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Archives of Applied Science Research, 2011, 3 (6):443-461
(http://scholarsresearchlibrary.com/archive.html)

ISSN 0975-508X
CODEN (USA) AASRC9

Stress of urban pollution on largest natural wetland ecosystem in East Kolkata-causes, consequences and improvement

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ABSTRACT

The traditional practice of utilizing wastewater into fish pond is a unique example of sustainable socio-economic development pertaining to resource recovery in the Eastern Kolkata wetlands, a Ramsar site in India. This paper revealed the stress of urban pollution and poor land use planning on the world's largest natural wetland. This is the first time to critically evaluate dynamics of oxygen demanding substances, nutrients and solids in waste water canal and fish ponds. This paper sheds some lights on absorbance of oxygen demanding substances on TSS and their adverse impact on fish ponds. Based on this concern, barriers to maintain water quality of wastewater canal and fish ponds; and opportunities to improve resource recovery efficiency have been explored. This study also explored that the radical technological change for fish pond management would not be effective in the prevailing socio-economic condition. But incremental changes and proper coordination between the concerned authority and fish farmers can easily accelerate the fish yield, functionality of pond ecosystem and reduction of pollutants.

Key Words: Wetland; fish culture; Urban Pollution; water quality; multivariate analysis; resource recovery.

INTRODUCTION

Improvement of resource efficiency in the present scenario of economic recession and pollution problems is the key element in sustainable socio-economic development. In Kolkata (India), utilization of wastewater for fish culture and irrigation in East Kolkata Wetland (latitude 22°33' – 22°40' N, Longitude 88°25' – 88°35'E) is the practical validation of the above statement. This ecosystem of international importance (listed by the Ramsar Bureau In August 2002) is an excellent combination of environmental protection and development where a unique and complex ecological process has been adopted by mastering the resource recovery activities [1]. This natural wetland supports the world's largest wastewater fish culture covering an area of

4000 Ha and contributes a significant percentage of the total Indian economy [2-3].This age-old practice of the fish cultivation utilizing wastewater in this wetland has been described extensively [4]. Nearly 10,915 tons of fish is produced annually in about 286 wastewater fed fishponds. At present only 30 percent of about 5, 50,000 m^3 of wastewater per day from Kolkata Metropolitan City flowing through network of canals [5-8] is utilised for aquaculture and irrigation purposes. The rest 70 percent of the wastewater is directly discharged into the Bay of Bengal [9]. This ecosystem [10-11] is presently stressed by poor land use planning; uncontrolled and unauthorized discharge of wastewater containing variety of chemicals and poor enforcement of existing environmental laws. This has caused a widespread threat and difficulties in marketing fish [12] and health hazard [13-15]. This is a common feature in most of the developing countries [16]. With rapid urbanization, wetlands are being reclaimed day by day leading to shortage of wetlands; thereby minimizing the scope of fish culture and subsequent natural purification of wastewater [9,17]. Siltation has further inhibited natural purification of the wastewater flowing through the canals. This ecosystem may completely lose its ecological significance in near future, if the problem is left unattended for.

According to Burger (2008)[18], "maintaining healthy ecosystems is cost effective whereas restoration of contaminated ecosystems is cost prohibitive". This statement beautifully explains the basis of this elaborate study and its importance in the present scenario. India is in dire need for providing food to the millions of people below the poverty line with limited resources. The country can hardly provide financial support to restore this wetland ecosystem once it is collapsed. Several studies have been already carried out on the characterization of wastewater by different authors [10,19-22]. They have mainly focused on the availability of nutrients in sewage and better utilization of these nutrients (directly or indirectly) through composite fish culture. The adverse impact of this composite wastewater on water quality of fish ponds and removal of contaminants through fish culture were also stidied[8]. Accumulation of metals in fish muscle in this these pond have studied by Bhupinder et al.(2011)[23]. Aheto et al. (2011)[24] pointed out that the loss of wetland would magnify the impact of climate change and could be disastrous for security of local communities due to its adverse impacts on fish and agricultural production. Bunting (2007)[25] studied the limitations of the traditional practices, efficiency of wastewater treatment, nutrient retention, fish production and financial performance under conventional and rational design using bioeconomic modeling and focused associated advantages and constraints. But no detail study has been done on dynamics of the pollutants in wastewater canal and fish ponds over the time and space and their impact on the fish pond ecosystem. This study aimed to fulfill the following objectives:

