallace 2009; Vymazal, 2011; Yan and Xu, 2014). In developing countries, especially in China, thousands of CWs are used as an alternative technique for wastewater treatment (Chen et al. 2011). In the 1960s and 1970s, mainly domestic and municipal wastewater were treated using CWs. However, in recent years, CWs are used for the treatment of a variety of wastewaters like domestic wastewater, industrial effluents, agricultural effluents, mine drains, leachates, polluted ponds, rivers, lakes, highway runoff, etc. for different climatic conditions (Wu et al., 2014). Many types of pollutants can be removed by plants like heavy metals, agricultural pesticides, explosives, and petroleum oil (USEPA, 2000). In tropical areas, the potential use of this phytoremediation technology is high due to the favorable climatic conditions which enhance plant growth and stimulates microbial activity (Zhang *et al.*, 2010). In recent times, the industrial economy and excessive use of chemicals used in agriculture (pesticide, herbicide, and fertilizers) result in environmental degradation around the world, so scientists and researchers are busy to develop new techniques for solving this problem and remove contaminants from wastewater. The phytoremediation technique is one of them (USEPA, 2000).

The working mechanisms and performance efficiency of any phytoremediation technology mainly depend on the type of contaminants (strong, medium, and weak), bio-availability, and soil properties (texture and structure) (Cunningham and Ow, 1996). In phytoremediation technology, there are several ways by which plants can remedy and remove contaminants on site. The plant uptake contaminants by the root system, which is the main mechanism for reducing toxicity. For plant growth, the plant's root provides a large area that accumulates contaminants and nutrients (Raskin and Ensley, 2000). The presence of bacteria and other microorganisms in soil rhizosphere is 100 times larger than in soil outside the rhizosphere (USEPA, 2000), which helps in breaking down the contaminants.

According to Garbisu (2002), phytoremediation is a cost-effective, non-intrusive, and aesthetically pleasing technique in which some specific plant species are used to remove or reduce various contaminants present in the wastewater by plant tissues. The phytoremediation technology is widely used for the removal of contaminants such as radionuclides, metals (heavy and toxic), organic compounds like poly chlorobiphenyls, polycyclic aromatic hydrocarbons, chlorinated solvents, insecticides, pesticides, explosives, and surfactants. Macek (2004), used green plants and microbes as a bioremediation technique to reduce the harmful pollutants like recalcitrant organic compounds or heavy metals in wastewater. Some specific plant species were used for bioremediation as plants reduce the contaminants and prevent the leaching of toxic substances to the surrounding areas. According to Huang and Cunningham (1996), by using genetic engineering, it is possible to modify plants characteristics in such a way that plants can remove contaminants easily, fast, and significantly from the wastewater.

## 3.0 STUDY AREA

### 3.1 General Details

The study area (i.e. Ibrahimpur Masahi revenue village) is falling under Shipla Nadi-Halzora Nadi watershed, District Haridwar (Uttarakhand). The location map of the CW-NTS pond and surroundings GW monitoring stations are given in Figs. 1a & 1b, respectively. The Shipla Nadi-Halzora Nadi watershed lies from 29º56' to 30º05' North latitude and 77º48' to 77º55' East longitude under SOI Toposheet Nos. 53 F/16 and 53 G/13 (1:50,000). The geographical area of the Shipla Nadi-Halzora Nadi watershed is 101.5 $km^2$ up to the river bridge at village Imlikhera. The area of Ibrahimpur Masahi revenue village is 14.26 $km^2$ which represents about $1/7^{th}$ of the watershed area up to Imlikhera bridge. The Ibrahimpur Masahi revenue village consists of main five sub-villages (Ibrahimpur Masahi, Masahi Kala, Belki Masahi, Inayatpur, and Halzora) under its jurisdiction (Singh & Goyal, 2018; Singh, et al.2018; Singh & Goyal, 2019). In the present study, two ponds located at Ibrahimpur Masahi (pond no.1, CW-NTS, Fig.2a) and Masahi Kala (pond no.4, control pond, Fig.2b) were selected for the present study (Table 1).

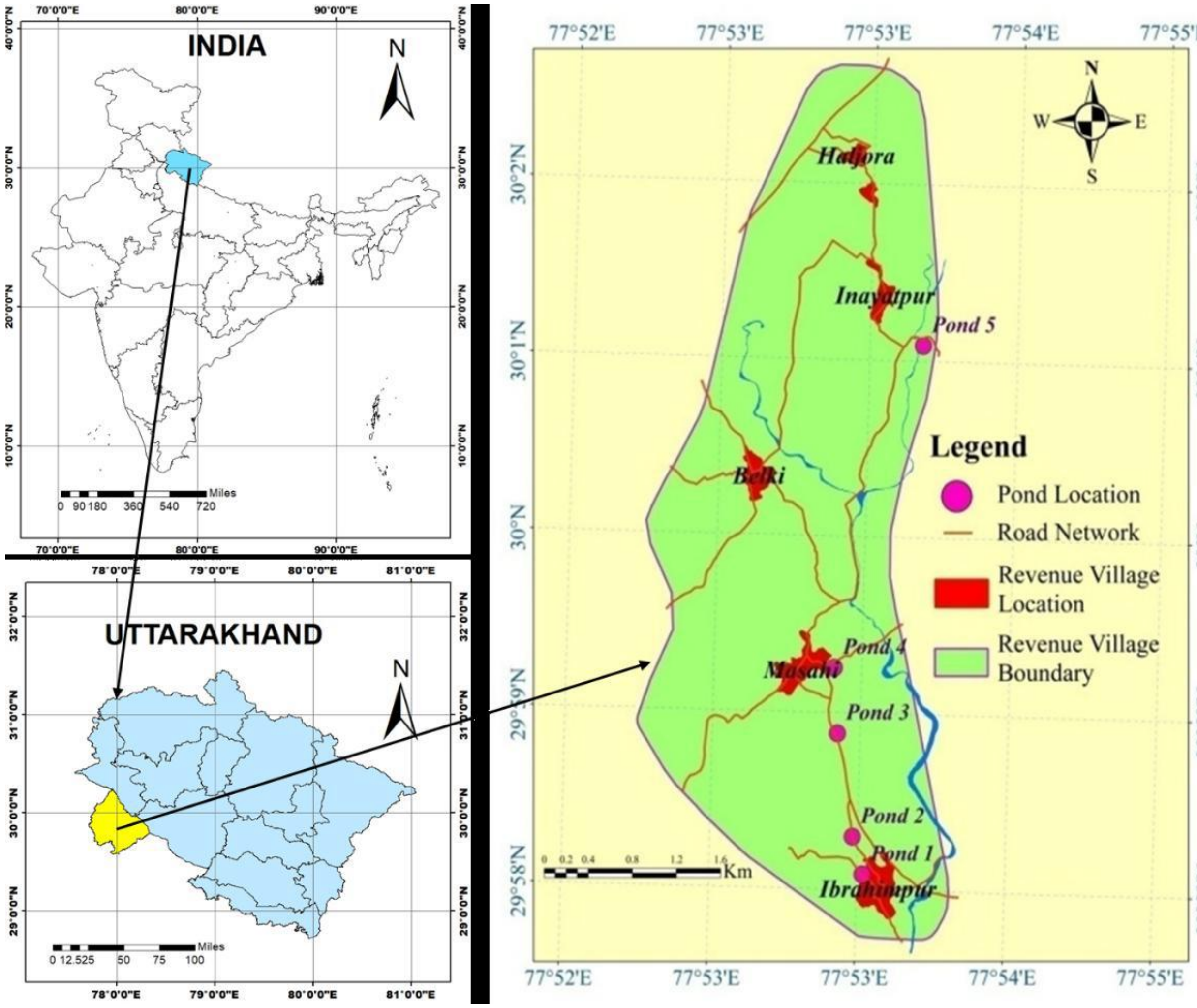



Fig. 1a: Location map of the Ibrahimpur Masahi Village

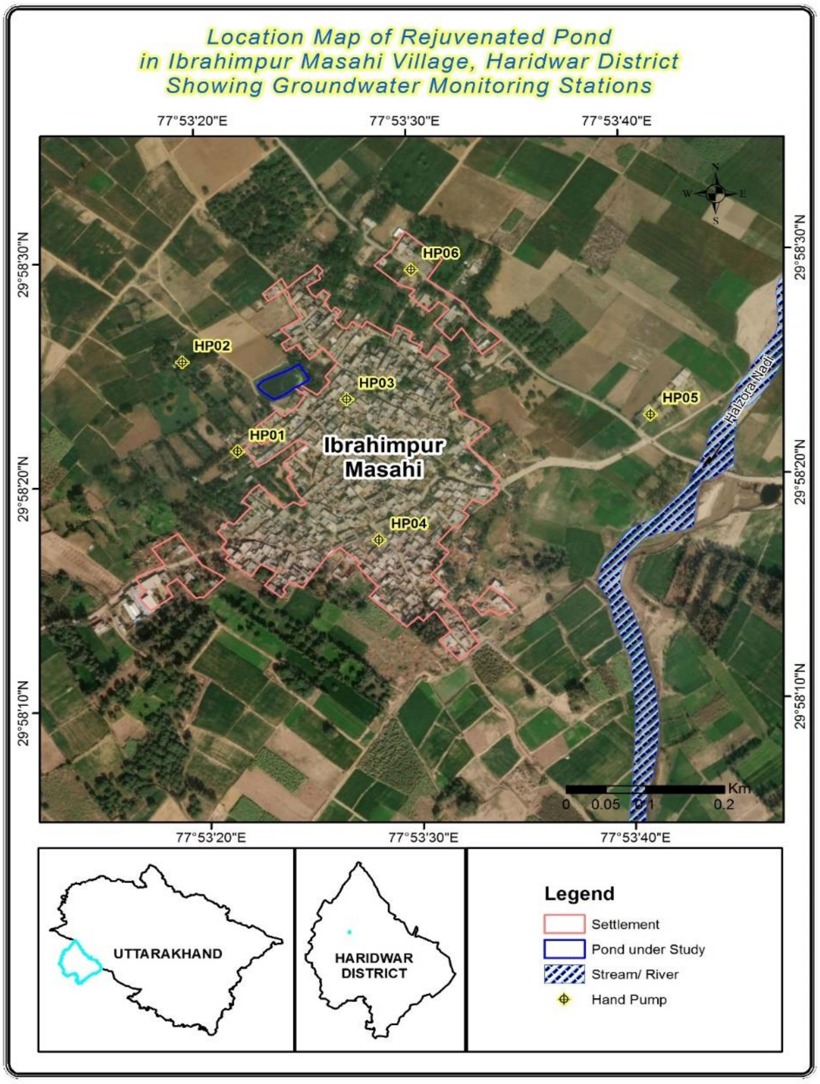



Fig. 1b: Location map of rejuvenated pond with surrounding GW monitoring sites

Table 1: Details of ponds under the study in Ibrahimpur Masahi Revenue Village

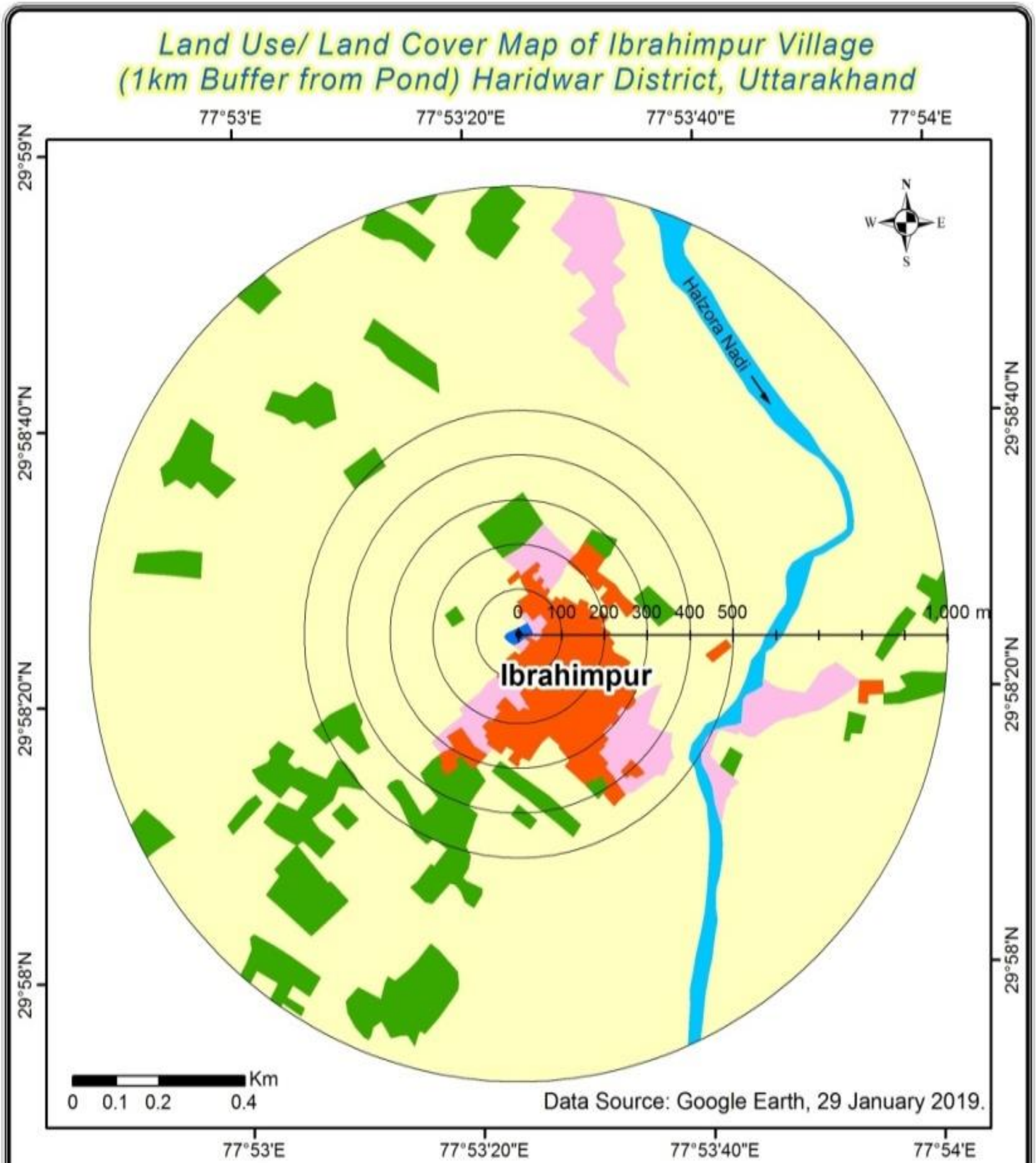
| Details | CW-NTS Pond (pond no.1) | Control Pond (pond no.4) |
|---|---|---|
| | Ibrahimpur Masahi | Masahi Kala |
| Latitude | $29^0$ 58’24.4” | $29^0$ 59’22.7” |
| Longitude | $77^0$ 53’22.3” | $77^0$ 53’11.11” |
| Altitude (m) | 250.59 | 241.64 |
| Area ($m^2$) | 2252 (0.6 Acre) | 2954 (0.74 Acre) |
| Perimeter (m) | 210.0 | 251.0 |
| Pond Depth (m) | 2.31 (3.4 after de-silting works) | 1.5 |
| Capacity ($m^3$) | 5202 | 4431 |
| After De-silting ($m^3$) | 7657 | - |

Fig. 2a: View of CW-NTS pond at Ibrahimpur Masahi

Fig.2b: View of control pond at Masahi Kala

**3.2 Land Use/ Land Cover**

Land Use/ Land Cover map of village (Fig. 3) was prepared using ArcMap 10 software as follows by considering a buffer of 1 Km around the pond which was rejuvenated. Digitized the pond as a polygon feature by adding an online satellite image (google earth images: Jan 2019) to ArcMap – ArcInfo window as a base map. Then digitized all land-use patterns as discussed above like croplands, orchard/ groves, barren lands, settlements, etc. using the editor tool. Also digitized obstructions like river/streams to know the difficulties to transport treated wastewater for reuse. Then combined all similar land use patterns using merge tool of editor. Clipped the polygon file using concentric circles of various radii like 100m, 200m, 300m, 400m and 500m to calculate area under various land use patterns at specified distances.The treated or semi-treated wastewater collected in Ibrahimpur village pond after rejuvenation can be used: to irrigate crop land of 14.55 Ha located upto a distance of 300m, orchard/ grove of 1.57 Ha located upto a distance of 300m and to produce fodder in barren land of 2.81 Ha located at a distance of 300m.




| S.No. | LU/LC Class | Area (Ha) covered within a radius of | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1000m | 500m | 400m | 300m | 200m | 100m |
| 1 | Barren Land | 11.37 | 5.06 | 4.36 | 2.81 | 1.80 | 0.30 |
| 2 | Crop Land | 258.66 | 56.51 | 32.05 | 14.55 | 5.59 | 1.40 |
| 3 | Orchard/ Grove | 26.37 | 6.14 | 3.57 | 1.57 | 0.21 | 0.00 |
| 4 | Settlement | 10.65 | 10.44 | 10.12 | 9.18 | 4.81 | 1.28 |
| 5 | Water Body (Pond under Study) | 0.16 | 0.16 | 0.16 | 0.16 | 0.16 | 0.16 |
| 6 | Water Body (River) | 6.92 | 0.21 | 0.00 | 0.00 | 0.00 | 0.00 |

Fig.3: Land Use/ Land Cover map of Ibrahimpur Masahi Village (CW-NTS)

## 4.0 MATERIALS AND METHODS

### 4.1. Establishment of CW-NTS

Constructed Wetland (CW) is an artificially constructed natural treatment system, using aquatic plants and microbes, for treatment of wastewater laden with organics and nutrients. It is constructed with the locally available material like gravel, brick ballast, and Reed grass & Canna plants etc. It is an eco-friendly, low cost, and chemical free technology. The system helps in maintaining the healthy aquatic ecosystem by reducing the oxygen need of the wastewater after treatment. Moreover, it also reduces the fecal coliforms present in the domestic wastewater harmful for human health. CW is highly suitable for treating the effluents generated from villages, especially septic tanks constructed under "Swachh Bharat Mission", to avoid the eutrophication of the ponds which are a source of sustainable water supply for the livelihood of the villagers. The pond rejuvenation stages and establishment of CW-NTS has been shown in Figs. 4a & 4b, respectively.

Fig. 4a: Pond Rejuvenation and establishment of CW-NTS at Ibrahimpur Masahi pond

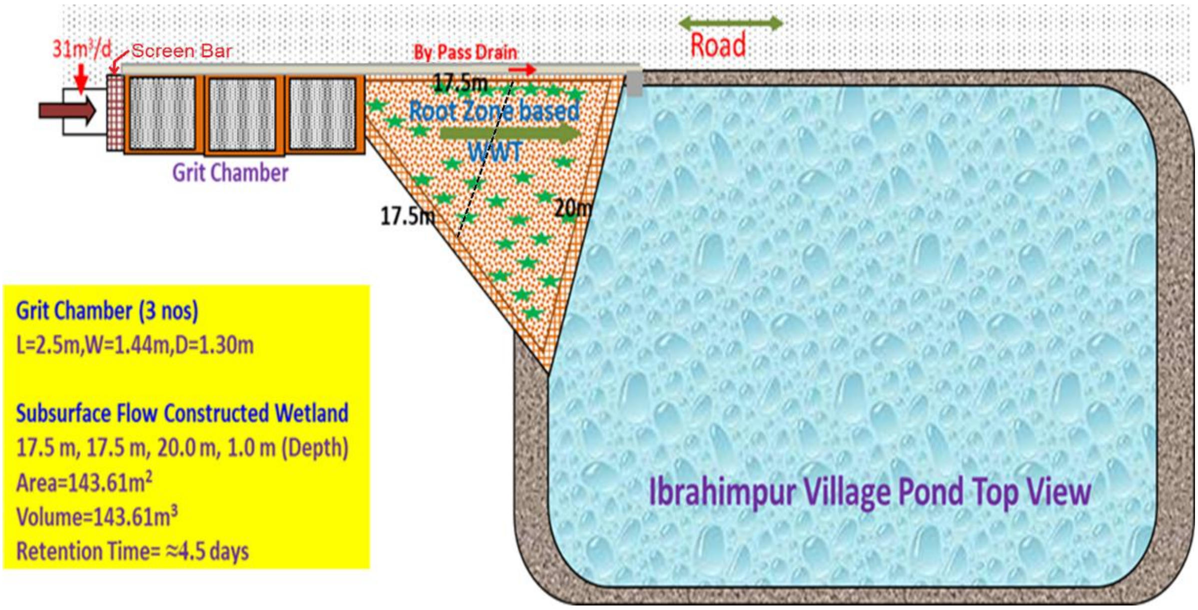



Fig. 4b: Plan view of the CW-NTS at Ibrahimpur Masahi village Pond (Dist. Haridwar)

### 4.2. Water Quality

Initially, the degraded village pond at Ibrahimpur Masahi was rejuvenated by de-weeding and desilting works. Thereafter, Natural treatment system i.e. constructed wetland was established in Ibrahimpur Masahi village in order to evaluate the performance of CW-NTS. Water quality of the samples from the treatment chain/units at CW-NTS pond (Ibrahimpur Masahi) and control pond (Masahi Kala) were collected at regular interval as given Table1. The samples from the two ponds (CW-NTS pond Ibrahimpur Masahi and control pond Masahi Kala) were collected in appropriate sampling bottles using the grab sampling method, preserved, and analyzed for indicator parameters like pH, EC, DO, BOD, COD, $NO_3$-N, $PO_4$ and $NH_3$-N as per standard procedures (APHA 2017). The samples were brought to the lab in the ice bath at around 6 °C and were kept in a freezer maintained at 4 °C. The samples were analyzed for BOD and Coliforms immediately after arriving in the laboratory on the same day of sampling, and the remaining parameters were analyzed within a week time. The hand-pumps were continuously pumped for at least 15 minutes before the sampling, to ensure the groundwater to be sampled was representative of the groundwater aquifer.

The specific water quality parameters (viz. GHGs, biota) were monitored and analyzed along with the UK-CEH team. The health of the rejuvenated pond and its impact on society was also assessed in association with UK-CEH. The water quality assessment for agriculture purposes (BIS-1987/2001; USDA 1954) and Fishery was performed as per recommended procedures and eutrophication of ponds assessed using Carlson's Trophic State Index (Carlson, 1977). The mass awareness activities were also carried out for creating awareness among the local people/school students for water conservation and management of local water sources. A schedule of water quality sampling in the study as carried out by NIH and UK-CEH is given in Table 2. Photographs showing field activities at both identified ponds are given in Fig.5.

Table 2: Schedule of Field Investigations Conducted in the Study Area at Ibrahimpur Masahi

| Months | Date of Sampling | Months | Date of Sampling |
|---|---|---|---|
| November 2018 | 2/11/2018 | April 2019 | 24/04/2019 |
| | 14/11/2018 | May 2019 | 09/05/2019 |
| | 20/11/2018 | | 23/05/2019 |
| | 28/11/2018 | June 2019 | 04/06/2019 |
| December 2018 | 12/12/2018 | July 2019 | 2/07/2019 |
| | 27/12/2018 | August 2019 | 28/08/2019 |
| January 2019 | 15/01/2019 | September 2019 | 13/09/2019 |
| | 30/01/2019 | October 2019 | 10/10/2019 |
| February 2019 | 13/02/2019 | | 25/10/2019 |
| | 28/02/2019 | November 2019 | 19/11/2019 |
| March 2019 | 13/03/2019 | December 2019 | 05/12/2019 |
| | 27/03/2019 | March 2020 | 02/03/2020 |
| | | October 2020 | 29/10/2020 |

Fig. 5: Photographs showing field activities at identified ponds

## 4.3 Chemicals and Reagents

All chemicals used for analysis were of analytical reagent grade (Merck/BDH/Thermo Fisher). Standard solutions were procured from Merck, Germany. De-ionized water was used throughout the analysis work. All glassware and other containers used for the analysis were thoroughly cleaned by soaking in detergent followed by soaking in 10% nitric acid for 48 hours and finally rinsed with de-ionized water several times before use.

## 4.4 Sampling & Analysis of Greenhouse Gas Emissions

Dissolved gas samples were collected from Ibrahimpur pond and Masahi pond on two occasions, in November 2018 and December 2019, following a simple headspace method (Billett & Moore, 2008; Kling et al., 1992). Both air and headspace samples were collected – in triplicate – on each sampling occasion, using a 200 mL syringe with a 3-way valve attached. Gas samples were stored in 20 mL glass vials, pre-sealed with a crimp cap and rubber plug. These vials were filled with a double-needle system; a large needle was attached to the syringe was used to fill the vial while a smaller needle acted as an outlet. Excess sample escaped through the outlet needle, thereby flushing the vial with the sample. Both needles were removed simultaneously to prevent any loss of sample. Samples of ambient air were collected at a height of 2 m above the water surface, with 100 mL of sample injected into the 20 mm vial using the double-needle system. For headspace samples, 100 mL of water was drawn up at approximately 10 cm below the surface of the water and 100 mL of air drawn from just above the surface. The 200 mL syringe was shaken vigorously for 90 seconds to equilibrate gas between the water and the headspace (Garnett et al., 2016). 100 mL of headspace gas was injected into the 20 mL vial using the double-needle system. Care was taken not to allow any water to enter the vial. Samples were stored in the 20 mL glass vials, in ambient conditions, for up to 3 months.

Samples were analyzed by gas chromatography, using an Agilent 7890B gas chromatograph (GC) and 7697A headspace autosampler (Agilent, Santa Clara, California). The GC was fitted with a flame ionization detector (FID) for the measurement of $CH_4$ and $CO_2$; and a micro electron capture detector (μECD) for the measurement of $N_2O$. Measured limits of detection were 40 ppb, 5000 ppb, and 5 ppb for $CH_4$, $CO_2$, and $N_2O$ respectively (Drewer et al., 2020). Concentrations were determined from the relationship between the known concentration of four mixed gas standards and the area of their chromatogram peaks. The concentrations of these standards ranged from below ambient to high: 1.12 to 98.2 ppm for $CH_4$; 202 to 5253 ppm for $CO_2$; and 0.208 to 1.04 ppm for $N_2O$. $CH_4$ concentrations in headspace samples were far higher 98.2 ppm, falling outside the range of calibration. These samples were diluted with inert nitrogen gas to levels that could be reliably measured by the instrument. The scale of dilution was determined for each batch of triplicate samples; one sample was analyzed without dilution, and the required dilution factor was estimated based on the measured concentration. Headspace samples taken from Ibrahimpur pond in November 2018 were diluted 10-fold, samples taken from Masahi pond in November 2018 were diluted 100-fold. Samples taken from both ponds in December 2019 were diluted 5-fold, though Masahi samples still exceeded the calibration range following this dilution – these samples were hence excluded from any mean calculations but were included in comparison plots. Dilutions were found to overestimate $CH_4$ and $CO_2$ concentrations; with errors of 5 to 19% for $CH_4$, and 19 to 22% for $CO_2$. $N_2O$ concentrations in the headspace samples could not be measured as dilution resulted in concentrations dropping below the detection limit.

### 4.5 Sampling & Analysis of Plankton and Freshwater macroinvertebrates

For phytoplankton samples, 50 mL of water was taken from the edge of the ponds from about 20 cm depth below the water surface. The samples were preserved with Lugol's iodine in the field and subsequently analyzed in Edinburgh, UK. Phytoplankton sub-samples were examined using a Zeiss Axiovert inverted microscope and analyzed quantitatively, with approximately 400 phytoplankton units counted per sub-sample at a range of magnifications and biovolume determinations made according to standard procedures (CEN, 2004 & 2008). Identification largely followed John et al. (2011). Crustacean zooplankton were sampled through a 2 m horizontal net tow, just below the water surface. For freshwater macroinvertebrates, surface net sweep samples were taken particularly to sample mosquito pupae and other freshwater invertebrates of the neuston (water surface) habitat. The samples were preserved using 40% ethanol in the field and subsequently analyzed in Edinburgh, UK. To provide an estimate of the relative abundance of the recorded zooplankton and invertebrate taxa, the following semi-quantitative DAFOR scale was used:

Dominant: >10, 000 individuals
Abundant: 1,000-9,999 individuals
Frequent: 100-999 individuals
Occasional: 10-99 individuals
Rare/Present: 0-9 individuals

### 4.6 Monitoring of Ground Water Levels

The groundwater levels were monitored from different handpumps located in the vicinity of the village pond. The details of monitored Handpumps and GW levels are given in Table 2. Photograph showing GW level monitoring from Handpump is given in Fig. 6.

Table 3: Details of monitored Handpumps with GW Levels in Ibrahimpur Masahi

| Hand Pump ID | Latitude | Longitude | Depth to Water (m, bgl) | | | | |
|---|---|---|---|---|---|---|---|
| | N | E | Jan. 2017 | Nov. 2017 | Apr. 2018 | Jun. 2019 | Mar. 2020 |
| HP01 | 29°58'21.47" | 77°53'21.36" | - | 13.6 | 13.8 | 14.4 | 12.5 |
| HP02 | 29° 58' 26.30" | 77° 53' 18.66" | - | 14.2 | 14.4 | 14.8 | 13 |
| HP03 | 29°58'23.69" | 77°53'26.57" | 14.3 | 14.5 | 14.7 | 15.3 | 13.6 |
| HP04 | 29° 58' 17.38" | 77° 53' 27.91" | - | 17.6 | 17.9 | 17.7 | - |
| HP05 | 29°58'22.70" | 77°53'40.86" | 3.5 | 3 | 3.1 | - | 2.4 |
| HP06 | 29° 58' 29.40" | 77° 53' 29.76" | 9.43 | 7.54 | 7.73 | 8.3 | 6.62 |

Fig. 6: Photograph showing GW level monitoring from Handpump

## 5.0 RESULTS AND DISCUSSION

### 5.1 Diurnal Variation of quantity and quality of domestic wastewater in Ibrahimpur Village

The 24-hour flow of domestic wastewater from Ibrahimpur village and discharge in the pond was measured at an interval of one hour on 22-12-2018, 04-06-2019, and 05-12-2019 by volumetric method with the help of known volume of container and stopwatch. Further, the hourly flow was measured on 03-02-2020 for 12 hours (07:00 HR to 19:00 HR).

To understand the variation in water quality parameters of the wastewater entering the wetland, the wastewater samples were collected at the interval of 3 hours for 24 hours on 04-06-2019 from the inlet of the grit chamber. The samples were analyzed for pH, electrical conductivity, dissolved oxygen, biochemical oxygen demand, nitrate, ammonia, and phosphate.

#### 5.1.1 Discharge

The average domestic wastewater discharge was around 0.04±0.07 million liters per day (MLD) or 43.83±0.25 cubic meters per day. The maximum discharge of domestic wastewater was observed in the morning hours, 8:00 HR-9:00 HR, and the flow reduced to almost zero in midnight, 12:00 -2:00 hr. Variation of domestic wastewater flow is shown in figure 7.

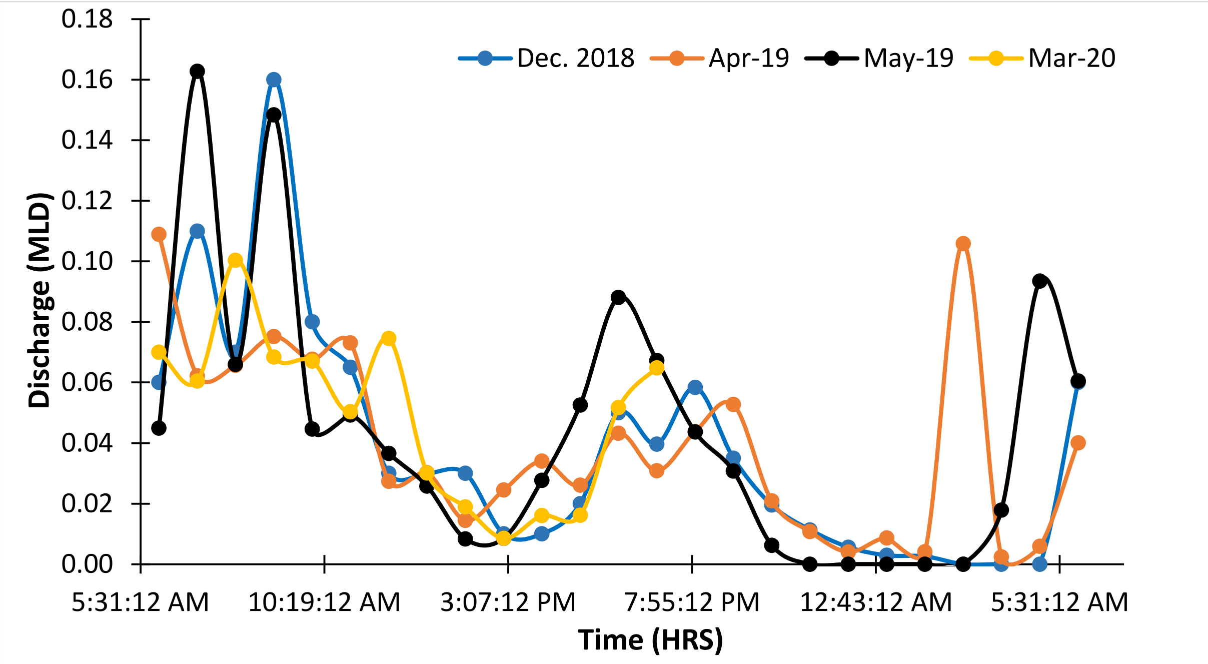



Fig. 7: Diurnal variation in Discharge of Domestic Wastewater in Ibrahimpur Village

### 5.1.2 pH

The maximum pH value (8.3) of wastewater of Ibrahimpur was observed at around 21:20 HR and the minimum value (7.85) at 18:20 HR (Fig. 8). The wastewater was alkaline throughout. The increase in pH was observed with an increase in the flows and may be due to an increase in the soaps and detergents in the wastewater from bathing and cleaning clothes and utensils.

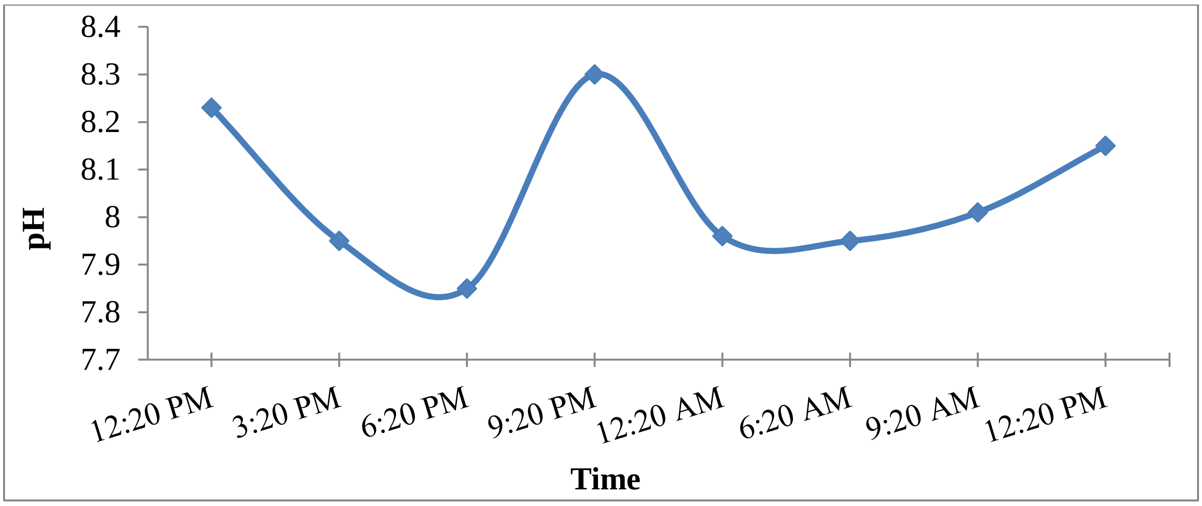



Fig. 8: Diurnal variation of pH in Domestic Wastewater of Ibrahimpur Village

### 5.1.3 Electrical Conductivity

The maximum electrical conductivity (2070 µs/cm) was observed at around 18:20 HR and the minimum value (1733 µs/cm) at around 21:20 HR (Fig. 9). The increase in conductivity is observed with the increase in the wastewater during peak hours and maybe again due to the increase in the salts due to the usage of detergents and salts from the food materials and animal feed. Moreover, the increase in conductivity coincides with the increase in BOD values in the wastewater. The organics get decomposed into organic acids which result in an increase in conductivity and a decrease in pH.

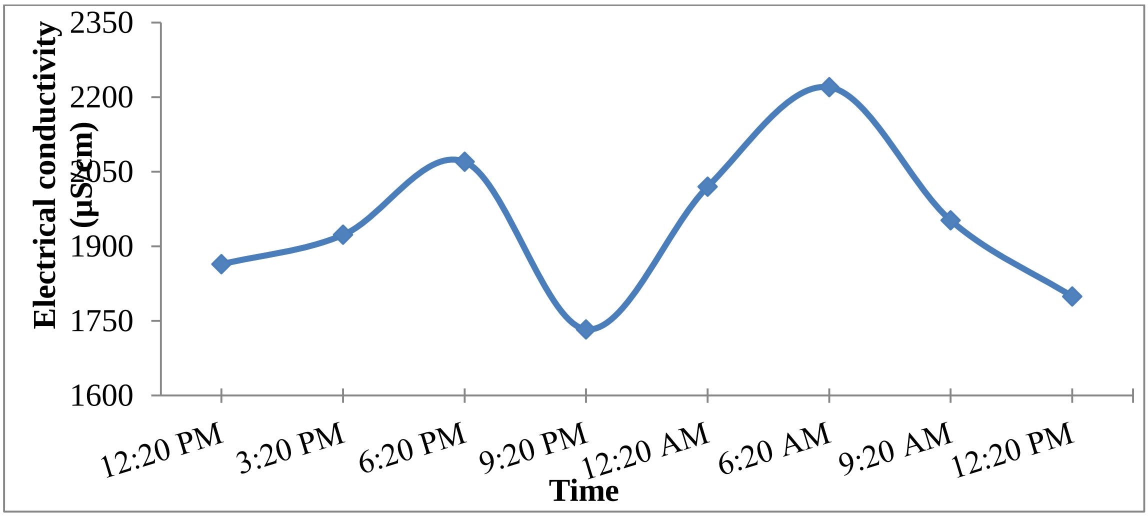



Fig. 9: Diurnal variation in Electrical Conductivity of village wastewater

### 5.1.4 Biochemical Oxygen Demand

The diurnal variation in BOD of the wastewater from the village ranges from 120 mg/L to 230 mg/L (Fig. 10). High BODs were observed during the periods of high flows and may be due to the presence of cow dungs and food particles due to cleaning of animal sheds and utensils respectively. High BODs may be also due to the sweeping of organics settled in the drains. During low flow periods, the organic solids may get settled in the drains and the discharge is mostly from the septic tanks due to which the BOD concentration is lower.

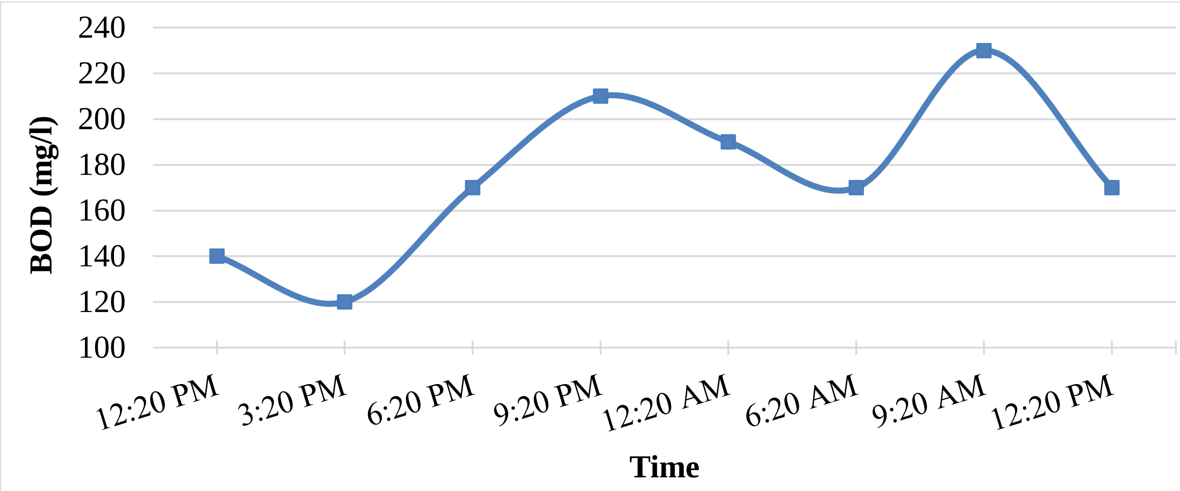



Fig. 10: Diurnal Variation of BOD in Domestic Wastewater of Ibrahimpur Village

### 5.1.5 Nitrate, Ammonia, and Phosphate

A higher concentration of nitrogen and phosphorus in the water bodies results in eutrophication and damages the ecological balance of the water body. The contaminated water when sips into the ground, the phosphorus gets trapped in the aquifer minerals but the nitrogen reaches the groundwater and contaminates it. The concentration of nitrate-nitrogen higher than 10 mg/L in drinking water is detrimental to human health and can cause methaemoglobinaemia in kids and even cancer.

Maximum Nitrate-nitrogen concentration, 6 mg/L, in wastewater of Ibrahimpur was observed at 21:20 HR and minimum value, 0.2 mg/L, was recorded at 06:20 HR (Fig. 11). The concentrations were as expected in the sewage and the fluctuation in the nitrate-nitrogen was observed similar to BOD in the wastewater. The nitrate in domestic wastewater is due to the oxidation of ammoniacal nitrogen.

The highest concentration of ammoniacal nitrogen in domestic wastewater, 3.52mg/L, was recorded at 09:20 HR and the lowest value, 0.06 mg/L, was observed at 06:20 HR (Fig. 11).

The reduced concentration of ammonia was observed during low flow conditions due to sufficient aeration of wastewater in the drains.

The phosphate concentration in the wastewater was observed in the range 0.8 mg/L at 15:20 HR to 2.3 mg/L at 12:20 HR (Fig. 11).

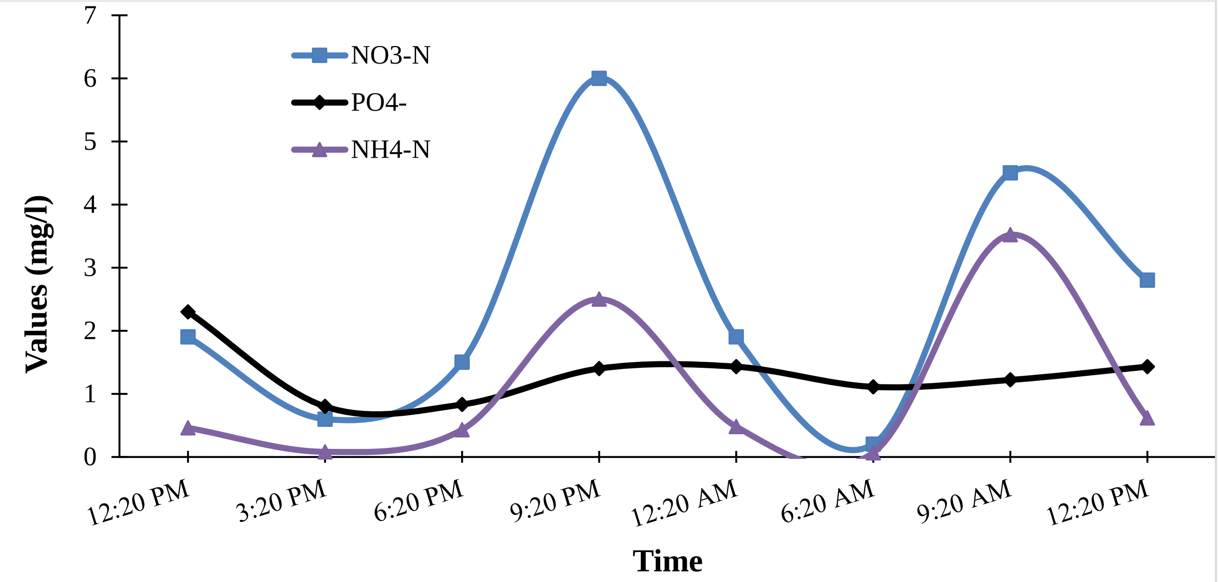



Fig. 11: Diurnal Variation in Concentration of Nitrate-Nitrogen, Ammoniacal-Nitrogen and Phosphate in Domestic Wastewater of Ibrahimpur Village

## 5.2 Characteristics of Domestic wastewater of Ibrahimpur village based on the monthly variation of water quality parameters

To understand the variation in water quality parameters of the wastewater entering the wetland, the wastewater samples were collected at the interval of 15 days from November 2018 to October 2020. The samples were collected almost at the same time, 11:00 HR. The samples were analyzed for pH, electrical conductivity, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, nitrate-nitrogen, ammoniacal-nitrogen, phosphate and bacteriological parameters, E. coliform and Total coliform

### 5.2.1 pH & Electrical Conductivity

The pH value of domestic wastewater of Ibrahimpur was always higher than 7 and lower than 8.5 (Fig. 9). The highest value of pH 8.35 was observed in February 2019 and the lowest value 7.0 was recorded in October 2019. The average annual pH value of the wastewater was 7.68±0.1.

The electrical conductivity of the wastewater, an indicator of dissolved solids, ranged from 1280 µs/cm to 2178 µs/cm with an average value of 1820±72.42µs/cm (Fig. 12).

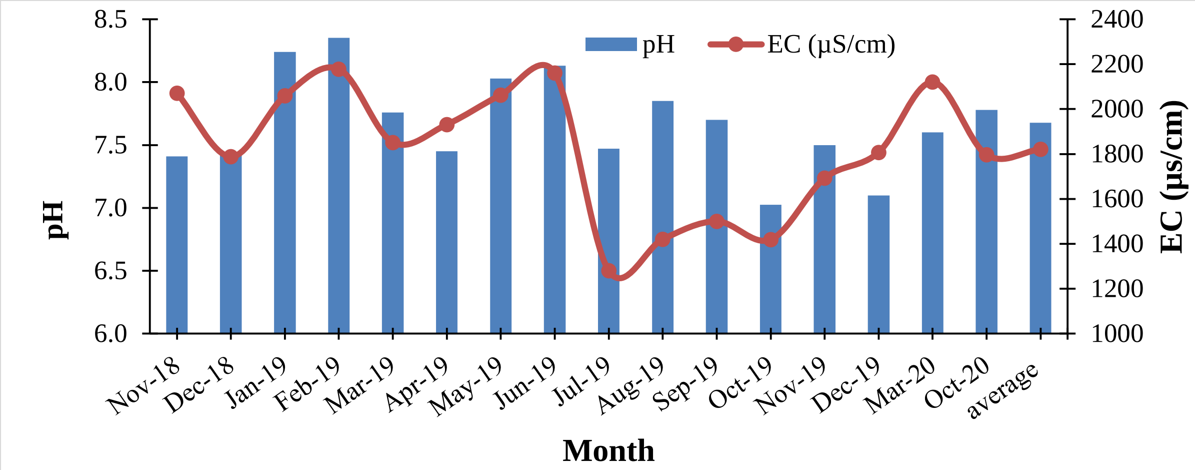



Fig. 12: Monthly Variation in pH and Electrical Conductivity of Domestic Wastewater of Ibrahimpur Village

### 5.2.2 Dissolved Oxygen

The average annual dissolved oxygen (DO) of domestic wastewater was 0.64±0.8mg/L. The highest value of dissolved oxygen was recorded in May and June 2019 which were 1.2 mg/L and 1.1 mg/L respectively and the lowest value of dissolved oxygen was 0.2 mg/L in March and October 2020 (Fig. 13).

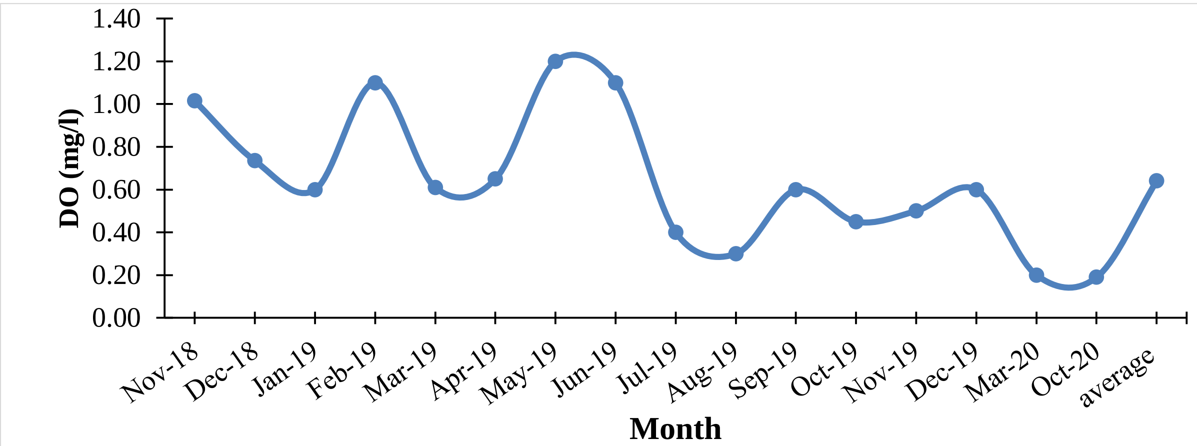



Fig. 13: Monthly Variation in Dissolved Oxygen of Domestic Wastewater of Ibrahimpur Village

### 5.2.3 Biochemical Oxygen Demand & Chemical Oxygen Demand

The average value of Biochemical Oxygen Demand during the monitoring period was 245.31±71.63 mg/L (Fig. 14). The maximum BOD value recorded was 360 mg/L in December 2018 and March 2019 and the minimum value, 130 mg/L, was recorded in November 2019.

The COD values ranged from 250.36 mg/L in November 2019 to 739.16 mg/L in December 2018 with an average value of 505.82±36.99 mg/L (Fig. 14).

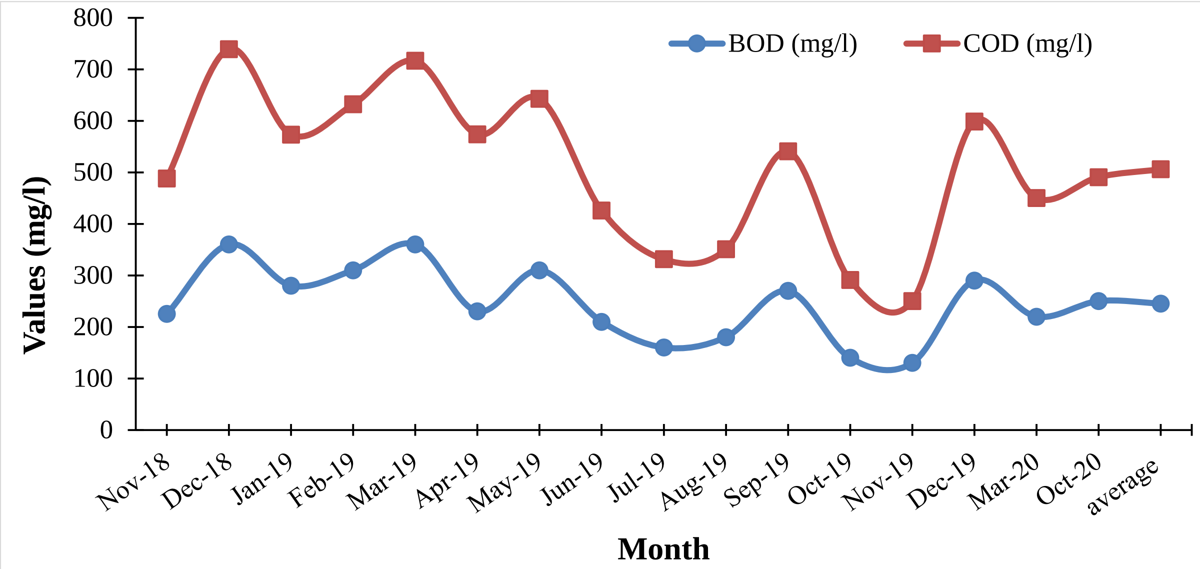


Fig. 14: Monthly Variation of BOD and COD in Domestic Wastewater of Ibrahimpur Village

### 5.2.4 Nitrate-Nitrogen, Ammoniacal-Nitrogen, and Phosphate

Nitrate-nitrogen, Ammoniacal-nitrogen, and Phosphate in the wastewater samples were observed in the range 1.48 mg/L to 6.2 mg/L, 2.13 mg/L to 27.90 mg/L, and 1.2 mg/L to 6.59 mg/L, respectively (Fig. 15). The average concentration of $NO_3$-N, $NH_4$-N, and $PO_4$ was recorded 2.68±0.29 mg/L, 9.42±1.77mg/L, and 3.02±0.38 mg/L respectively.

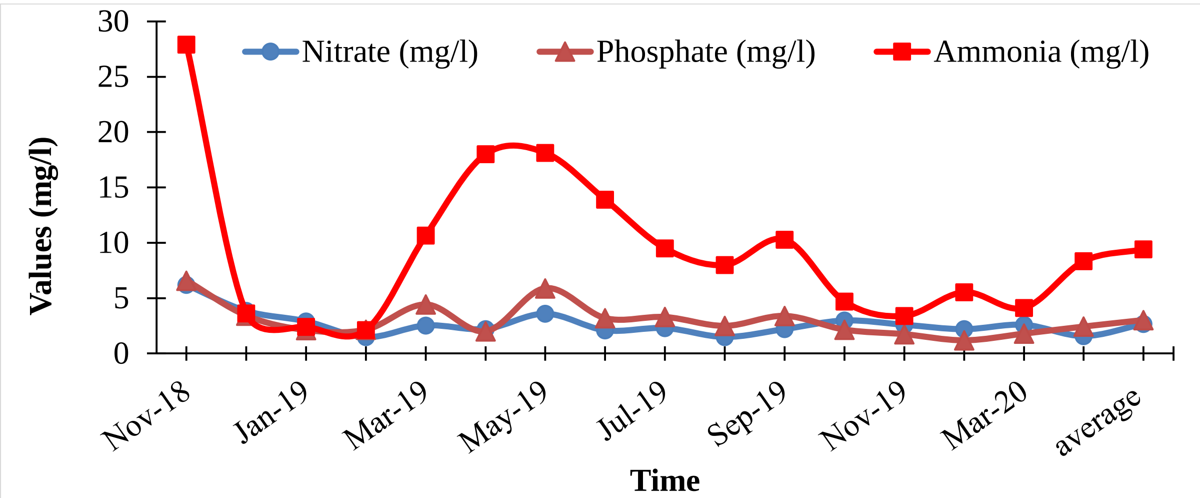


Fig. 15: Monthly Variation in $NO_3$-N, $NH_4$-N, and $PO_4$of Domestic Wastewater of Ibrahimpur Village

### 5.2.5 Bacteriological analysis

Coliforms in the water are an indicator of pathogens and therefore were analyzed in the wastewater and the treatment chain. The total coliforms and E. coliforms in the wastewater were observed in the range 2.04x$10^6$ MPN/100 mL to 7.7x$10^8$ MPN/100 mL and 2.6x$10^5$ MPN/100 mL to 4.61x$10^7$ MPN/100 mL respectively (Fig. 16).

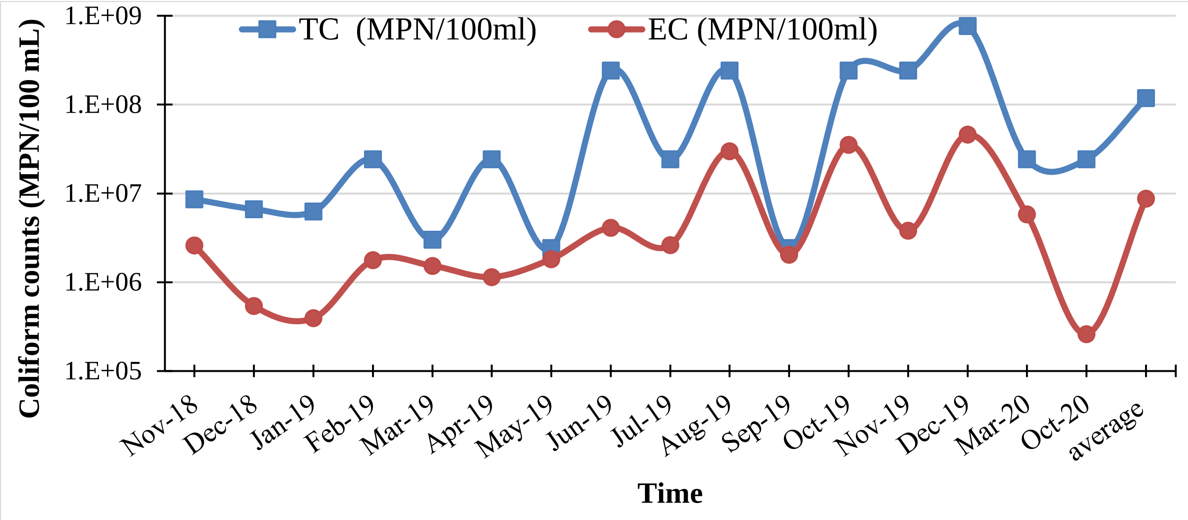



Fig. 16: Monthly Variation in Coliform Counts of Domestic Wastewater of Ibrahimpur Village

### 5.3 Performance of Grit Chamber (Sedimentation Tank)

A sedimentation tank/grit chamber is required to remove settleable matter from the wastewater by slowing down the velocity. These chambers help in removing the inorganic matter before entering the constructed wetlands and in this way enhances the life and efficiency of the constructed wetland. In doing so, it also removes the pollutants associated with the suspended solids. The effluents with high settleable solids like village wastewater, the settling chambers removes a significant amount of pollution load along with the suspended solids. The grit chamber in the Ibrahimpur village is with three baffles and around 2.5 hrs HRT, resulted in significant removal of pollutants from the wastewater. Further, the cleaning of the sedimentation tank was performed once in 6 months resulting in almost complete digestion of settled sludge suitable for disposal.

#### 5.3.1 pH & Electrical Conductivity

The pH of the effluent from the sedimentation chamber ranged from 7.23 to 9.54 with average pH of 7.85±0.65 (Fig. 17).

The electrical conductivity of the wastewater after passing through the sedimentation basin ranged from 783 µs/cm to 1897 µs/cm (Fig. 17). The average electrical conductivity of domestic wastewater of Ibrahimpur Village was 1820.83±289.68 µs/cm and after passing through grit chamber average value reduced to 1635.23±332.72 µs/cm, around 10.2% reduction, which may be as a result of the reduction in organics in the chamber.

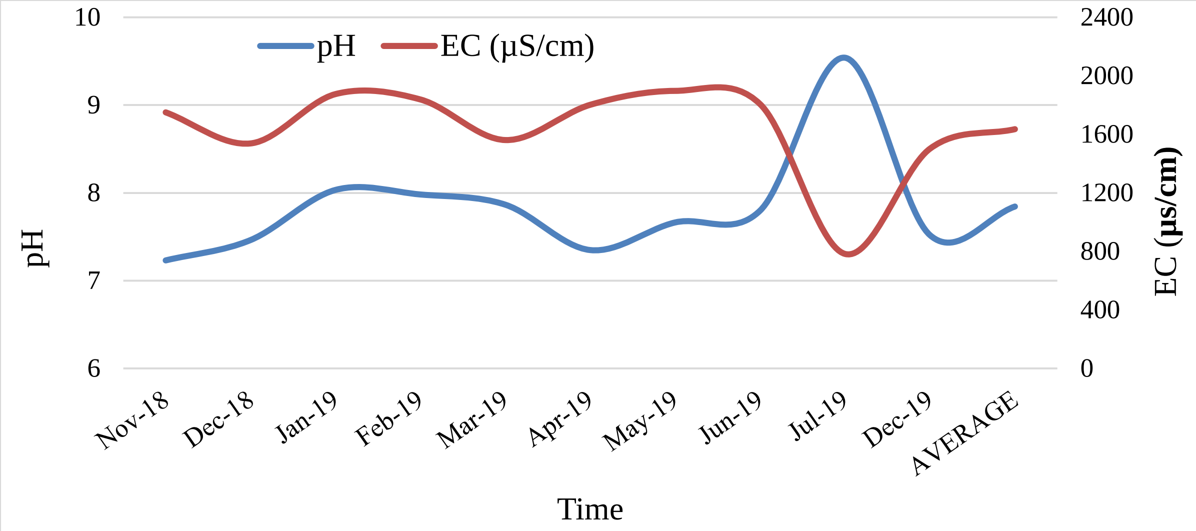



Fig. 17: Monthly Variation of pH and Electrical Conductivity in the discharge of Grit Chamber

### 5.3.2 Dissolved Oxygen

The average dissolved oxygen of domestic wastewater of Ibrahimpur Village was 0.64±0.32 mg/L and after passing through the grit chamber the annual average value was 1.98±0.75 mg/L, indicating around 209.78% increase in the dissolved oxygen level (Fig. 18).The increase in DO may be due to the movement of water through the baffles which obstructs the flow and hence turbulence.

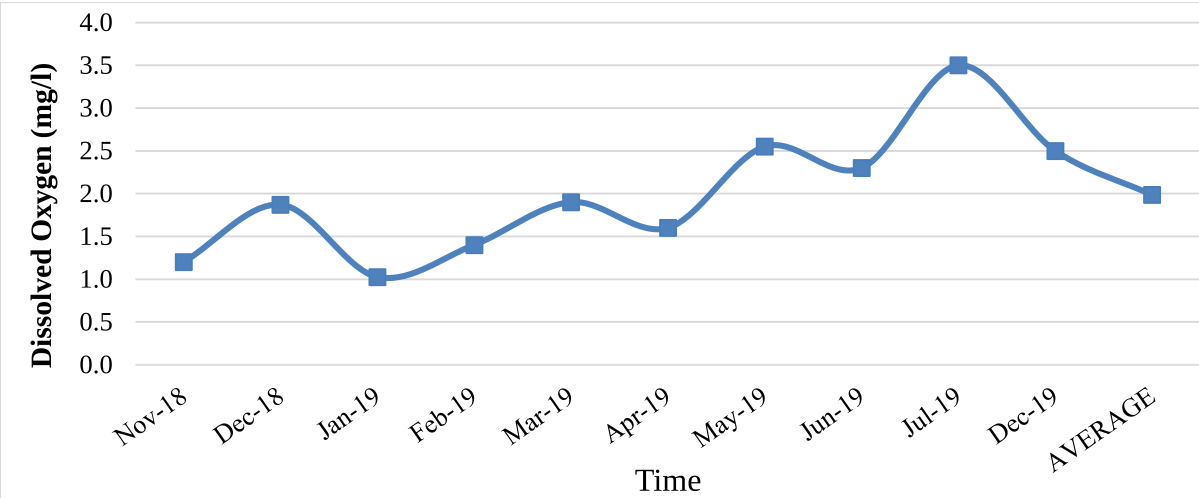



Fig. 18: Monthly Variation in Dissolved Oxygen in the discharge of Grit Chamber

### 5.3.3 Biochemical Oxygen Demand & Chemical Oxygen Demand

The BOD and COD of the effluent after passing through the sedimentation chamber was observed in the range 60 mg/L to 240 mg/L and 124.4 mg/L to 499.3 mg/L respectively (Fig. 19). The annual average BOD of domestic wastewater of Ibrahimpur Village was 245.31±71.63

mg/L and after passing through the sedimentation chamber, it reduced to 180±62.69 mg/L resulting in approximately 26.3% BOD removal. Similarly, a reduction of approximately 27.5% was observed in the annual average value of COD in the sedimentation chamber. The reduction in BOD and COD values was due to the removal of settleable matter in the sedimentation chamber and anaerobic degradation of organic matter.

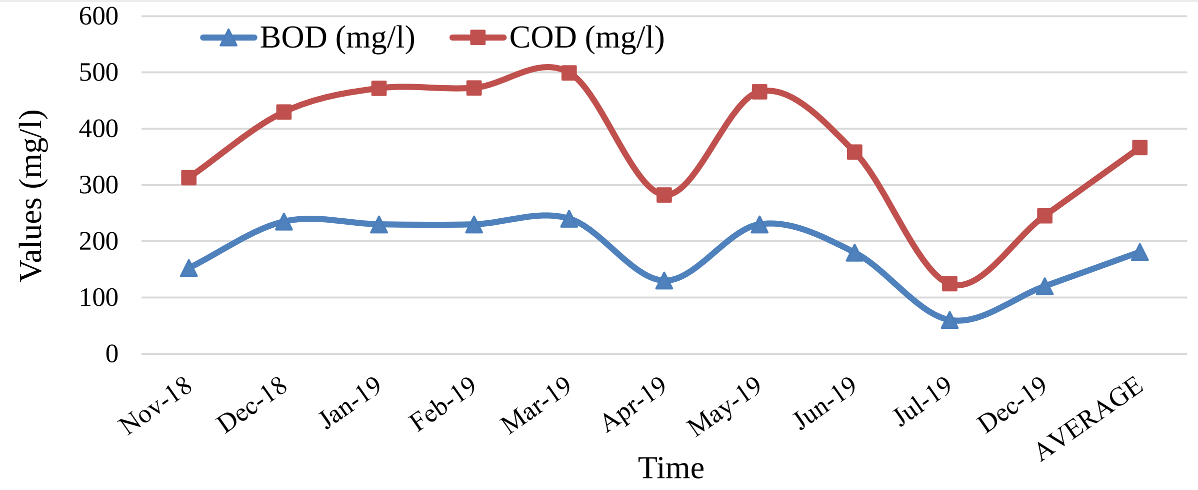



Fig. 19: Monthly Variation of BOD and COD in the discharge of Grit Chamber

### 5.3.4 Nitrate-Nitrogen, Ammoniacal-Nitrogen, and Phosphate

The concentration of $NO_3$-N, $NH_4$-N, and $PO_4$ in the wastewater coming out of the sedimentation chamber was 0.9 mg/L to 12.35 mg/L, 1.58 mg/L to 15.32 mg/L, and 1.65 mg/L to 11.30 mg/L respectively (Fig. 20). The average annual $NO_3$-N in the domestic wastewater of Ibrahimpur Village was 2.68±1.15 mg/L which reduced to 3.19±3.37 mg/L after passing through the sedimentation chamber and an increase of 19% in the wastewater nitrate concentration was observed. In the case of annual average $NH_4$-N concentration, a reduction of approximately 6.5% was observed. The increase in $NO_3$-N and decrease in $NH_4$-Nconcentration was because of the nitrification of $NH_4$-N to $NO_3$-N.

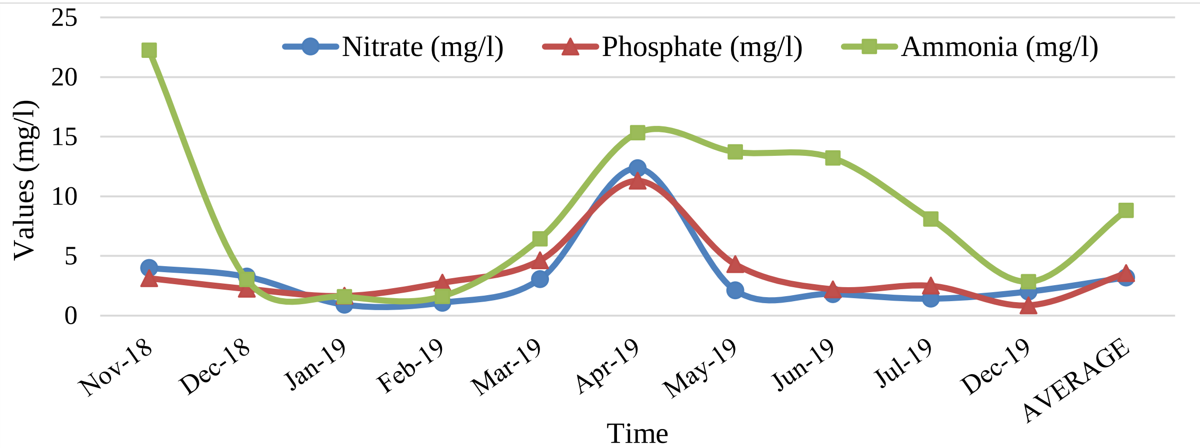



Fig. 20: Monthly Variation of $NO_3$-N, $NH_4$-N, and $PO_4$ in the discharge of Grit Chamber

The average annual phosphate concentration in the domestic wastewater of Ibrahimpur was 3.02±1.50 mg/L and after passing through the grit chamber average value the concentration reduced to 3.56±2.95 mg/L corresponding to around 17.59% increase in concentration. This may be due to the decomposition of the settled organic matter in the sedimentation chamber and the release of phosphorus from the decomposed matter.

### 5.3.5 Bacteriological Analysis

The TC and EC count in the outlet of the sedimentation chamber was $3.66x10^{6}$ MPN/100 mL to $4.11x10^{8}$ MPN/100 mL and $2.92x10^{5}$ MPN/100 mL to $1.55x10^{8}$ MPN/100 mL respectively (Fig. 21). The average annual total coliform counts in domestic wastewater of Ibrahimpur Village was$1.1x10^{8}±5.03x10^{7}$MPN/100 mL before entering the sedimentation chamber and after passing through the grit chamber, the average value reduced to $7.4x10^{7}±4.3x10^{7}$indicating approximately 36.49% removal of total coliform. Similarly, the average annual E. coliform (MPN/100mL) of domestic wastewater was $8.7x10^{6}±3.6x10^{6}$ before entering the grit chamber and after passing through the grit chamber the average annual value was $2.39x10^{7}±1.5x10^{7}$ which represent around 37.36% increase in E. coliform. The increase in E. coliforms in the wastewater may be due to prevailing septic conditions in the sedimentation chamber which provide a conducive environment for the E. coli to multiply.

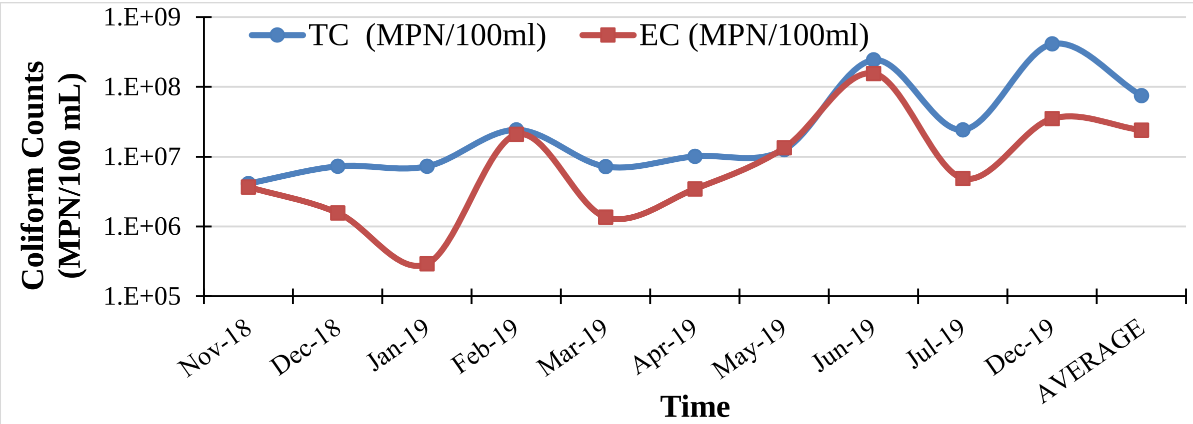



Fig. 21: Monthly Variation in Coliform of Domestic Wastewater at Grit Chamber Outlet

## 5.4 Performance of Constructed Wetlands of Ibrahimpur Village

After passing through the grit chamber, the wastewater is passed through subsurface flow constructed wetland (CW) before entering the village pond. The surface area of the constructed wetland is approximately 143 $m^2$ with 0.6 m liquid depth and 4.5 days HRT. The actual HRT for this wetland is 1.2 days and was calculated by using the equation-

$$HRT = \frac{nLWD}{Q} = \frac{0.4 \times 143 \times 0.6}{43.24}$$

Where,

HRT=Hydraulic Retention Time (Day)
n=Porosity (Dimension)
L=Length (m)
W=Width (m)
D=Depth (m)
Q=Flow rate ($m^3$/day)

Indian shot and common reed were grown for phytoremediation of the wastewater. The performance of wetland to remediate the village wastewater is given below.

### 5.4.1 pH & Electrical Conductivity

The pH of the wastewater after passing through the constructed wetland was in the range of 7.12 to 7.80 (Fig. 22).The average annual pH at the inlet of CW was 7.85±0.65 and at the CW outlet, it was 7.5±0.24. The reduction in pH may be due to the oxidation of organics and an increase in the concentration of $CO_2$ in the water. Also, the anaerobic degradation of organics results in the formation of organic acids which again results in the reduction of pH.

The EC of the treated water after constructed wetland was observed in the range 1164µs/cm to 1790 µs/cm (Fig. 22). The average annual EC of domestic wastewater before entering constructed wetland was 1635.23±332.72µs/cm and after passing through constructed wetland, it reduced to 1497.92±186.7 µs/cm, around 8.4% lower than the input value.

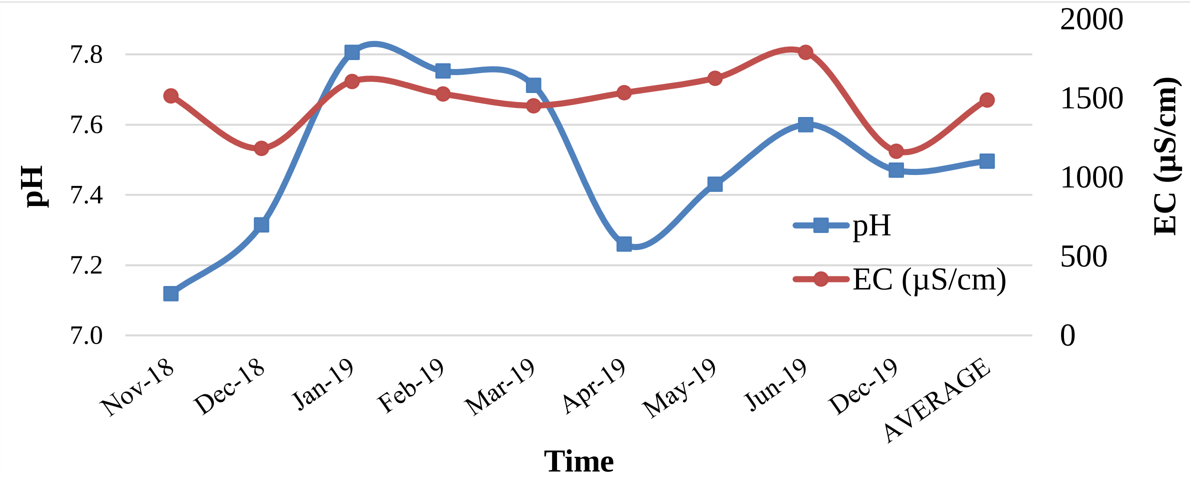



Fig. 22: Monthly Variation of pH and Electrical Conductivity in CW Discharge

### 5.4.2 Dissolved Oxygen

The dissolved oxygen in the treated water from the constructed wetland was observed in the range 2.15 mg/L to 4.35 mg/L (Fig. 23). The average annual dissolved oxygen in the domestic wastewater before entering constructed wetland was 1.98±0.24 mg/L and after passing through constructed wetland the average annual dissolved oxygen was 2.82±0.23 mg/L, indicating approximately 42.42% increase in dissolved oxygen level. This increase in DO levels in the treated water was due to the oxygen diffusion from the roots into the rhizosphere and assimilation into the water, and this increase indicates the proper functioning of the aquatic plants. However, this level of increase in DO indicates the underperformance of the system, and the efficiency of the system can be improved by introducing microbes into the system.

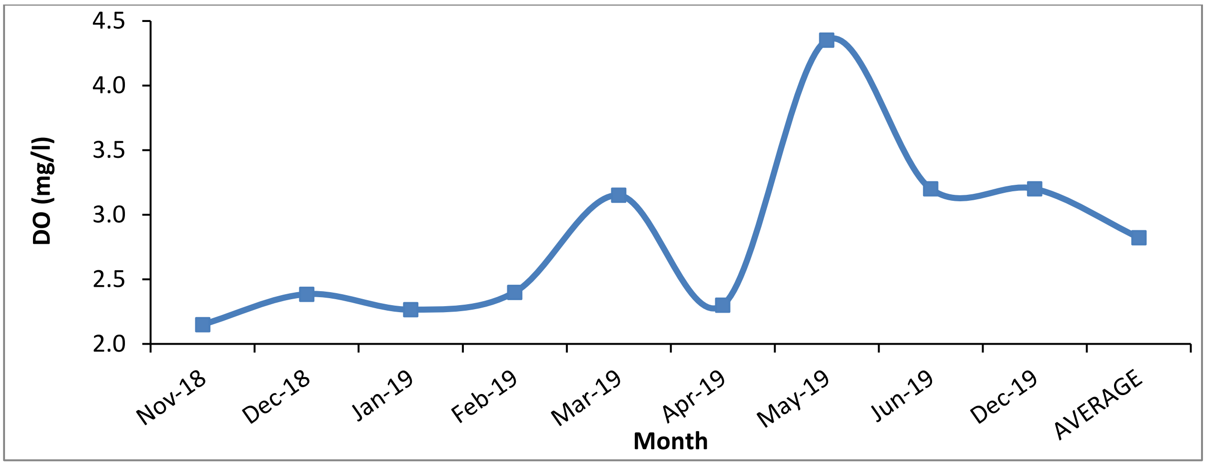



Fig. 23: Monthly Variation of Dissolved oxygen in Constructed Wetland Discharge

### 5.4.3 Biochemical Oxygen Demand & Chemical Oxygen Demand

The BOD and COD of the effluent after passing through the constructed wetland was observed in the range 60 mg/L to 180 mg/L and 185.62 mg/L to 365.57 mg/L respectively (Fig. 24). The annual average BOD at the inlet of constructed wetland was 180.75±19.83mg/L and at the outlet, it reduced to 121.67±12.53 mg/L resulting in approximately 32.67% BOD removal. Similarly, a reduction of approximately 30% was observed in the annual average value of COD in the constructed wetland.

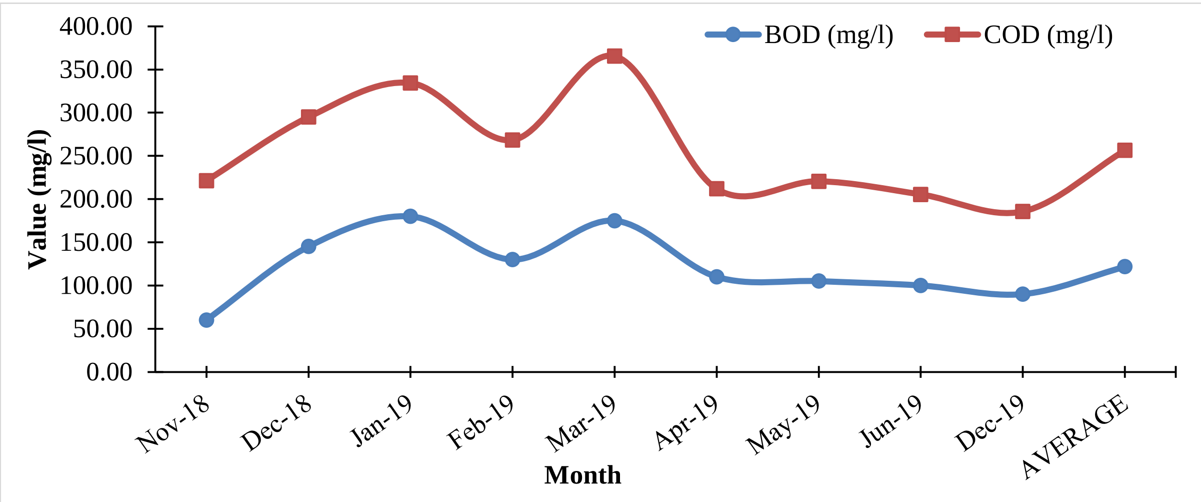



Fig. 24: Monthly Variation of BOD and COD of Domestic Wastewater at Constructed Wetland

### 5.4.4 Nitrate-Nitrogen, Ammoniacal-Nitrogen, and Phosphate

The concentration of $NO_3$-N, $NH_4$-N, and $PO_4$ in the treated wastewater from the constructed wetland was 1.05 mg/L to 12.76 mg/L, 0.5 mg/L to 11.25 mg/L, and 0.72 mg/L to 5.70 mg/L respectively (Fig. 25). The average nitrate-nitrogen of domestic wastewater before entering constructed wetland was 3.19±1.06 mg/L and after passing through constructed wetland average value comes 4.60±0.45 mg/L which represents a 44% increase in $NO_3$-Nconcentration. The average $NH_4$-N concentration of wastewater at the inlet and outlet of CW was 8.80±2.23 mg/L and 4.01±1.22 mg/L respectively, which corresponds to approximately 54.4% reduction in the $NH_4$-N concentration. Similarly, the average annual phosphate concentration reduced from 3.56±0.93 mg/L to 2.71±0.45 mg/L, amounting to around 23.9% reduction in the $PO_4$ concentration.

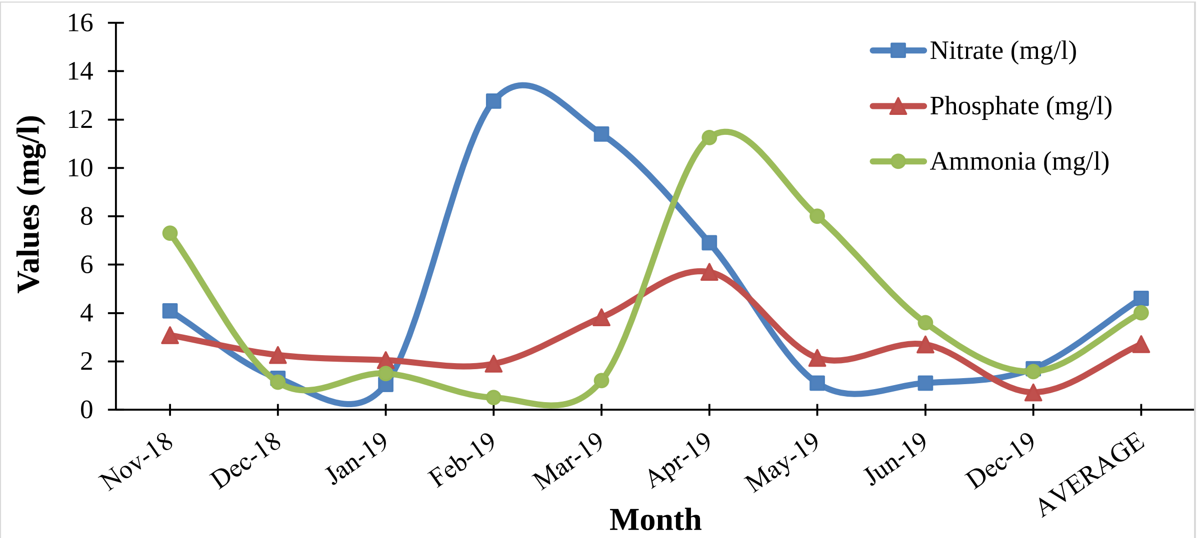



Fig. 25: Monthly Variation of Nitrate-Nitrogen, Ammoniacal-Nitrogen and Phosphate of Domestic Wastewater at Constructed Wetland

### 5.4.5 Bacteriological Analysis

The TC and EC count in the treated wastewater from constructed wetland was $1.40x10^6$ MPN/100 mL to $2.42x10^8$ MPN/100 mL and $1.68x10^5$ MPN/100 mL to $3.44x10^7$ MPN/100 mL respectively (Fig. 26). Average annual TC counts in the inlet and outlet of CW were $7.50x10^7$±$4.38x10^7$ MPN/100 mL and $4.3x10^7$±$2.49x10^7$ MPN/100 mL which represent 42.76% removal of Total Coliform. Similarly, the average annual E. Coliform count reduced from $2.40x10^7$±$1.50x10^7$ MPN/100 mL to $6.10x10^6$±$3.48x10^6$ MPN/100 mL after passing through the CW resulting in around 74.55% reduction in E. coli counts.

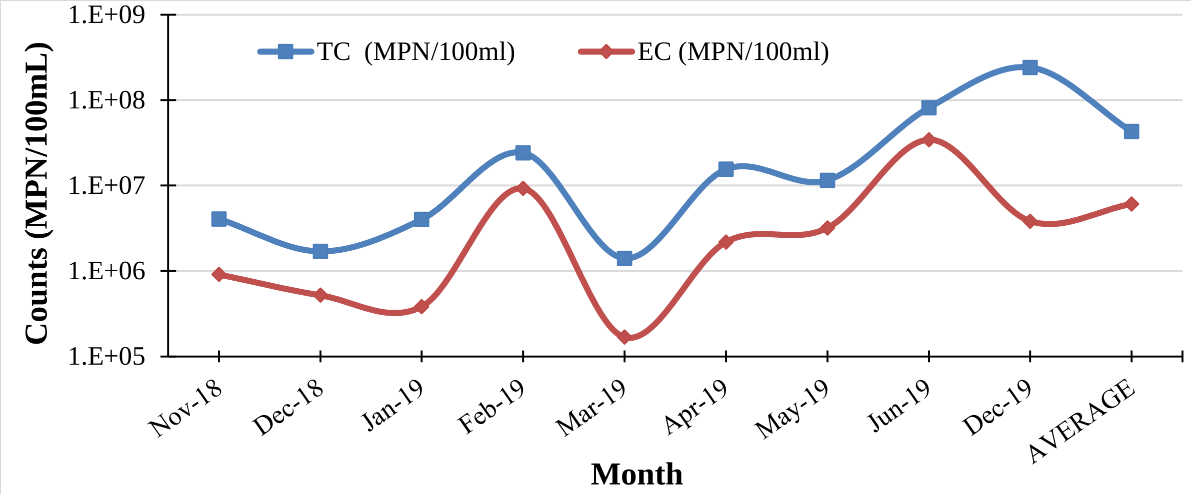



Fig. 26: Monthly Variation of Coliform of Domestic Wastewater at Constructed Wetland

## 5.5 Water Quality of the Ibrahimpur Pond and Overall Improvement in Water Quality

The village pond is last in the treatment chain and the water quality of the pond was monitored to understand the overall improvement in water quality. It was observed that the complete system was able to significantly improve the overall water quality and making it more acceptable to the villagers for recreational activities and suitable for economic usage. The overall improvement in water quality is discussed in the below sections-

### 5.5.1 pH & Electrical Conductivity

The pH of Ibrahimpur pond ranges from 7.05 to 7.39 with an annual average value of 7.18±0.11 (Fig. 27). The average annual pH of the pond was 6.47% lower than the wastewater average annual pH. The pH range observed in the pond was near neutral and suitable for the pond ecology.

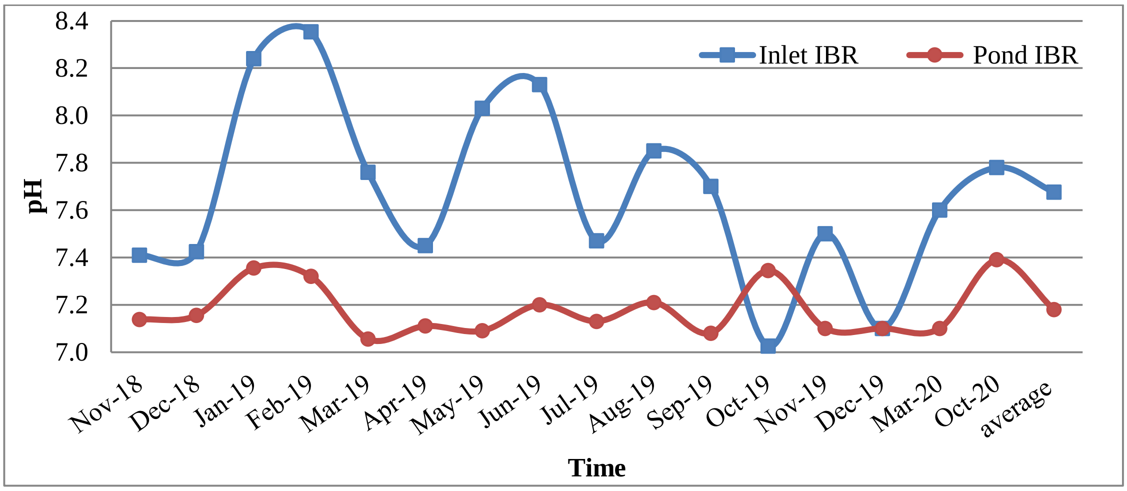



Fig. 27: pH value of wastewater and pond water of Ibrahimpur Village

The conductivity of the pond water during the observation period ranges from 1280 µs/cm to 2178 µs/cm (Fig. 28). The average electrical conductivity of domestic wastewater before entering the treatment chain was 1820.83±289.68µs/cm and in the pond, the value comes down to 985.30±195.83 µs/cm. This reduction in overall EC was around 45.9% removal efficiency of Electrical conductivity. This decrease in conductivity was due to the removal of organics from the wastewater.

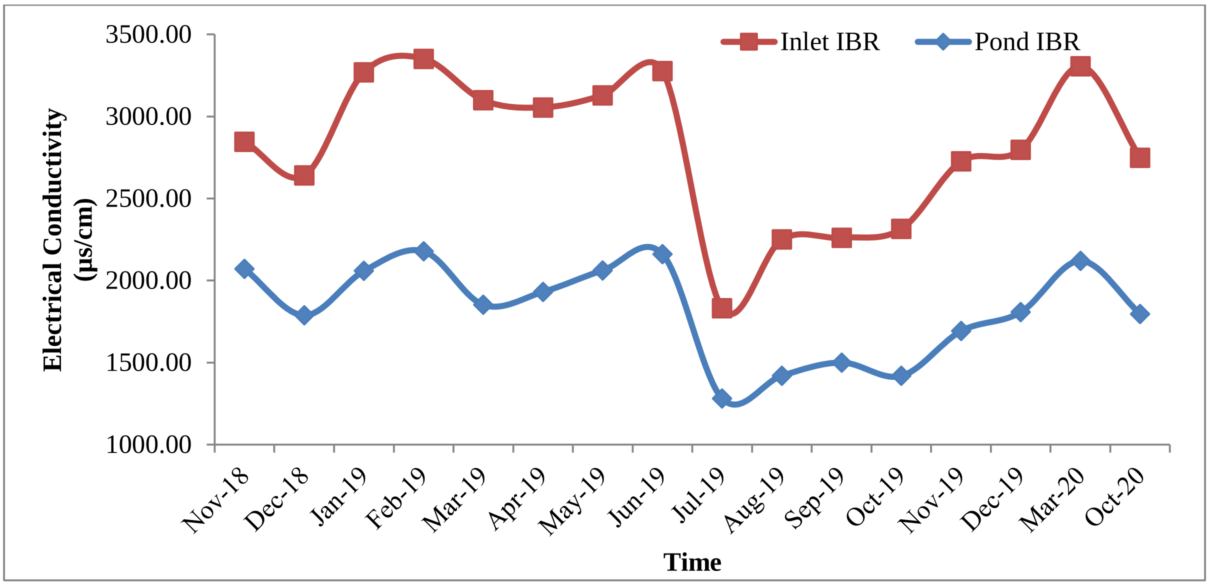



Fig. 28: Monthly Variation in EC of Wastewater and Ibrahimpur pond water

### 5.5.2 Dissolved Oxygen

The DO levels in the pond water ranges from 4.3 mg/L to 9.9 mg/L (Fig. 29). The average annual DO in the wastewater was 0.64±0.32 mg/L and in the pond, the average annual DO was 5.92±1.68 mg/L indicating an almost 824.44% increase in dissolved oxygen level. These values indicate good Do levels in the pond water suitable for the fisheries and therefore, the diurnal variation in DO levels in the pond was monitored and it was found that the diurnal variation of DO in the pond ranges from 0.56 mg/L in the early morning to 11.55 mg/L in the evening (Fig. 29). Very high DO, higher than the saturation limit, was the result of algal photosynthesis which reduces slowly due to algal and bacterial respiration in the absence of light and reaches a minimum in the early morning and then again increases with the sunrise. Therefore, the pond environment is still not suitable for all kinds of fishes and only those fish that can survive in low DO conditions can be grown.

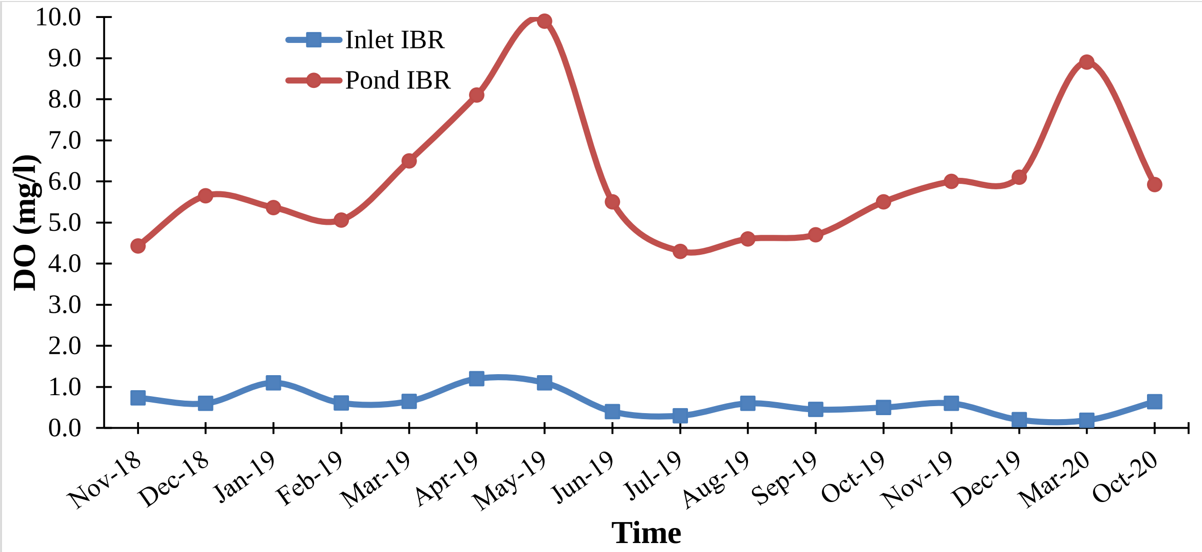



Fig. 29: Monthly Variation in DO levels between Wastewater and Ibrahimpur pond water

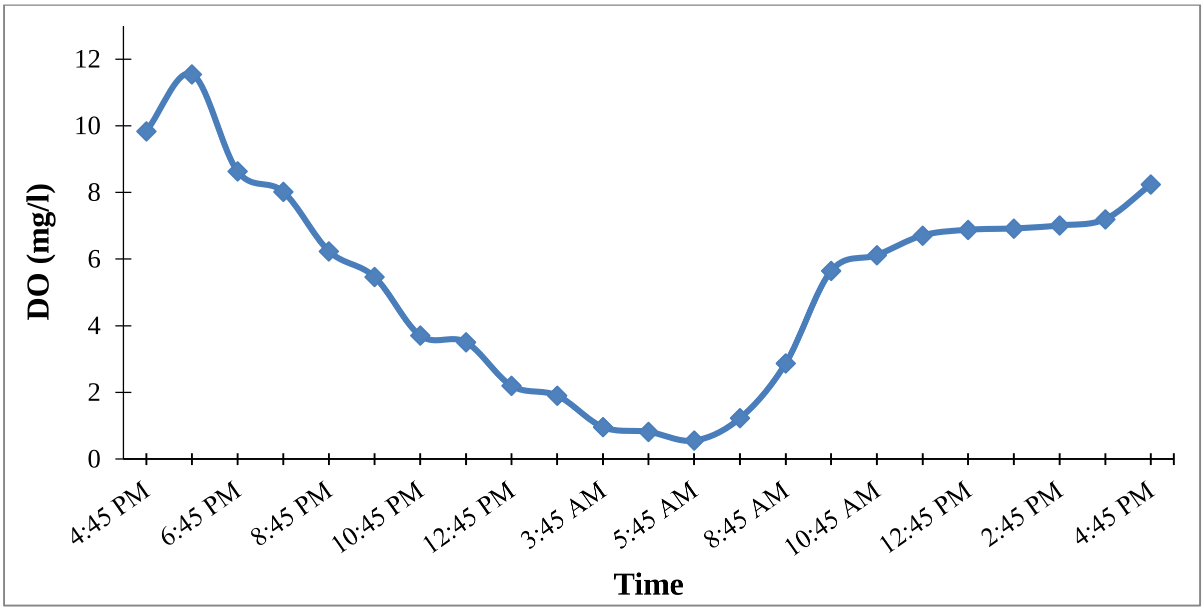



Fig. 30: Diurnal variation in DO levels of Ibrahimpur pond

### 5.5.3 Biochemical Oxygen Demand & Chemical Oxygen Demand

The BOD levels of pond water ranges from 27 mg/L to 60 mg/L (Fig. 31). The average annual BOD in the wastewater was 245.31±71.63 mg/L which was reduced by approximately 83.2% to 41.28±7.85 mg/L with the aid of the sedimentation basin and constructed wetland in the pond.

The COD values in the pond water ranges from 52.76 mg/L to 134.25 mg/L (Fig. 32). The average annual COD of domestic wastewater and the pond water was 505.82±147.95 mg/L and 96.54±22.98 mg/L respectively indicating around 80.92% reduction in COD value.

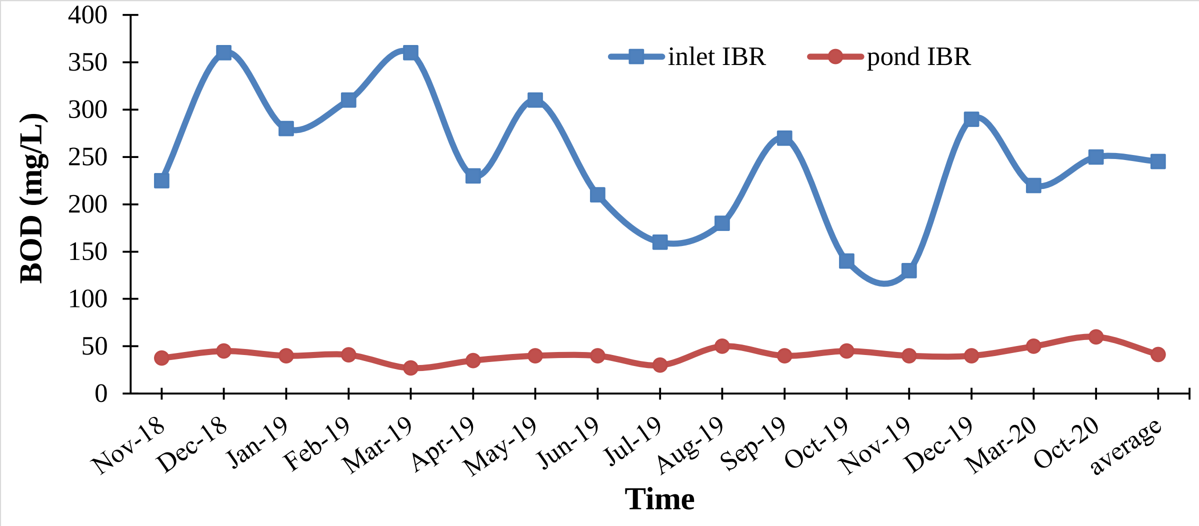



Fig. 31: Monthly Variation of BOD in Domestic Wastewater and pond water of Ibrahimpur Village

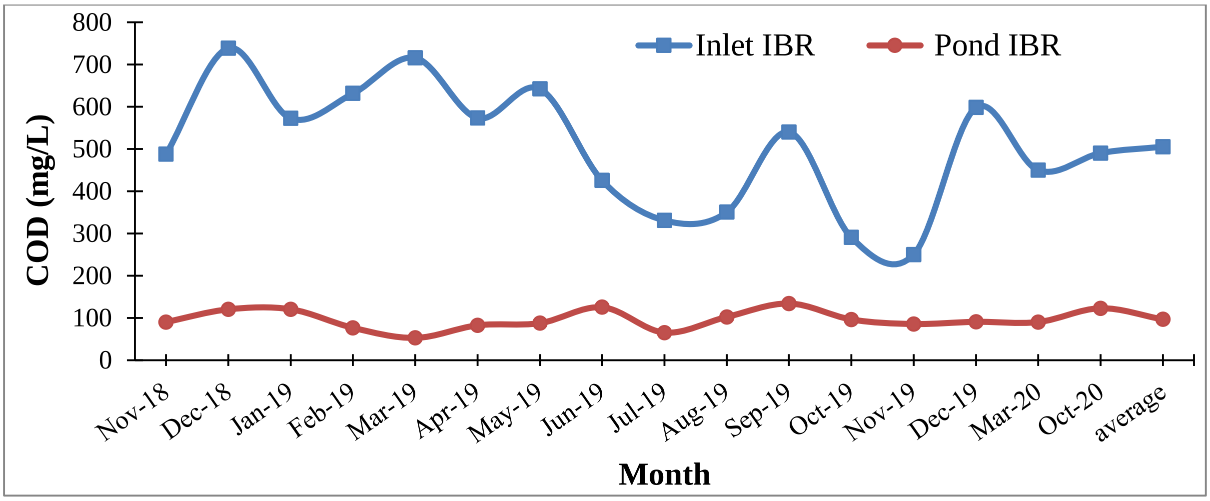



Fig. 32: Monthly Variation of COD in Domestic Wastewater and pond water of Ibrahimpur Village

### 5.5.4 Nitrate-Nitrogen, Ammoniacal-Nitrogen, and Phosphate

The concentration of $NO_3$-N, $NH_4$-N, and $PO_4$ in the treated wastewater from the constructed wetland was 0.22 mg/L to 8.92 mg/L, 0.19 mg/L to 8.00 mg/L, and 0.2 mg/L to 2.70 mg/L respectively (Fig. 33). The average annual nitrate-nitrogen in the domestic wastewater was 2.68±1.15 mg/L and in the pond, the value was 1.88±2.68 mg/L which represents a 29.93% decrease in Nitrate-Nitrogen. Similarly, the $NH_4$-N average annual concentration reduces from 9.42±7.09 mg/L to 1.71±1.91 mg/L resulting in 81.85% decrease in the concentration of $NH_4$-N. The overall reduction in the nitrogen concentration in terms of nitrate and ammonia was 70.3% indicating both nitrification and denitrification taking place in the system along with the nutrient uptake by the aquatic plants.

The average annual phosphate also reduced from 3.02±1.50 mg/L in the wastewater to 0.76±0.71 mg/L in the pond representing almost 74.96%. A significant reduction in the concentration of the nutrient was observed with the installation of the treatment system, still, the concentration of nutrients in the pond is sufficient enough for eutrophication and hence further efforts are needed to reduce the concentration.

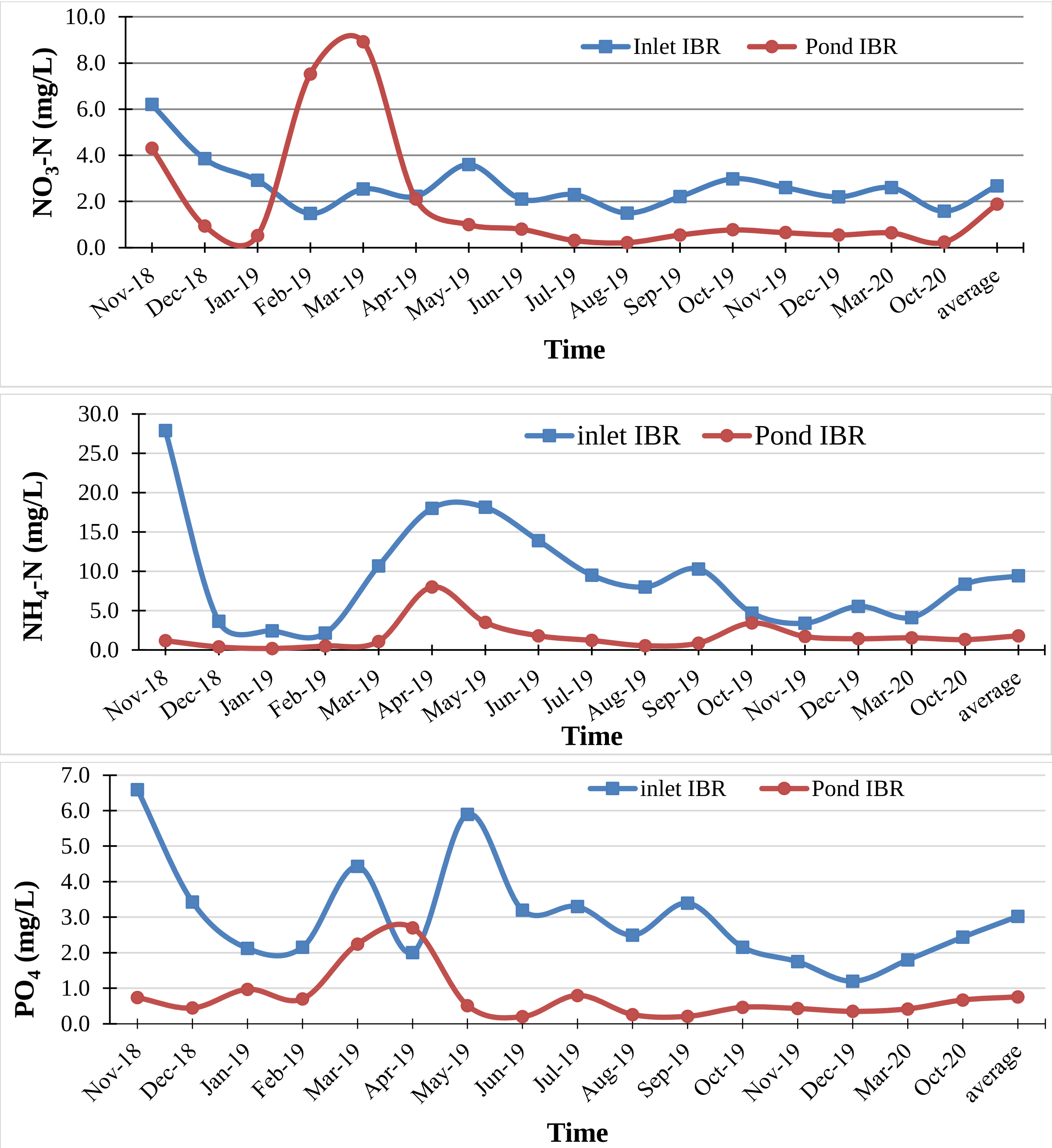
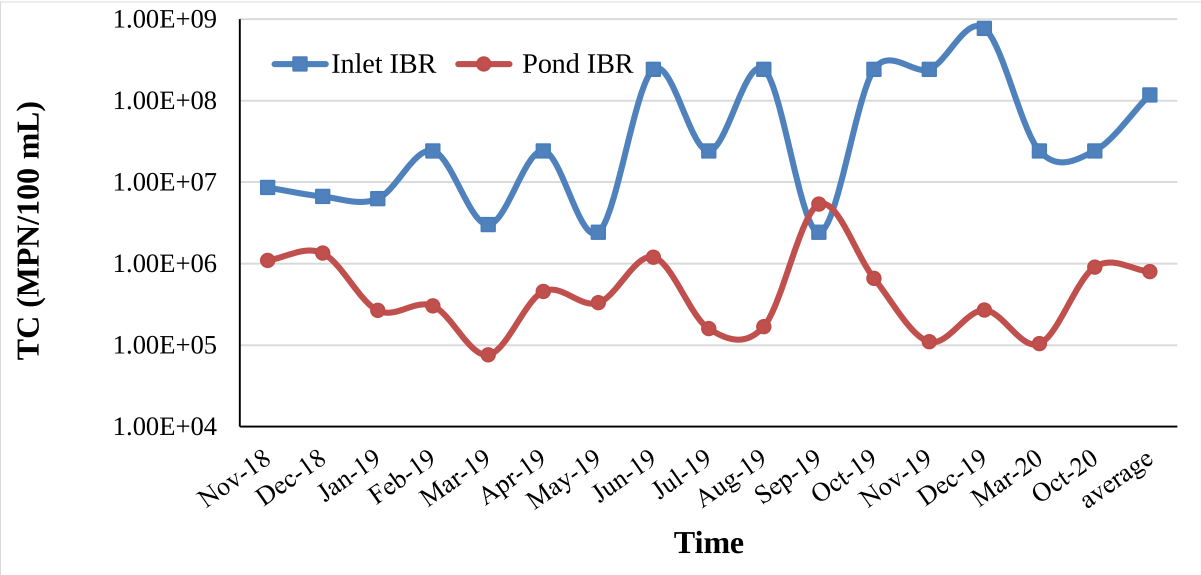



Fig. 33: Comparison of Nitrate-Nitrogen, Ammoniacal-Nitrogen, and Phosphate between Domestic Wastewater and pond water of Ibrahimpur Village (Monthly Variation)

### 5.5.5 Bacteriological Analysis

The TC and EC counts in the pond water ranges from $7.60 \times 10^4$ MPN/100 mL to $5.36 \times 10^6$ MPN/100 mL and $1.0 \times 10^3$ MPN/100 mL to $2.0 \times 10^4$ MPN/100 mL respectively (Fig. 34). The average annual TC count in the wastewater was $2.02 \times 10^8 \pm 1.87 \times 10^8$ MPN/100 mL which reduced to $8.01 \times 10^5 \pm 1.29 \times 10^6$ MPN/100 mL in the pond which represent 99.60% removal of Total Coliform.

Similarly, the average annual E. coliform count reduced from $1.02 \times 10^7 \pm 1.48 \times 10^7$ MPN/100 mL in the wastewater to $6.31 \times 10^3 \pm 5.07 \times 10^3$ MPN/100 mL in the pond which represents approximately 99.9% reduction in E. coli counts.



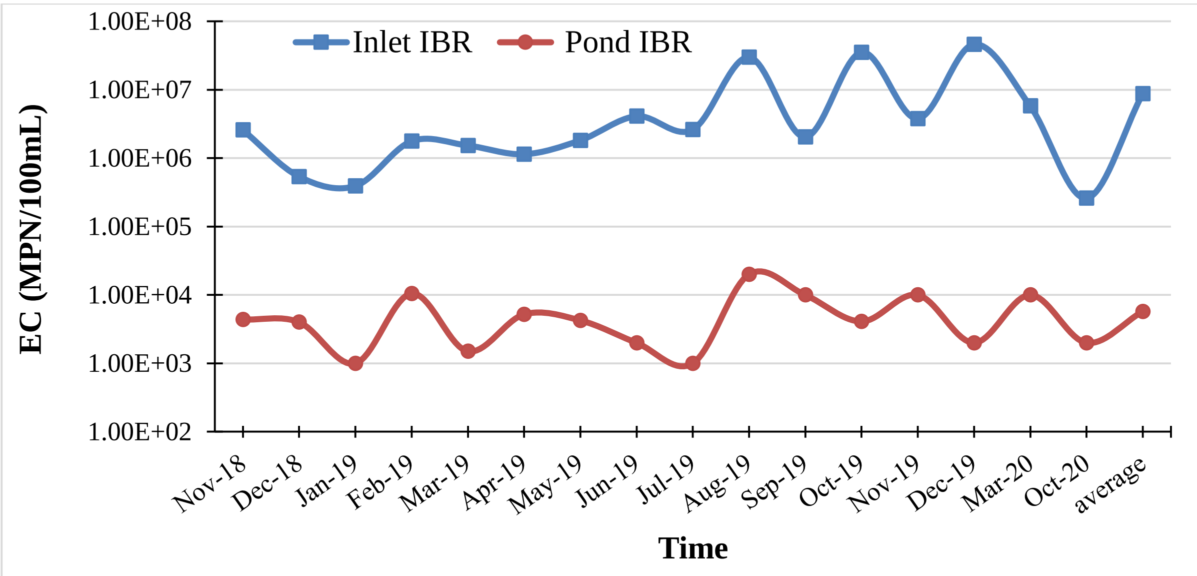




Fig. 34: Coliform counts in domestic wastewater and pond water of Ibrahimpur village (Monthly Variation)

## 5.6 Water Quality Characteristics of Domestic wastewater of Masahi Village and the Control Pond at Masahi

To understand the actual impact of constructed wetland on the pond water quality at Ibrahimpur, a similar pond receiving village wastewater at Masahi village, 1.8 km to the north of Ibrahimpur, was monitored as a control pond. The samples were collected from the wastewater drain draining into the pond and from the pond along with the sampling expedition for Ibrahimpur pond, the experimental pond. The analytical results are discussed in the below sub-sections.

### 5.6.1 pH Value & Electrical Conductivity

The pH value of inlet wastewater and Masahi pond was in the range 7.1 to 8.17 and 6.75 to 7.94 respectively (Fig. 35). The annual average pH of inlet wastewater to the Masahi pond was 7.68±0.34 and for the pond, it was 7.32±0.34. A reduction in pH was observed in the pond and this may be due to an increase in $CO_2$ concentration due to the oxidation of organic matter.

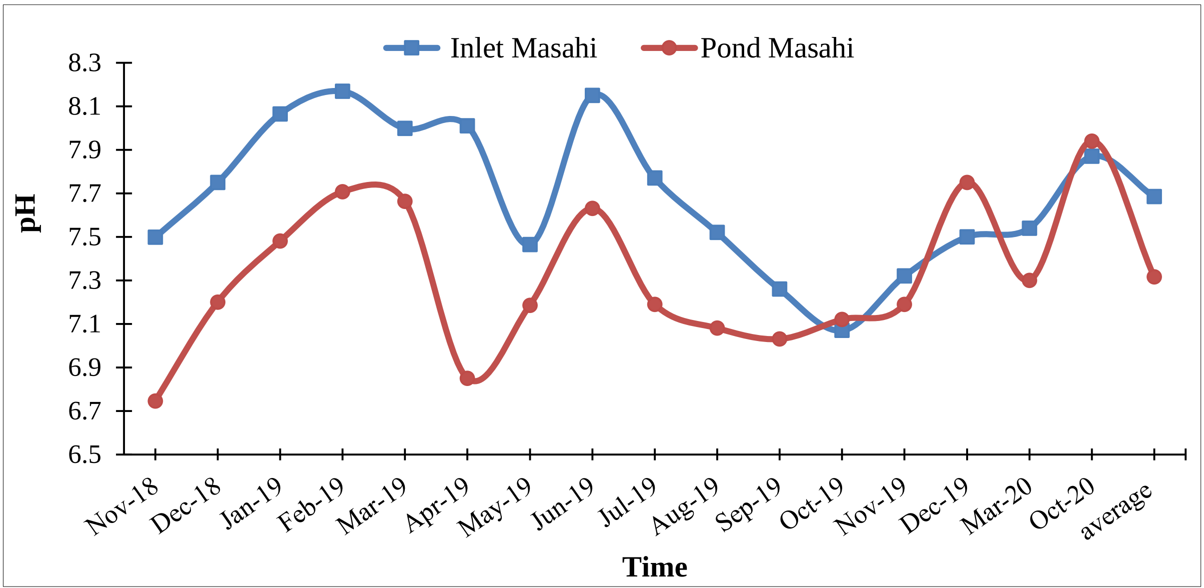



Fig. 35: Monthly Variation in pH of Inlet Wastewater and pond water of Masahi Village

The electrical conductivity of domestic wastewater and pond of Masahi Village has been recorded in the range 893 µs/cm to 1964 µs/cm and 779 µs/cm to 1534 µs/cm respectively (Fig. 36). The average EC of the wastewater for the wastewater was 1189.45±272.43 µs/cm and for the pond, it was 1054.20±198.73 µs/cm. Approximately, 11.37% reduction in EC values was observed.

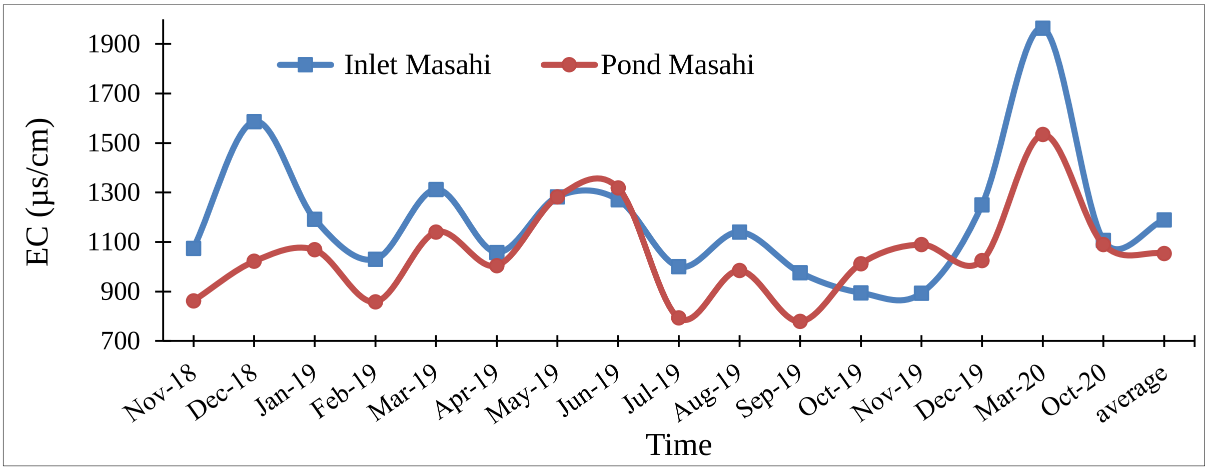



Fig. 36: Monthly Variation in Electrical Conductivity of Domestic Wastewater and Pond in Masahi

### 5.6.2 Dissolved Oxygen

The DO value in the wastewater was in the range non-detectable (ND) to 2.0 mg/L and in the pond was water the DO concentration varied from ND to 2.20 (Fig. 37). The DO of the pond was almost zero for most of the year due to the highly eutrophic condition of the pond and the high organic load entering the pond. The average annual DO values of the wastewater and the pond water were 0.75±0.59 mg/L and 0.35±0.15 mg/L respectively.

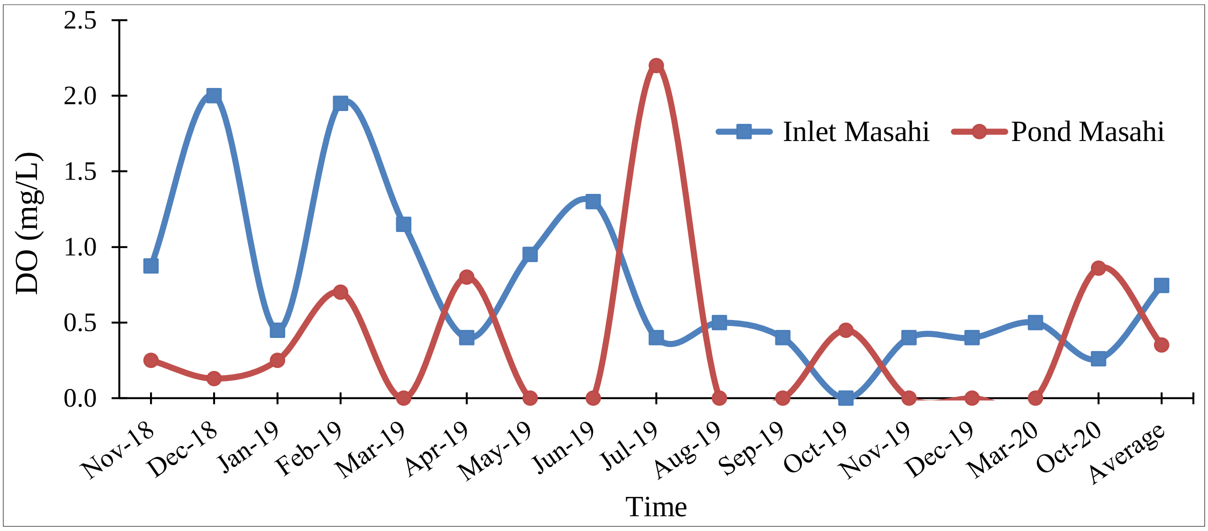



Fig. 37: Monthly Variation of Dissolved Oxygen of Domestic Wastewater and pond in Masahi Village

### 5.6.3 Biochemical Oxygen Demand & Chemical Oxygen Demand

BOD of the influent to pond and the pond water was 100 mg/L to 315 mg/L and 80 mg/L to 170 mg/L respectively (Fig. 38). The average annual BOD of the wastewater and pond water was 190.16±70.68 mg/L and 113.91±26.69 mg/L respectively. Approx. 40.1% reduction in BOD was observed in the pond.

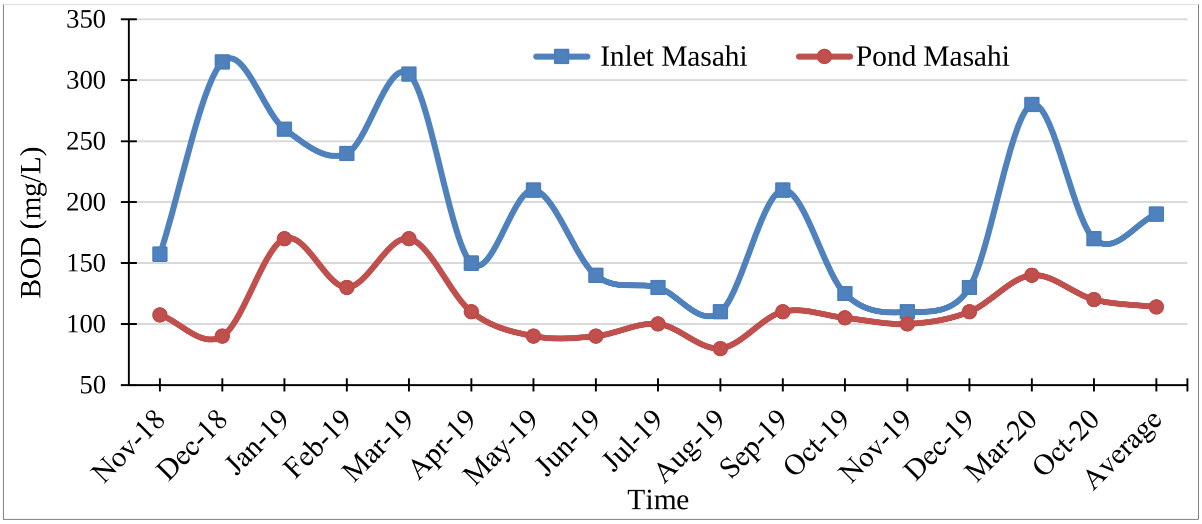



Fig. 38: Monthly Variation in BOD of Domestic Wastewater and pond in Masahi Village

The COD of the domestic wastewater and pond water ranges from 224.5 mg/L to 652.7 mg/L and 170.5 mg/L to 355.5 mg/L respectively (Fig. 39). The average annual COD of the wastewater was 389.29±147.33 mg/L and the pond was 232.98±56.10 mg/L and the resultant reduction in COD was approximately 40.2%.

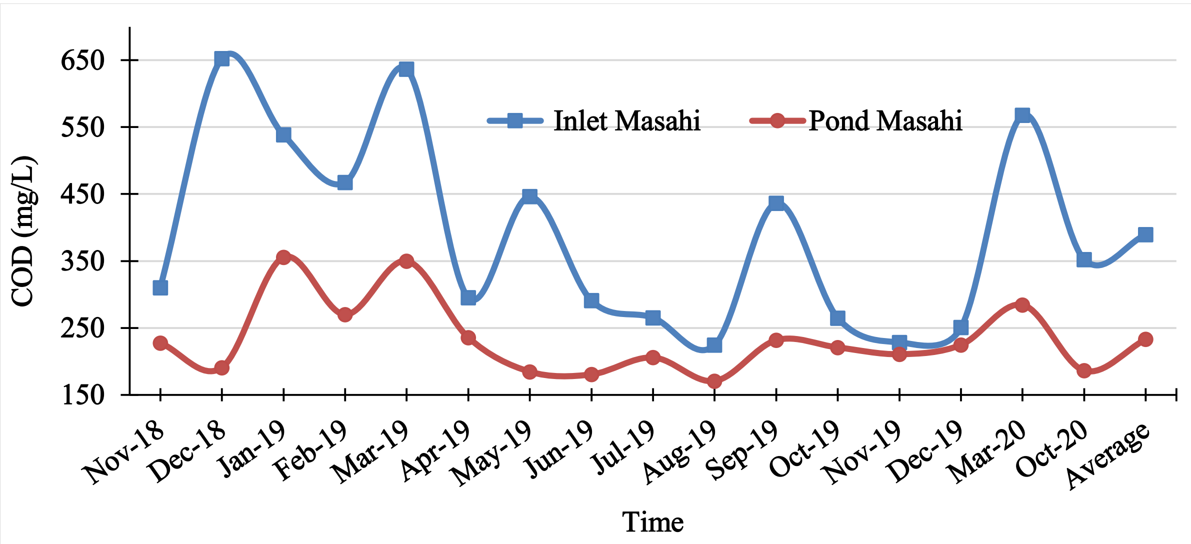
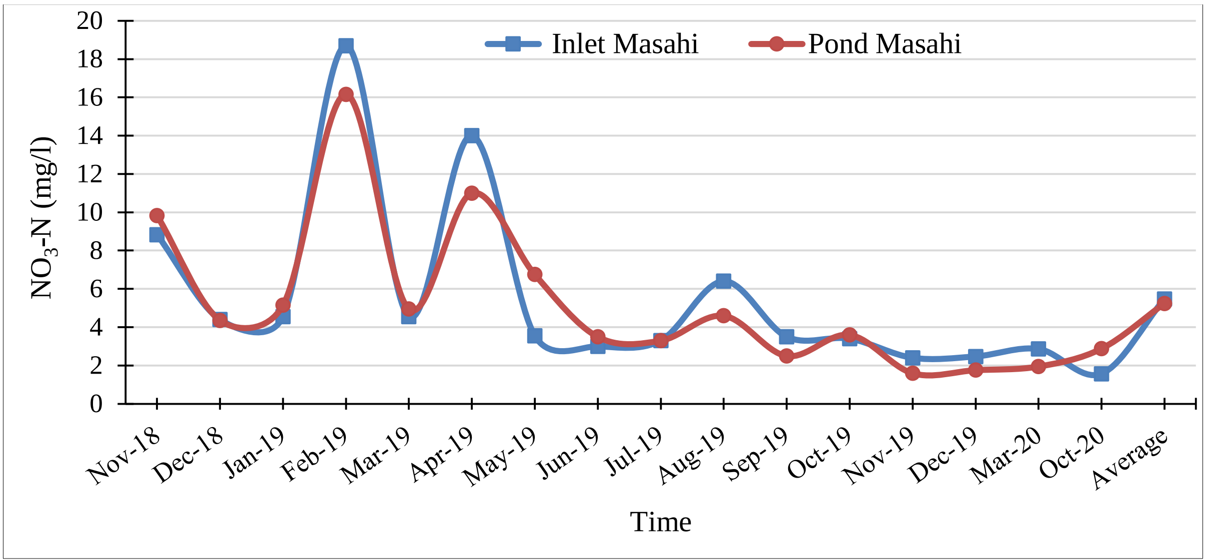
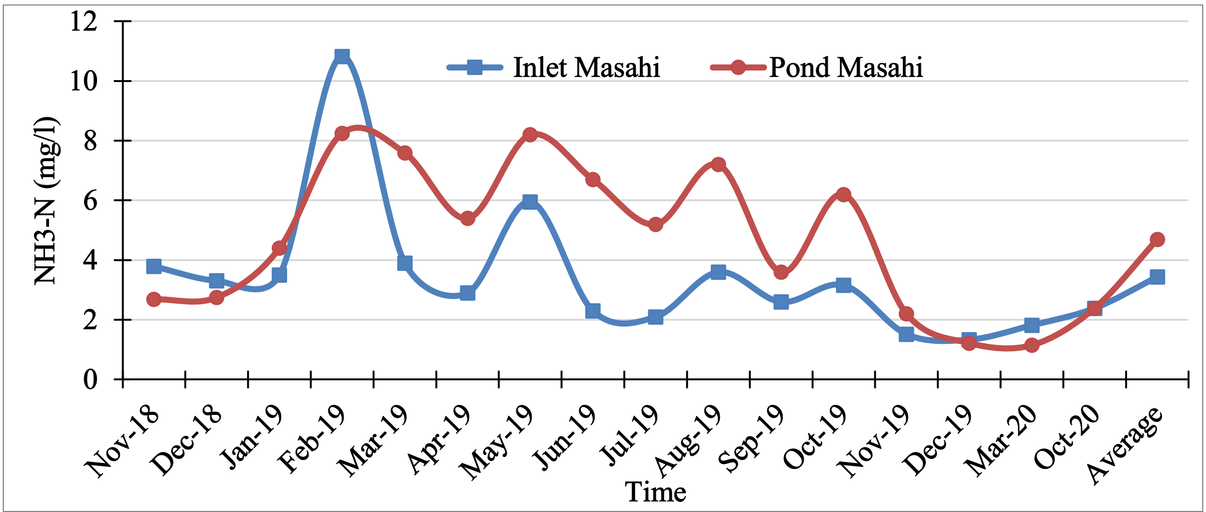



Fig. 39: Monthly Variation in COD of Domestic Wastewater and pond in Masahi Village

### 5.6.4 Nitrate-Nitrogen, Ammoniacal-Nitrogen, and Phosphate

The concentration of $NO_3$-N, $NH_4$-N, and $PO_4$ in the pond water was 1.6 mg/L to 16.15 mg/L, 1.15 mg/L to 8.25 mg/L, and 1.88 mg/L to 27.25 mg/L respectively (Fig. 40). The average annual nitrate-nitrogen in the domestic wastewater was5.47±4.66 mg/L and in the pond, the value was5.24±3.96mg/L which represents a 4.1% decrease in Nitrate-Nitrogen.



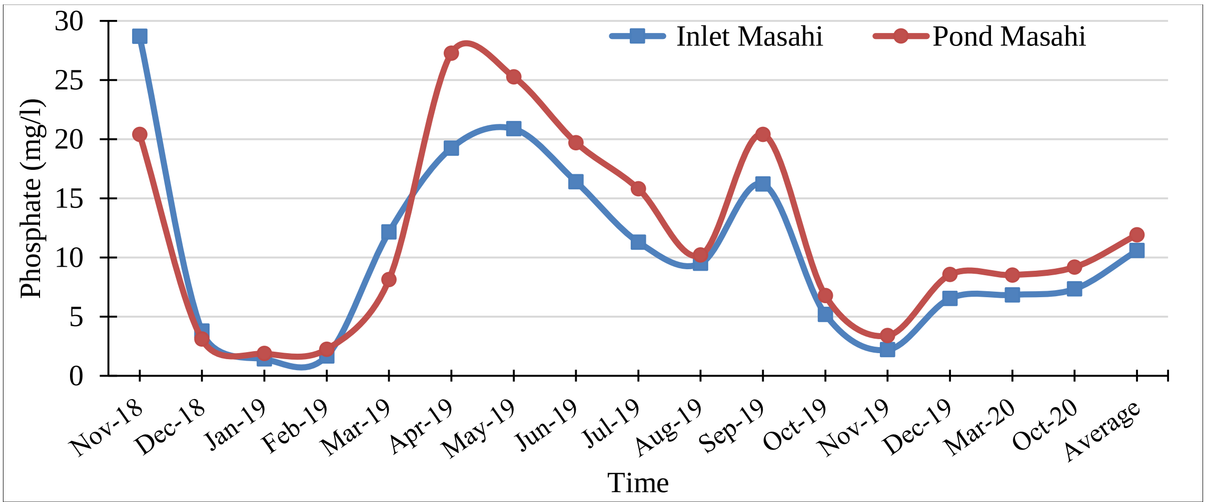




Fig. 40: Monthly Variation $NO_3$-N, $NH_4$-N, and $PO_4$ of Domestic Wastewater and Pond in Masahi

Similarly, the $NH_4$-N average annual concentration reduces from 10.58±7.87 mg/L to 11.92±8.37 mg/L resulting in a 12.7% increase in the concentration of $NH_4$-N. The average annual PO4 concentration in the wastewater and pond was 3.44±2.27 mg/L and 4.70±2.48 mg/L respectively. An increase of 36.6% PO4 was observed in the pond water.

The nutrients, N and P, were observed to increase in the pond water and this was due to the decomposition of vegetation matter in the pond and accumulation in the bed sediments.

### 5.6.5 Bacteriological Analysis

The TC counts in the wastewater and pond were in the range $5.25 \times 10^5$ MPN/100 mL to $2.42 \times 10^8$ MPN/100 mL and $5.65 \times 10^5$ MPN/100 mL to $4.25 \times 10^8$ MPN/100 mL respectively (Fig. 41). The average annual TC count in the wastewater was $3.12 \times 10^7 \pm 4.03 \times 10^7$MPN/100 mL which increased to $3.79 \times 10^7 \pm 1.05 \times 10^8$MPN/100 mL in the pond which represent a 21.58% increase in Total Coliform.

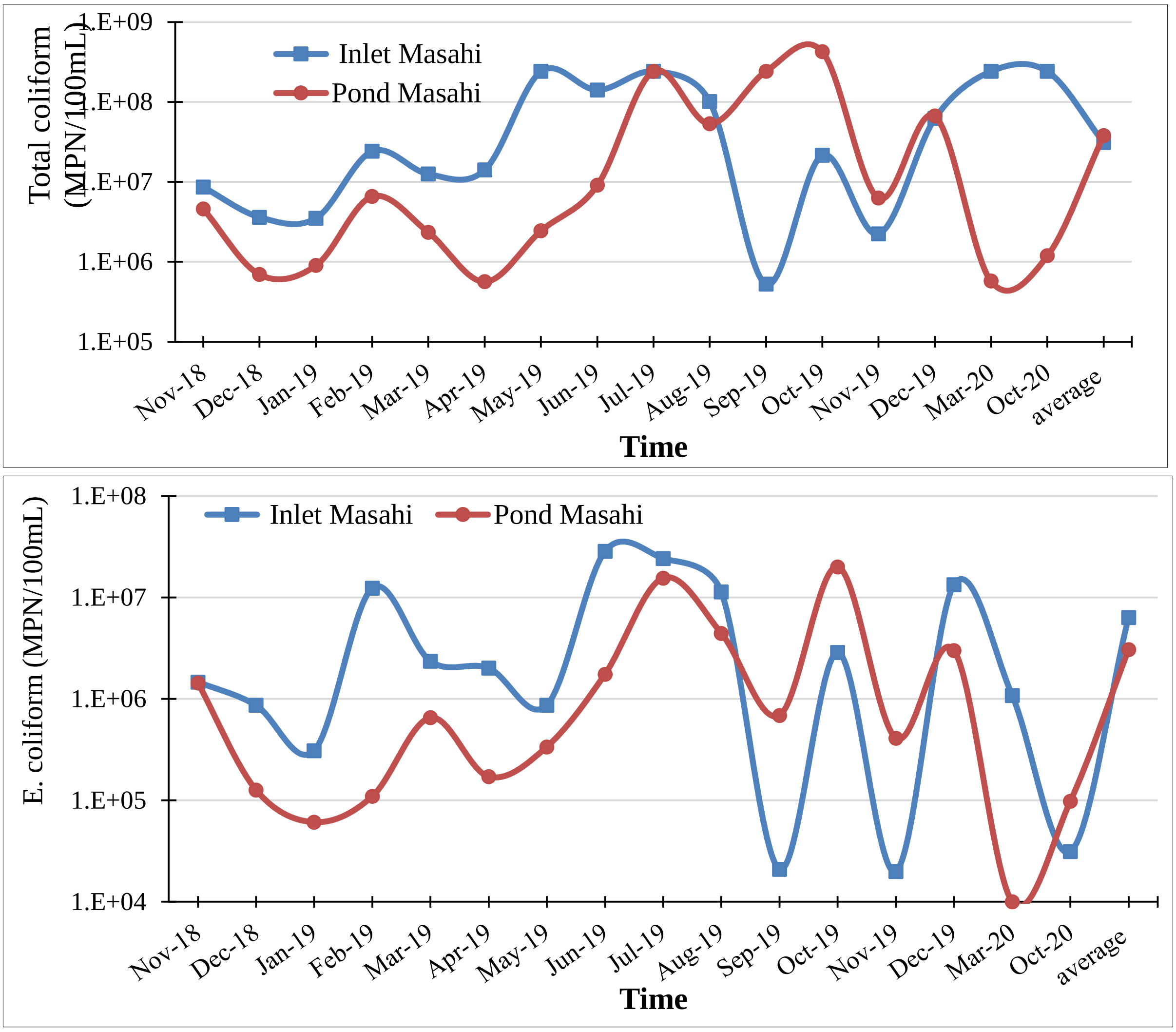



Fig. 41: Monthly Variation of Coliform Counts in Domestic Wastewater and Pond in Masahi Village

The EC counts in the pond water ranges from $2.0x10^4$ MPN/100 mL to $2.85x10^7$ MPN/100 mL and $1.0x10^4$ MPN/100 mL to $2.0x10^7$ MPN/100 mL respectively (Fig. 41). A reduction in average annual E. coli counts from $6.36x10^6±9.08x10^6$MPN/100 mL in the wastewater to $3.06x10^6±5.93x10^6$MPN/100 mL in the pond represents approximately a 51.9% reduction in E. coli counts.

## 5.7 Characteristics of pond water of Ibrahimpur and Masahi kala village based on the monthly variation of water quality parameters

The water quality of the ponds at Ibrahimpur, with the constructed wetland-based treatment system, and at Masahi, without any intervention, was studied to understand the impact of the treatment system on the pond. Further, the reduction in the pollutants was also compared and is shown in Table 4.

**Table 4:** Average annual water quality of ponds and removal efficiency

| S. No. | Parameter | Unit | Ibrahimpur village | | | Masahi village | | |
|---|---|---|---|---|---|---|---|---|
| | | | Waste-water | Pond water | Removal % | Waste-water | Pond water | Removal % |
| 1. | pH | -- | 7.68 | 7.18 | 6.47 | 7.68 | 7.32 | 4.8 |
| 2. | E. Cond. | µs/cm | 1820.83 | 985.30 | 45.88 | 1189.45 | 1054.20 | 11.37 |
| 3. | DO | mg/L | 0.64 | 5.92 | -824 | 0.75 | 0.35 | 52.74 |
| 4. | BOD | mg/L | 245.31 | 41.28 | 83.17 | 190.16 | 113.91 | 40.09 |
| 5. | COD | mg/L | 505.82 | 96.54 | 80.91 | 389.29 | 232.98 | 40.15 |
| 6. | T. coli. | MPN/100 mL | $1.18x10^8$ | $8.01x10^5$ | 99.32 | $3.12 x10^7$ | $3.79x10^7$ | -21.58 |
| 7. | E. coli | MPN/100 mL | $8.72x10^6$ | $5.75x10^3$ | 99.93 | $6.36x10^6$ | $3.06x10^6$ | 51.9 |
| 8. | $NO_3$-N | mg/L | 2.68 | 1.88 | 29.93 | 5.47 | 5.24 | 4.13 |
| 9. | $NH_4$-N | mg/L | 3.02 | 0.76 | 81.01 | 3.44 | 4.70 | -12.66 |
| 10. | $PO_4$ | mg/L | 9.42 | 1.79 | 74.96 | 10.58 | 11.92 | -36.62 |

The improvement in the water quality of the Ibrahimpur pond is quite significant in comparison to the Masahi pond. The average annual pH of water in Ibrahimpur pond water was 7.17±0.11and in Masahi pond the value was 7.31±0.31 (Fig. 42). The pH of the Ibrahimpur pond was stable throughout the year in comparison to the Masahi pond which fluctuates from 6.7 to 7.9. Because of the reduction in the organics (Fig. 43-44), the DO levels (Fig. 45) in the Ibrahimpur improved appreciably and are suitable for the development of fisheries. The DO levels in Ibrahimpur were always more than the recommended value of 4.0 mg/L, whereas, the DO levels in the Masahi pond were less than 1.0 mg/L throughout the year and dipped to zero on several occasions. The average annual DO in the Masahi pond was 0.35±0.58 and in the Ibrahimpur pond, the value was 5.92±1.68. Further, the nutrients were appreciably lower in the Ibrahimpur pond as compared to the Masahi pond (Fig. 46).

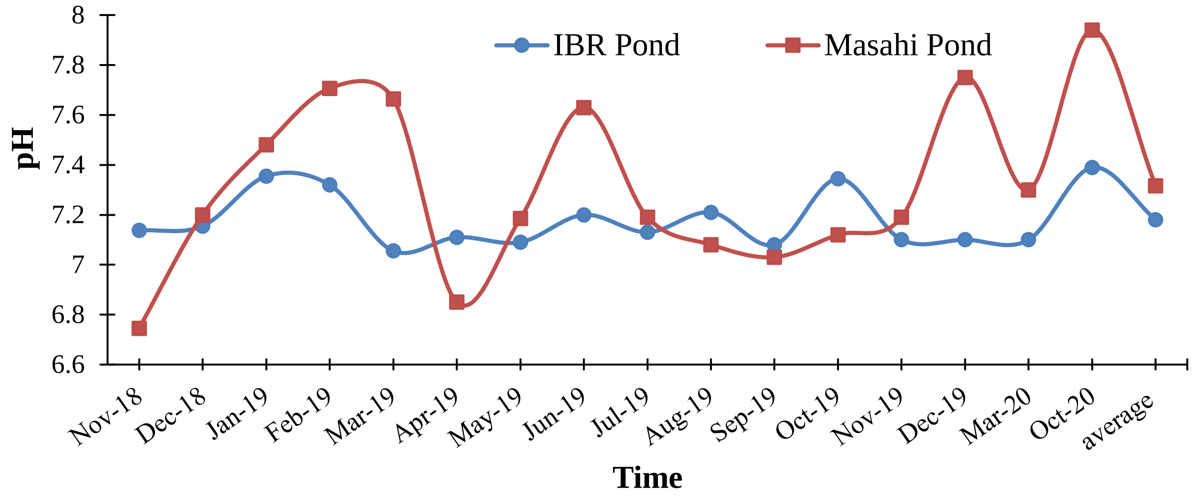


Fig. 42: Monthly Variation in pH of Ibrahimpur and Masahi Pond

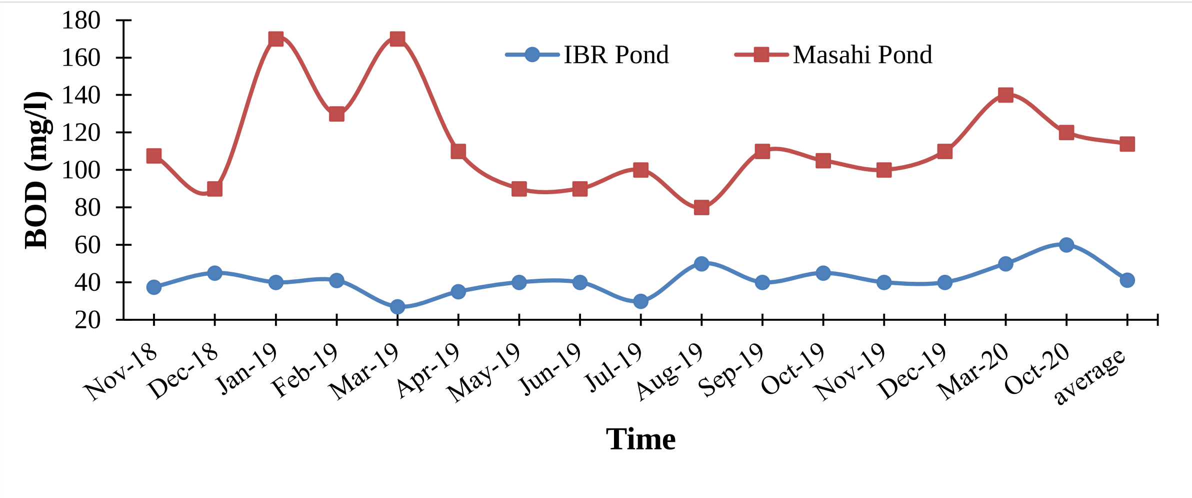


Fig. 43: Monthly Variation in BOD of Ibrahimpur and Masahi Pond

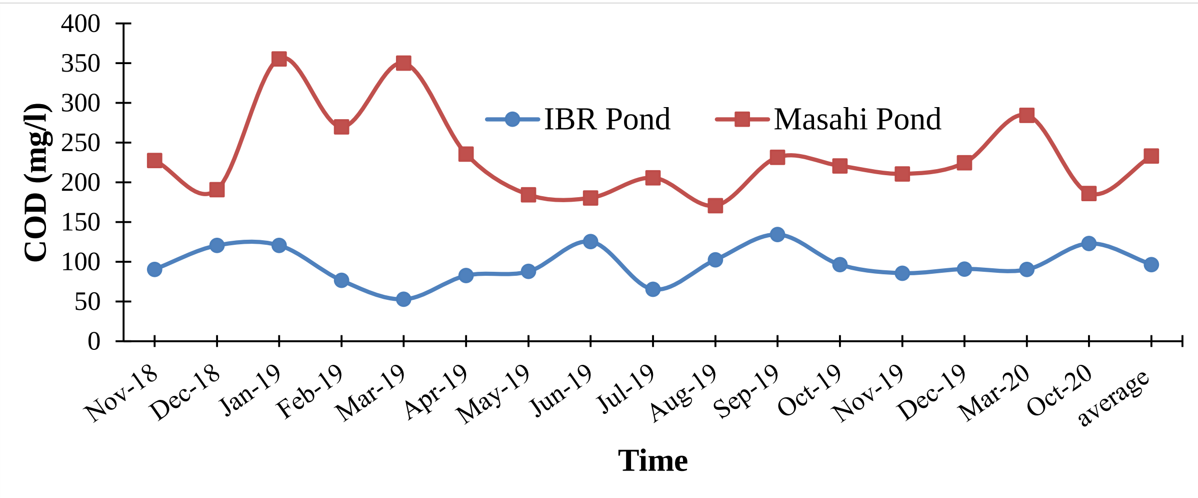


Fig. 44: Monthly Variation in COD of Ibrahimpur and Masahi Pond

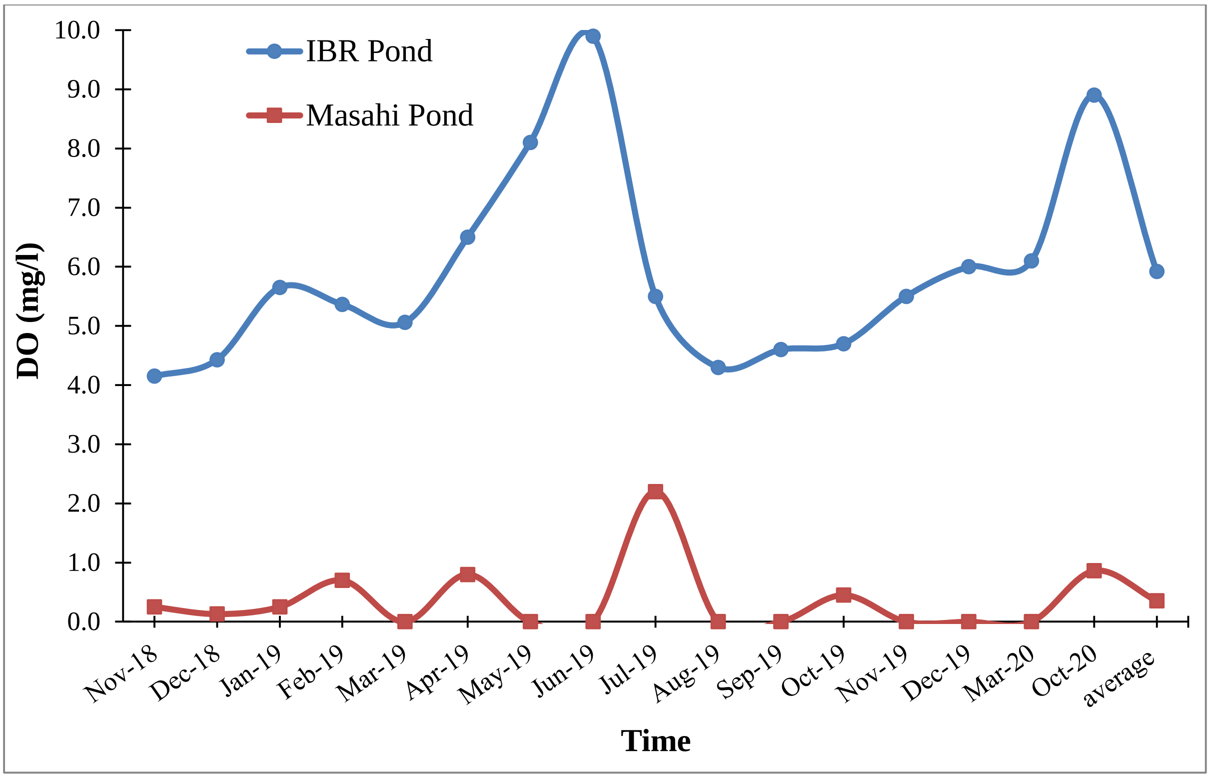



Fig. 45: Monthly Variation in DO of Ibrahimpur and Masahi Pond

The level of nutrients observed in the Ibrahimpur pond helped in subsiding the eutrophic status of the pond, however, the Masahi pond was hypereutrophic throughout the study period. Further, the free ammonia in the Ibrahimpur pond was 0.002 mg/L to 0.08 mg/L, quite less than the 2 mg/L limit above which gill damage and poor growth are encountered. Further, a significant reduction in the coliform counts was observed. The E. Coli counts reached below the maximum permissible limit of 2500 MPN/100 mL for organized bathing on several occasions in Ibrahimpur pond, therefore, the pond can be used for recreational activities and the water can be used for the irrigation of crops (Fig. 47). Therefore, it can be concluded that the installation of constructed wetland based treatment system to treat the village wastewater drained in the pond is having a significant positive impact on the water quality and the pond can be used for pisciculture, recreational activities, and irrigation.

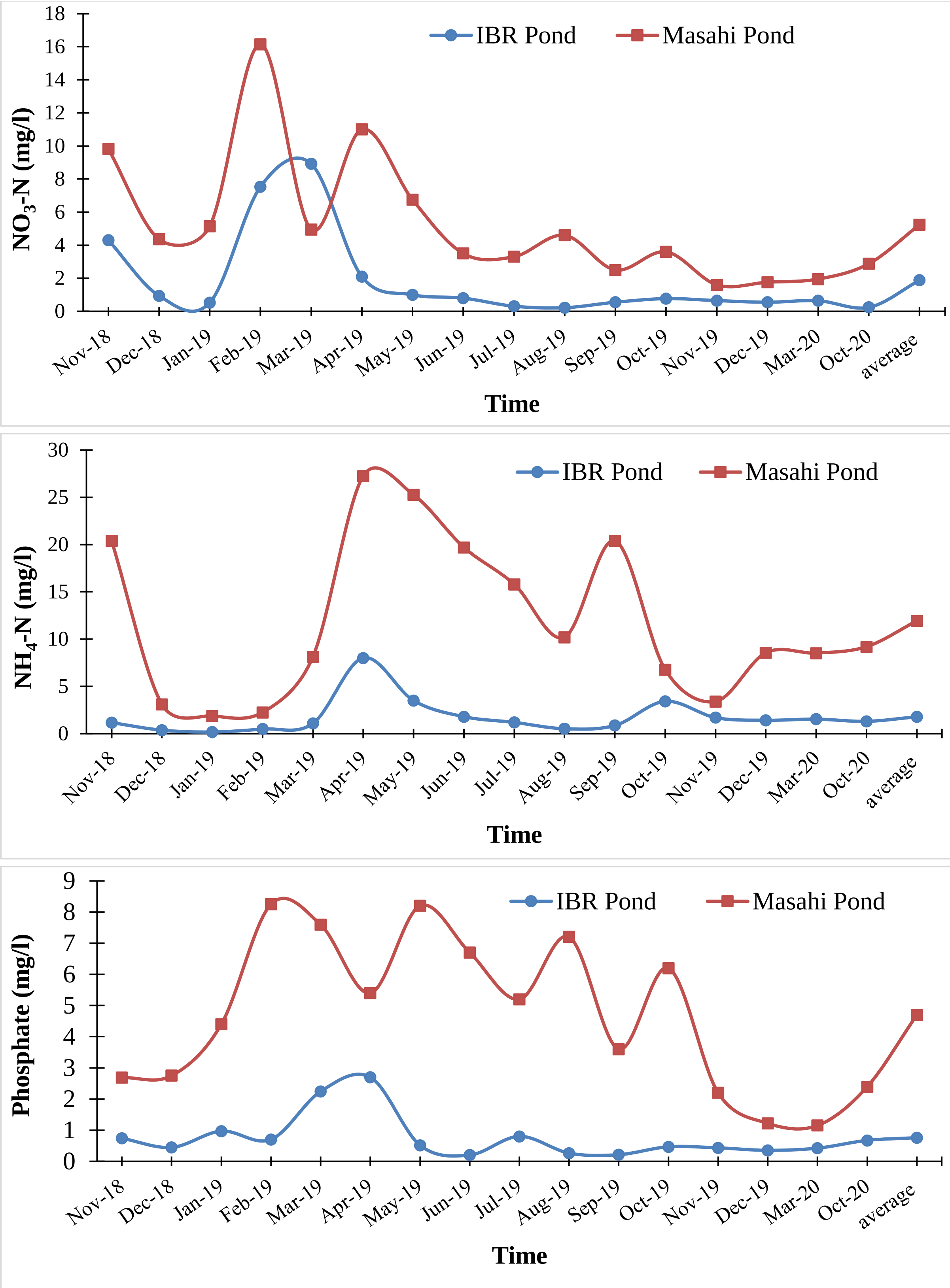



Fig. 46: Monthly Variation of nutrients in Ibrahimpur and Masahi Pond

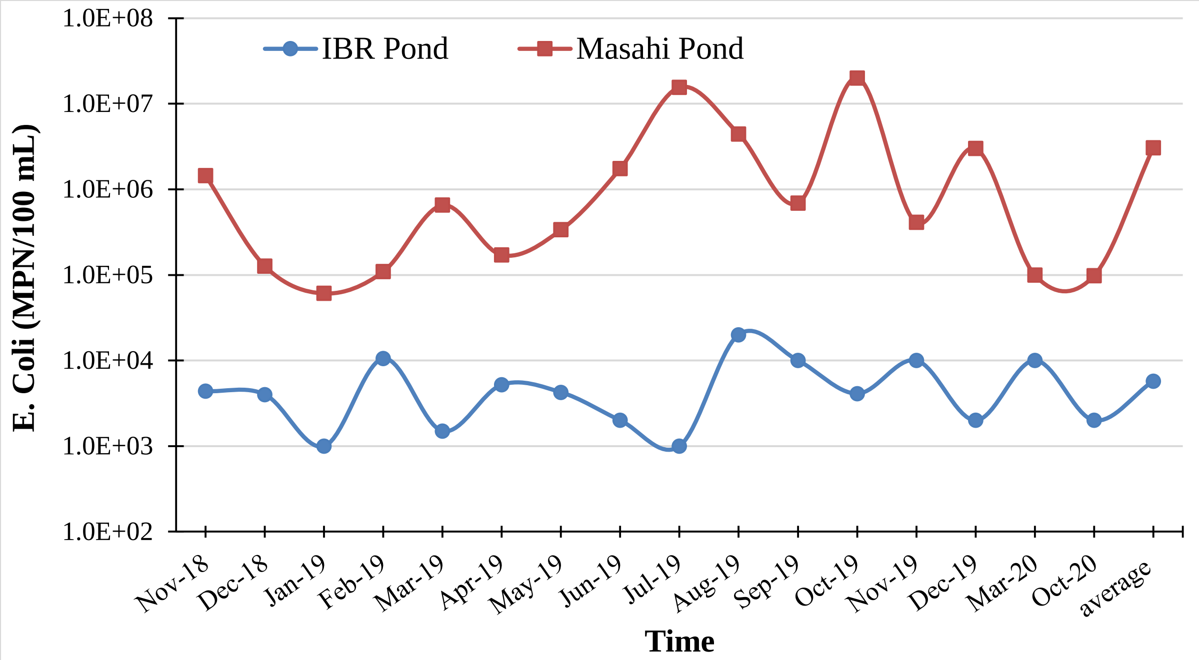



Fig. 47: Monthly Variation in E. coli counts in Ibrahimpur and Masahi Pond

## 5.8 Assessment of GHGs Emissions from ponds (CW-NTS and Control Ponds)

Mean $CH_4$-C and $CO_2$-C concentrations measured in Masahi pond were an order of magnitude greater than those measured in Ibrahimpur; 7.66 mg $CH_4$-C $L^{-1}$ and 7.69 mg $CO_2$-C $L^{-1}$ in Masahi compared to 0.237 ± 0.0550 mg $CH_4$-C $L^{-1}$ and 0.933 ± 0.720 mg $CO_2$-C $L^{-1}$ in Ibrahimpur (Figure 48). Some variability was observed between concentrations measured in November 2018 and December 2019 (Table 5, Figure 48), this is most likely due to uncertainties in measured concentrations, rather than to any differences between sampling occasions. The headspace method relies on sufficient shaking to equilibrate gas between water and the headspace. If an equilibrium is not reached concentrations can be underestimated, as such the maximum concentrations are often reported. Sample dilution also introduced errors, of roughly 20%. The results from Masahi samples taken in December 2019 are particularly uncertain as the sample concentrations lay outside the instrument calibration range, even following dilution.

Large uncertainties were associated in the measurements, partly due to sample dilution and partly due to the variability between sample replicates. Though no firm conclusions can be made from the limited number of samples these results indicate that dissolved concentrations of $CH_4$ and $CO_2$ are far higher in Masahi pond than in Ibrahimpur pond. As such, results suggest that the reduction in organic matter inputs at Ibrahimpur – due to primary screening and the constructed wetland – play a significant role in reducing $CH_4$ and $CO_2$ concentrations from village ponds.

**Table 5.** Maximum dissolved concentrations of methane ($CH_4$-C) and carbon dioxide ($CO_2$-C) in mg $L^{-1}$ measured in Ibrahimpur (IBR) and Masahi (MAS) ponds in November 2018 and December 2019.

| Site | Sampling Date | $CH_4$-C (mg $L^{-1}$) | $CO_2$-C (mg $L^{-1}$) |
|---|---|---|---|
| IBR | 20/11/2018 | 0.198 | 1.44 |
| IBR | 05/12/2019 | 0.276 | 0.424 |
| MAS | 20/11/2018 | 7.66 | 7.69 |
| MAS | 05/12/2019 | 4.61 | 3.85 |

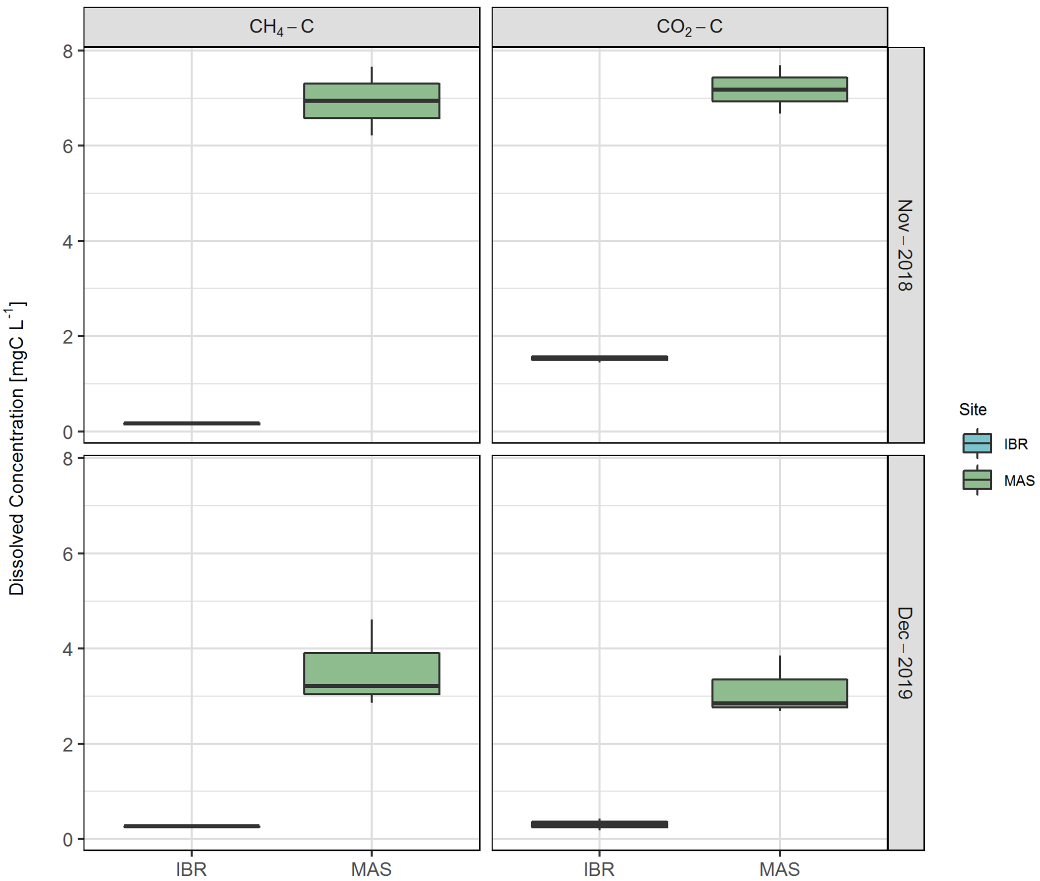



Fig. 48: Dissolved concentrations of methane ($CH_4$-C) and carbon dioxide ($CO_2$-C) in mg $L^{-1}$ measured in Ibrahimpur (IBR) and Masahi (MAS) ponds on two sampling occasions, in November 2018 and December 2019.

## 5.9 Analysis of Plankton and Invertebrates

### 5.9.1 Phytoplankton

The phytoplankton community from the two ponds are shown in Figure 49 and Table 6. Ibrahimpur was generally dominated by Chlorophyta algae (on average 57% of biovolume) with Euglenophyta also very abundant (on average 32% of biovolume) (Figure 49a). Masahi was always dominated by Euglenophyta, accounting for on average 70% of the biovolume (Figure 49b). Euglenophyta are common in stagnant water in ponds and ditches, which are rich in organic matter. This fits well with the organic pollution in these two lakes. Both ponds had low densities of cyanobacterial cell numbers, below the World Health Organization threshold considered of risk to human and animal health (WHO 2003).

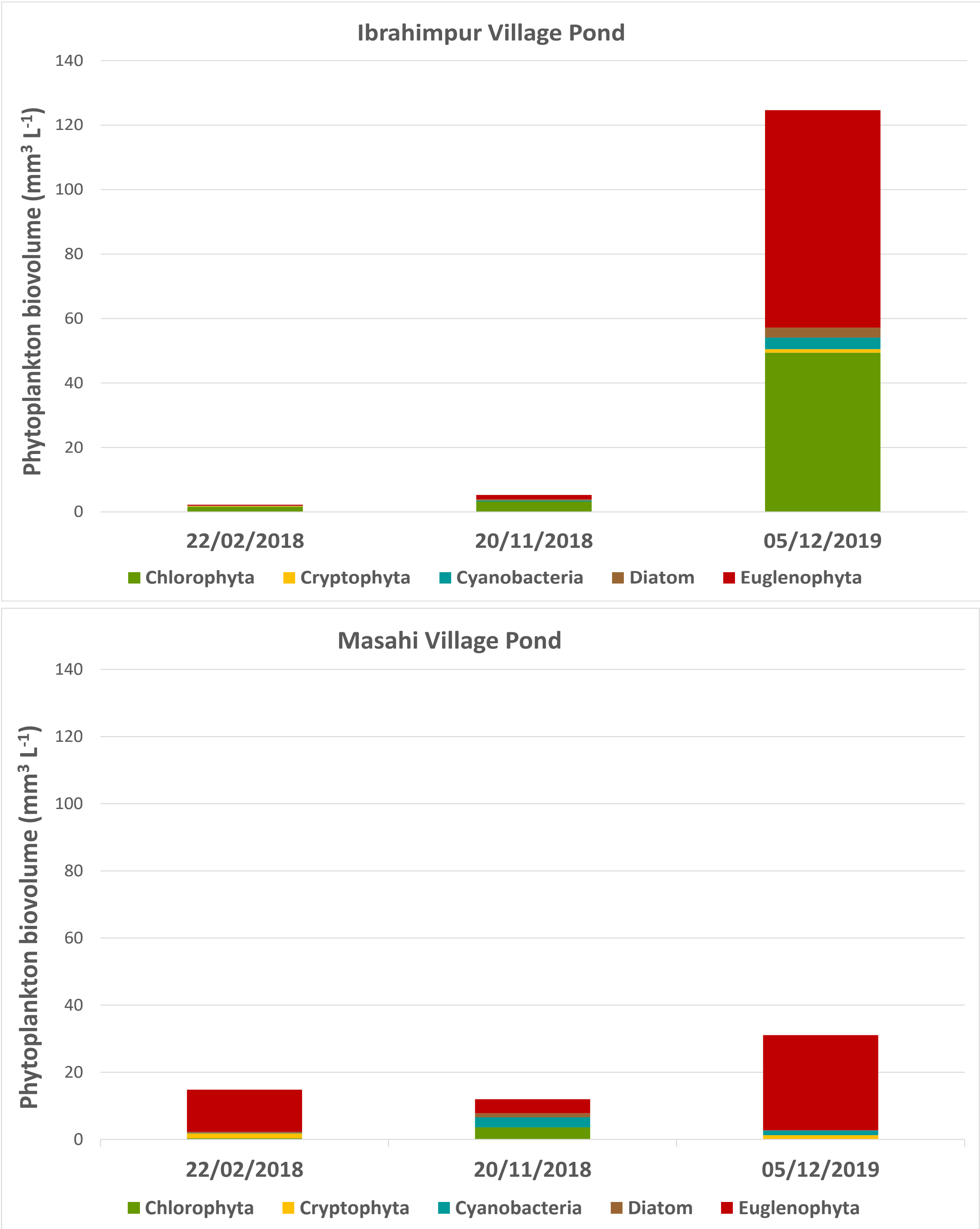


Fig. 49: Biovolume of main phytoplankton groups in (a) Ibrahimpur and (b) Masahi Village Ponds

**Table 6:** Phytoplankton species lists for Ibrahimpur and Masahi Village Ponds

| Class | Species | Ibrahimpur | Masahi |
|---|---|---|---|
| Chlorophyta | Ankistrodesmus falcatus | X | |
| | Chlamydomonas | X | |
| | Coelastrum | X | |
| | Micractinium pusillum | | X |
| | Monoraphidium arcuatum | X | |
| | Monoraphidium contortum | X | |
| | Monoraphidium griffithii | | X |
| | Monoraphidium minutum | X | X |
| | Pandorina morum | X | X |
| | Scenedesmus | X | |
| | Schroederia setigera | X | |
| | Sphaerocystis schroeteri | X | |
| | Tetrastrum komarekii | X | |
| | Unidentified green | X | X |
| Cryptophyta | Chroomonas | | X |
| | Cryptomonas | X | X |
| | Rhodomonas | X | |
| Cyanobacteria | Aphanocapsa | X | |
| | Merismopedia | X | X |
| | Pseudanabaena | X | X |
| | Snowella lacustris | | X |
| | Pico-cyanobacteria <2 µm diameter | X | X |
| Diatom | Asterionella formosa | X | |
| | Nitzschia | X | X |
| | Synedra acus | | X |
| Euglenophyta | Euglena | X | X |
| | Phacus | X | X |
| | Strombomonas | | X |
| | Trachelomonas | X | X |
| | Total number of species | 23 | 17 |

### 5.9.2 Crustacean Zooplankton, Mosquito Larvae and other Invertebrates

The results from the two ponds are summarized in Tables 7 and 8. Samples could not always be obtained from Masahi village pond due to the frequent full coverage of floating duckweed (Figure 51). Despite the variable sampling methods, it is clear from Table 7 that Ibrahimpur village pond contained a good diversity of invertebrates, some indicative of moderately good water quality. This included water boatmen and mayflies. Importantly, on two occasions dense populations of crustacean zooplankton were also present, suggesting that Ibrahimpur village pond has the potential to support a healthy fishery. Although these zooplankton had an intense red pigmentation, indicating the low levels of oxygen present in the water (Figure 52).

Importantly, mosquito larva do not appear to be a particular issue in the Ibrahimpur village pond, as this taxa was only recorded once and in very low numbers. Mosquito larvae were recorded on both occasions that Masahi village pond was sampled but, again, in relatively low numbers. As results in Table 8 indicate, the February 2018 sampling of the Masahi village pond would suggest the invertebrate community there was reasonably diverse and was indicative of a small enriched standing water.

Fig. 50: A view of rejuvenated Ibrahimpur Masahi village pond with CW-NTS (June 2019)

Fig. 51: Masahi Village Pond covered in duckweed (*Lemna* sp.), June 2019

**Table 7.** Macroinvertebrates and zooplankton recorded in Ibrahimpur Pond, 2018-2019

| | **Sample Date** | | |
|---|---|---|---|
| | **February 2018** | **November 2018** | **June 2019** |
| **Method** | 2 m zooplankton net samples | Surface net sweep sample (1x3 m) + 2 m zooplankton net tow | Surface net sweep sample + 4 m zooplankton net tow + sub-surface net tow |
| ***Macroinvertebrates*** | | | |
| Culicidinae (mosquito larvae) | - | Rare/Present | - |
| Chironomidae (adults, exuviae, larvae & pupae) (non-biting midges) | - | Occasional | Rare/Present |
| Diptera (larvae & pupae) (non-chironomid flies) | - | Rare/Present | Rare/Present |
| Corixidae (lesser water boatmen) | - | Rare//Present | Rare/Present |
| Dytiscidae (water beetles) | - | - | Rare/Present |
| Ephemeroptera (mayflies) | - | Rare/Present | - |
| Hydracarina (water mites) | - | - | Rare/Present |
| Notonectidae (greater water boatmen) | - | Rare/Present | Occasional |
| ***Crustacean zooplankton*** | | | |
| *Daphnia* sp. | Dominant | - | Dominant |
| Cylopoida | Rare | - | Dominant |

**Table 8.** Macroinvertebrates and zooplankton recorded in Masahi Pond, 2018-2019

| | **February 2018** | **November 2018** | **June 2019** |
|---|---|---|---|
| | 1 surface net sample | 1 surface net sample | No invertebrate sample collected due to duckweed cover |
| ***Macroinvertebrates*** | | | |
| Culicidinae (i.e. mosquito larvae) | Rare/Present | Occasional | |
| Chironomidae (larvae & pupae) (i.e. non-biting midges) | Occasional | - | |
| Dipteran (larvae & pupae) (i.e. non-chironomid flies) | Rare/Present | - | |
| Hemiptera (i.e. bugs) | Occasional | Rare/Present | |
| Collembola (springtails) | Rare/Present | - | |
| Zgoptera (i.e. damselfly larvae) | Rare/Present | - | |
| ***Crustacean zooplankton*** | | | |
| *Daphnia* sp. | Rare/Present | - | |
| Cylopoida | - | - | |

Fig. 52: Zooplankton sample from Ibrahimpur Pond, 22nd February 2018

## 5.10 Variation of Groundwater Levels around Identified Ponds

The variation of ground water levels (DTW, m bgl) are given in Fig. 53, which indicates improvement of groundwater levels as compared to pre-rejuvenation period of pond (Jan. 2017) with post rejuvenation period (Nov. 2017 onwards). The trend lines of GWL are showing improved groundwater conditions around the pond at Ibrahimpur Mashai after rejuvenation due to enhanced capacity of ponds to retain water and thereby enhancing recharging from pond.

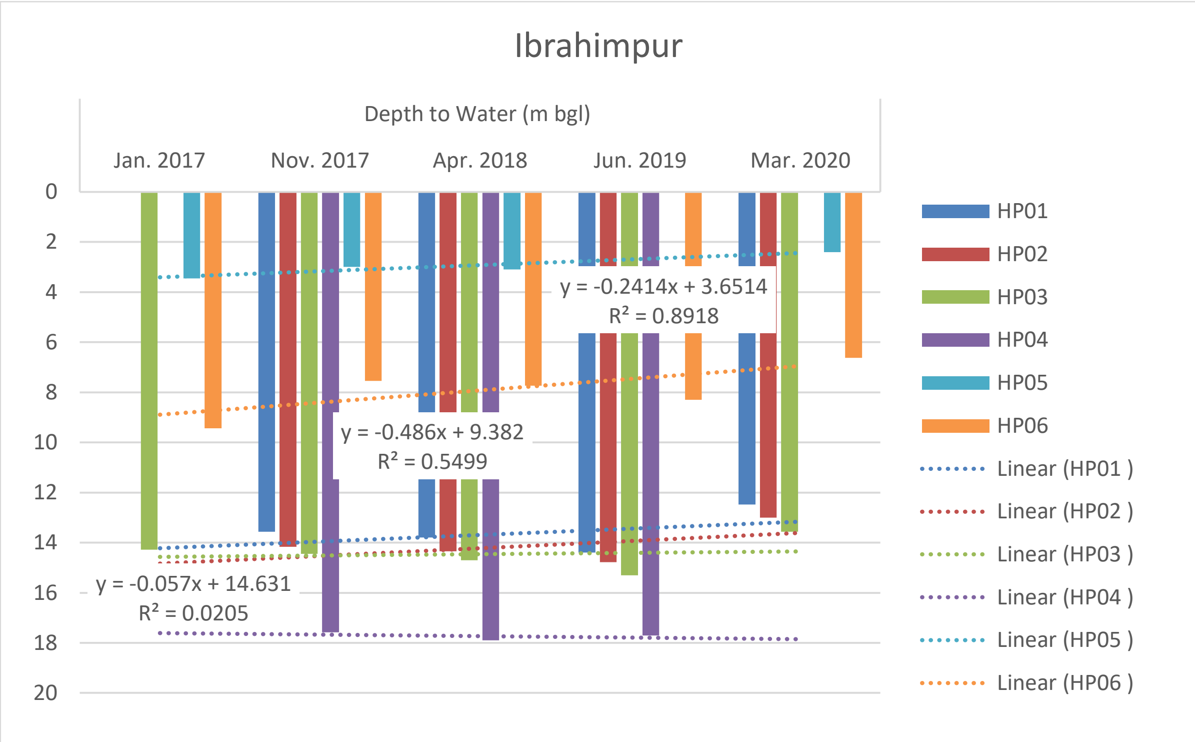


Fig. 53: Depth to Water (DTW) in Hand Pumps of Ibrahimpur Masahi Village

## 5.11 Societal Impact: Survey of Villagers

These summaries had founded from a survey of residents in Ibrahimpur village. This survey was conducted on the 7th and 10th of June 2019. The objectives of this survey were to better understand:

1. Sources of wastewater that local people found important
2. Issues faced relating to wastewater and flooding
3. The impact of the natural treatment system (constructed wetland) from a local perspective.

The survey was mostly open questions, as well as a card sorting exercise for water sources and check list of wastewater issues. A blank sample data recording sheet is included at the end of this report. The survey was intended for a single respondent. However, as soon as a request for an interview was made in a household a group of people would gather. Asking questions and gathering responses from all of those present was chosen as a more practical method. A total of 20 households were surveyed. Some of these surveys took part with several households gathered together in the same location. The task of sorting wastewater source cards was usually given to one or two members of the household, they then read their ranking aloud to confirm with other members of the household. The team began the survey by selecting households living immediately adjacent to the pond and NTS. For the first 6 interviews we were accompanied by the Gram Pradhan, following this the 'right-hand man' of the GP stayed with us, and introduced the survey team to each household. On the second day of surveying we went to the other side of the village. The aim was to compare responses from a location which was far from the pond, and which also was on a more steeply sloping street - meaning water did not gather anywhere in the area. A view of social survey with UK-CEH Team and density plot of the survey locations are given in Figs. 54 & 55, respectively.

Fig. 54: A view of social survey in Ibrahimpur Masahi with UK-CEH Team

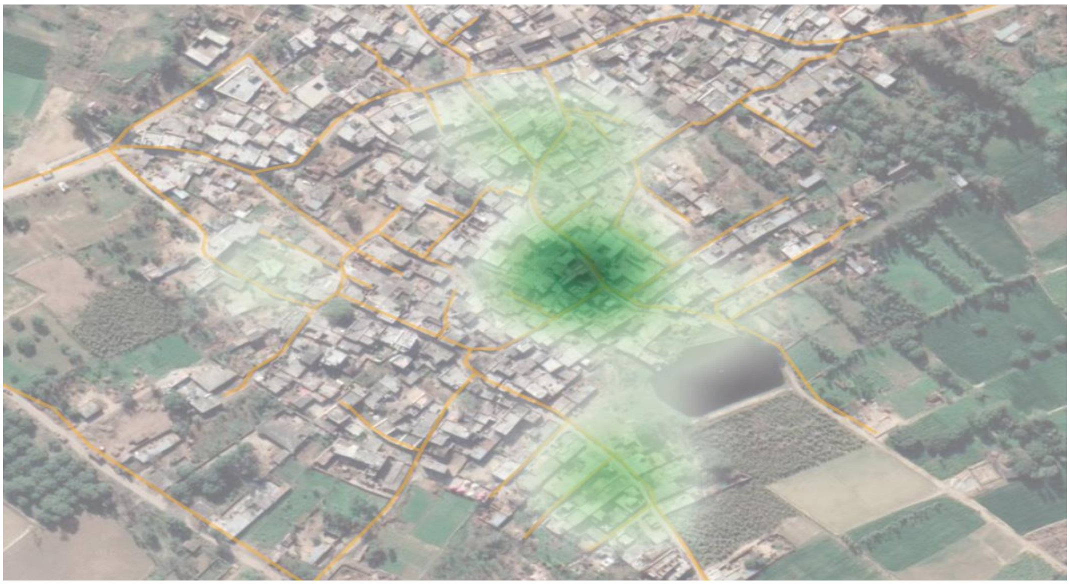


Fig. 55: Density plot of sampling locations in Ibrahimpur Masahi village

The basis of this report is translated material from the interviews, which were conducted in Hindi. This is a major limitation of the survey, as these translations were brief summaries. The full complexity is not available as remarks were not recorded. Some longer conversations were summarized in very short remarks.

### 5.11.1 Findings of Survey

The wastewater that flows into the treatment system is a mixture of water sources, which carry with them different contaminants of concern. Through a card sorting exercise participants were asked to select the wastewater sources that were of most importance. Importance is clearly a subjective measure - this survey does not clarify which wastewater sources are producing the most water. However, the results show clearly which wastewater sources are most significant in marking wastewater as an issue of concern. This selection was done by ranking a set of nine cards. The wastewater sources on the cards were developed by the survey team beforehand, and translated into Hindi for writing on the cards. Card sorting was usually carried out by one or two members of the household, and then the results were read out for confirmation. I occasionally asked clarifying questions regarding the position of certain cards. Figure 56 provides a count of the rank given to each source, along with an average ranking (dotted line).

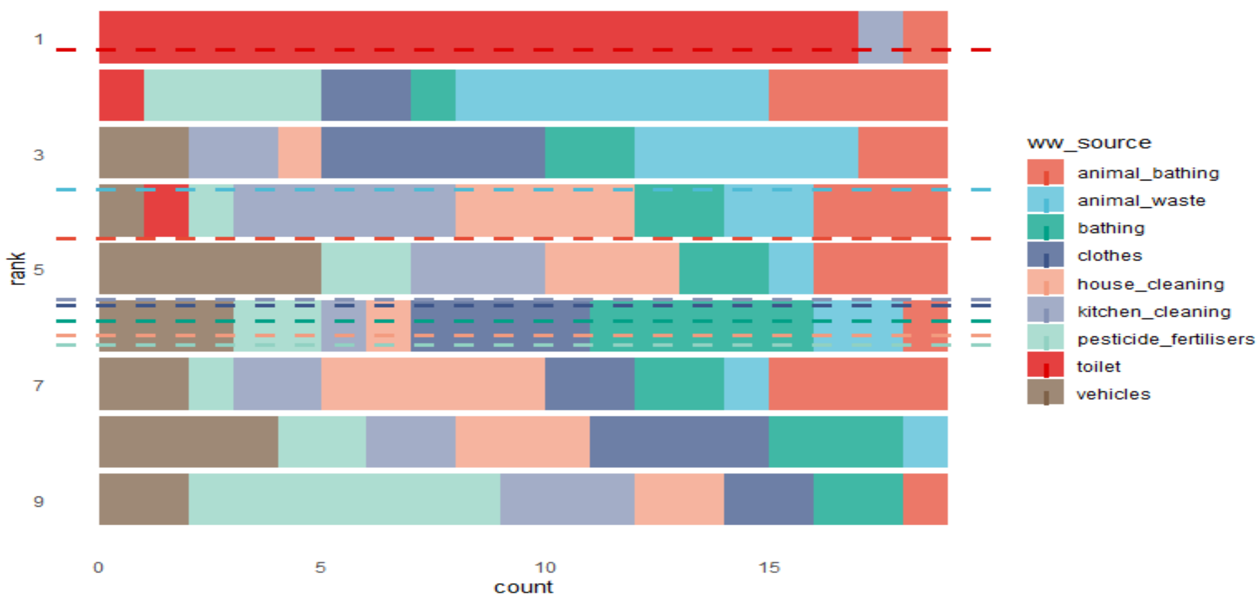



Fig. 56: Ranking of wastewater sources

The clearest result from this exercise was the importance of human waste/sewage. This was almost always the first issue identified. Animal waste was also identified as important. Some sources such as pesticide residues and house cleaning were clearly not important. However, for many of the middle rankings it is not possible to make firm conclusions about their relative importance. Some context arose from the discussions with households. For example, pesticides aren't a concern because farmers tend to either hire the equipment, or wash it out in the fields. For both human and animal waste the major impact of this is that it makes the water smell.

### 5.11.2 Issues Related to Wastewater

Most of the households were readily able to identify issues that they faced related to Gan*da pani* (literally 'bad water', the Hindi term we used for wastewater). The most common issue linked with wastewater was mosquitos, this was mentioned in half (10) of the replies, although one respondent didn't consider mosquitos to be a wastewater issue. Other animals also were linked with wastewater - people had issues with snakes and frogs entering their houses. This causes some alarm, and, according to one respondent the snakes are then killed. Turtles were also mentioned twice. One household where animals have not been an issue suggested that this was because they were further from the pond. The main disease issue linked with wastewater was skin diseases that occur after walking through wastewater. A key dynamic in wastewater issues is the interplay between household wastewater and monsoon rainfall. The same drainage pathways carry both wastewater and rainwater runoff. Wastewater flows and rainfall runoff combine to produce flooding, which was mentioned as an issue impacting eight of the households. Other issues are either heightened by rainfall or are only a concern during the rainy season, for example, the rainy season means that roads are blocked or flooded. As a result, walking through wastewater is unavoidable, leading to skin diseases, and other diseases. Besides from these main concerns, a few respondents mentioned bad smells as an issue and there were two mentions of groundwater contamination. Four respondents initially replied that they had no issues. There was a varying degree of concern about wastewater.

### 5.11.3 Impact of NTS

The installation of the NTS and the rejuvenation of the pond have clearly had an impact. Almost all households suggested that there has been a significant improvement. Midway through the interviews, through a miscommunication, we were asking respondents to estimate a percentage improvement. This was confusing for both interviewer and interviewee, but it still seems worth noting that the range was from 60-80% improved. What was the meaning of 'improvement'? For most participants improvement was closely linked to an increased cleanliness. Two households disagreed with the majority opinion - one claiming no significant change had taken place as the pond still received wastewater from toilets, and there are still mosquitos and flies. Another household also did not see much advantage from the pond cleaning. Respondents judged the improvement with their senses. Smell and sight were the main ways to determine an impact. In seven of the household surveys it was noted that odors or bad smells from the pond had reduced. One response suggested that before the project it was difficult to breathe near the pond, and was now much better. Another, who lived near the pond suggested that the reduction in smell had made it more pleasant in their house. As for the visual impact, some households simply noted that the pond looked cleaner. Various factors contributed to this impression. The water in the pond looks cleaner. There is also a reduction in the amount of garbage in the pond. This was seen as significant in its own right, while also contributing to reduced odors. This cleaner state of the pond also contributes to a shift in practices. While before the pond could be used as a dumping ground for waste, this has now decreased - helping to keep the pond in a clean state.

### 5.11.4 Impact of Flooding

On previous visits to Ibrahimpur, flooding of the area around the pond had been raised as a concern. Therefore, I added a survey question about the impact of this flooding. The issues raised were similar to those from wastewater. Five households faced flood waters entering their homes following rains. This floodwater brings with it solid waste. Issue with animals such as snakes, frogs, insects and turtles were also linked with flooding. Roads and pathways become difficult to pass through. The impact of flooding was more localized than wastewater issues, only half of the households faced any issues related with flooding, with the rest saying that they had no problems.

## 5.12 Mass Awareness Activity/Transfer of CW-NTS to Gram Panchayat

An outreach activity was conducted for villagers/Gram Panchayat Members and concerned local State Govt. officials at village Ibrahimpur Masahi on dated 20/11/2018 (Fig. 57) and transferred the CW-NTS to Gram Panchayat (Vill. Ibrahimpur Masahi, Dist. Haridwar). The UK-CEH team also participated in mass awareness activity. The Institute has also provided Standard Operation Procedure (SOP) to Gram Pradhan, Ibrahimpur Masahi for convenient operation and maintenance of CW-NTS at GP Level (Fig. 58).


Fig. 57: Photographs showing mass awareness activity at village Ibrahimpur Masahi


Fig.58: Standard Operating Procedure (SOP) for Maintenance of CW-NTS

## 6.0 CONCLUSIONS

From the above study, following conclusions can be drawn-

- The wastewater generated from the village habitation is contaminated with organics (BOD: 245±71 mg/l; COD: 506±37 mg/l), nitrogen (NO3-N: 2.68±0.29 mg/l; NH4-N: 9.42±1.77 mg/l), and phosphorus (3.02±0.38 mg/l), and corresponds to high strength sewage. The wastewater is generally drained in the ponds and as a result of the elevated organics and nutrients concentration, most of the ponds are in eutrophic to hypereutrophic conditions.

- The settling chamber with around 2.5 hrs HRT can arrest the settleable matter for almost 6 months and also reduces approximately 26% BOD, 27% COD, and 6.5% $NH_4$-N from the wastewater. An increase in 19% $NO_3$-N was observed due to nitrification of $NH_4$-N to $NO_3$-N due to the movement of water through the baffles which obstructs the flow and creates turbulence. An increase of around 17.6% $PO_4$ concentration was observed may be due to the release of phosphorus from the decomposed matter. Reduction of approximately 36.5% total coliforms was observed in the settling chamber, however, a 37.4% increase in E. coliform counts was recorded. The increase in E. coliforms in the wastewater may be due to prevailing septic conditions in the sedimentation chamber which provide a conducive environment for the E. coli to multiply.

- Subsurface flow constructed wetland consisting of Canna indica and Phragmites australis with 4.5 days HRT (1.2 days actual HRT) was able to reduce approximately 32.7% BOD, 30% COD, 54.4% $NH_4$-N, and 23.9% $PO_4$. An increase in $NO_3$-N concentration of about 44% was observed. The constructed wetland also helped in reducing the total coliforms and E. coliforms counts to 42.8% and 74.6% respectively.

- The treatment chain comprises of settling chamber (≈2.5 hr HRT), constructed wetland (≈4.5 days HRT), and pond (≈160 days HRT) resulted in a reduction of 45.9% electrical conductivity, 83.2% BOD, 80.9% COD, 29.9% $NO_3$-N, 81.85% $NH_4$-N, and 75% $PO_4$ concentration. An increase of around 824.4% in the DO levels was observed. Further, a 99.6% reduction in average annual total coliform counts and a 99.9% reduction in E. coliform counts were observed. The results indicate a positive impact on the pond water quality and avoided algal blooms.

- Comparison of water quality of pond equipped with natural treatment system with the pond without any intervention indicates the improved water quality and pond ecosystem. Treatment of influent of the ponds reduces the eutrophication status of the ponds and helps in increasing the DO levels, which is beneficial for fish production. The average annual DO in the pond without any intervention was 0.35±0.58 and in the pond with the treatment system, the value was 5.92±1.68. The DO of the pond without any intervention dipped to zero on several occasions and the status of the pond was hypereutrophic throughout the study period.

- The treated wastewater in the pond was found suitable for irrigation and propagation of fisheries. Dissolved Oxygen levels were observed to be improved considerably but still low in the wee hours before sunrise making it still unsuitable for fish production. But Gouramis, Paradise Fish, fighting fish, eels, walking catfish, mudskipper, tarpon, lungfish, snake fish, and some types of carp can be grown in this water, and they will reduce the algal levels in the pond which will help in reducing the algal respiration in after sunset and hence reduction of DO levels.

- An improved pond may be used for boating and other recreational activities. Even the pond can be used for swimming with some improvement in the treatment to bring down the coliform counts.

- Reduction in organic matter inputs at Ibrahimpur – due to primary screening and the constructed wetland – play a significant role in reducing $CH_4$ and $CO_2$ concentrations from village pond.

- Ibrahimpur pond was dominated by Chlorophyta algae (on average 57% of biovolume) and Euglenophyta (on average 32% of biovolume), however, Masahi was always dominated by Euglenophyta (on an average 70% of biovolume) fitting weel with the organic pollution in these two lakes.

- Mosquito larva do not appear to be a particular issue in the Ibrahimpur village pond, as this taxa was only recorded once and in very low numbers, however, mosquito larvae were recorded on both sampling occasions from Masahi village pond but, again, in relatively low numbers.

- The household survey indicated a positive impact in the range of 60-80% with the installation of the natural treatment system. The residents appreciated the reduction in bad odor and change in the villager's behavior towards the pond.

- Improved groundwater conditions were observed around the pond at Ibrahimpur Mashai after rejuvenation due to enhanced capacity of ponds to retain water and thereby enhancing recharge from pond.

- Overall, the study concludes that the Settling chamber followed by Root zone wastewater treatment is a sustainable and effective treatment method for rural areas. It also helps in minimizing the water borne diseases to the people.

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