1. Environmental behavior of nutrients, solids and organic substances in wastewater canals and status of natural purification
2. Impact of wastewater on fish ponds
3. Barriers and opportunities to maintain fish farming in sustainable manner.

2.0 Fish culture in sewage fed pond

Generally major carps such as rohu (*Labeo rohita), catla (Catla catla), mrigel (Cirrhinus mrigala), silver carp (Hypophthalmichthys molitrix), common carp (Cyprinus carpio), and grass carp (Ctenopharyngodon idella)* are reportedly reared in these ponds. Stocking density are generally maintained at 6000-7000 fingerlings per ha but farmers are more interested to stock greater proportion of more tolerant and bottom grazing fishes like Tilapia, common carp, air breathing fishes and mrigal to maximize the fish yield. Tilapia is dominant among all the fishes due to its tolerance to wide variation of salt content, ammonia, pH, DO etc. [26]. As a result, no definite stocking ratios are maintained. Farmers maintain their own nursing area for healthy seeds collected from local hatcheries. The exotic fishes are produced on their own farm. The rate of dosing is regulated based on the color and odor of the pond water. The stocking of fingerlings/fry are made in several installments in a year particularly after each harvesting to accelerate stocking density per ha. Approximately 10 percent of harvested weight of different species is introduced daily though not exactly quantified.

3.0 Study Area

The study area covered the Eastern fringe of Kolkata, where the wastewater of industrial and domestic origin flows through Dry weather flow (DWF) canal and Storm weather flow canals (SWF). The basic structure of the present sewerage system of Kolkata was completed in 1884. The underground trunk sewer line is linked with a total of 17 pumping stations (three main stations and 14 intermediate stations) and is located in the eastern margin of the city. The system carried about 545 MLD of domestic wastewaters and 227 MLD of industrial wastewater [3]. The dry weather flow canals after covering a distance of few kilometers ends either to be fed into fish ponds or to be used for irrigation. The SWF considered as main canal receives the wastewater from tributary drains flowing through the different areas of the city and ultimately drains off to sea via Kulti river. The wastewater flowing through this canal is artificially diverted through small canals as feeder canals to feed fish ponds. In this study six sampling stations along the main canal (SWF) , three sampling stations at the inlets to the ponds; and five ponds (one sampling point for each pond) were selected. The study area is shown in Figure-1. The study stretch was about 8 kms. The sampling stations (Figure-1) on wastewater canals were marked as M-1(0 km), M-2(2 km), M-3(4.5 km), M-4(5.5 km), M-5(6.5 km) and M-6(8 km). Inlets to Sajna Ponds, Harhara Ponds and Naskar Ponds were marked as F-1, F-2, F-3 respectively. The five ponds namely Harhara -1, Harhara - 2, Naskar-1, Naskar -2 and Sajna are marked as P-1, P-2, P-3, P-4 and P-5 respectively.

MATERIALS AND METHODS

A small boat equipped with handheld multiparameter kit, sample containers, samplers, preservatives etc was put in use for collecting the samples and in situ analysis and preservation. The acids and other chemicals used in any purpose were of high purity (GR grade or Suprapure, Merck, Germany). All materials coming in contact with the samples were properly cleaned. Water samples were collected from the mid stream of wastewater canal and midpoint of the ponds either by hand or by the sampler depending on the accessibility to sampling points. The sampler was fabricated locally using good quality stainless steel (S-316) putting extra weight of 3 kg at the bottom of the sampler. The lid of the container

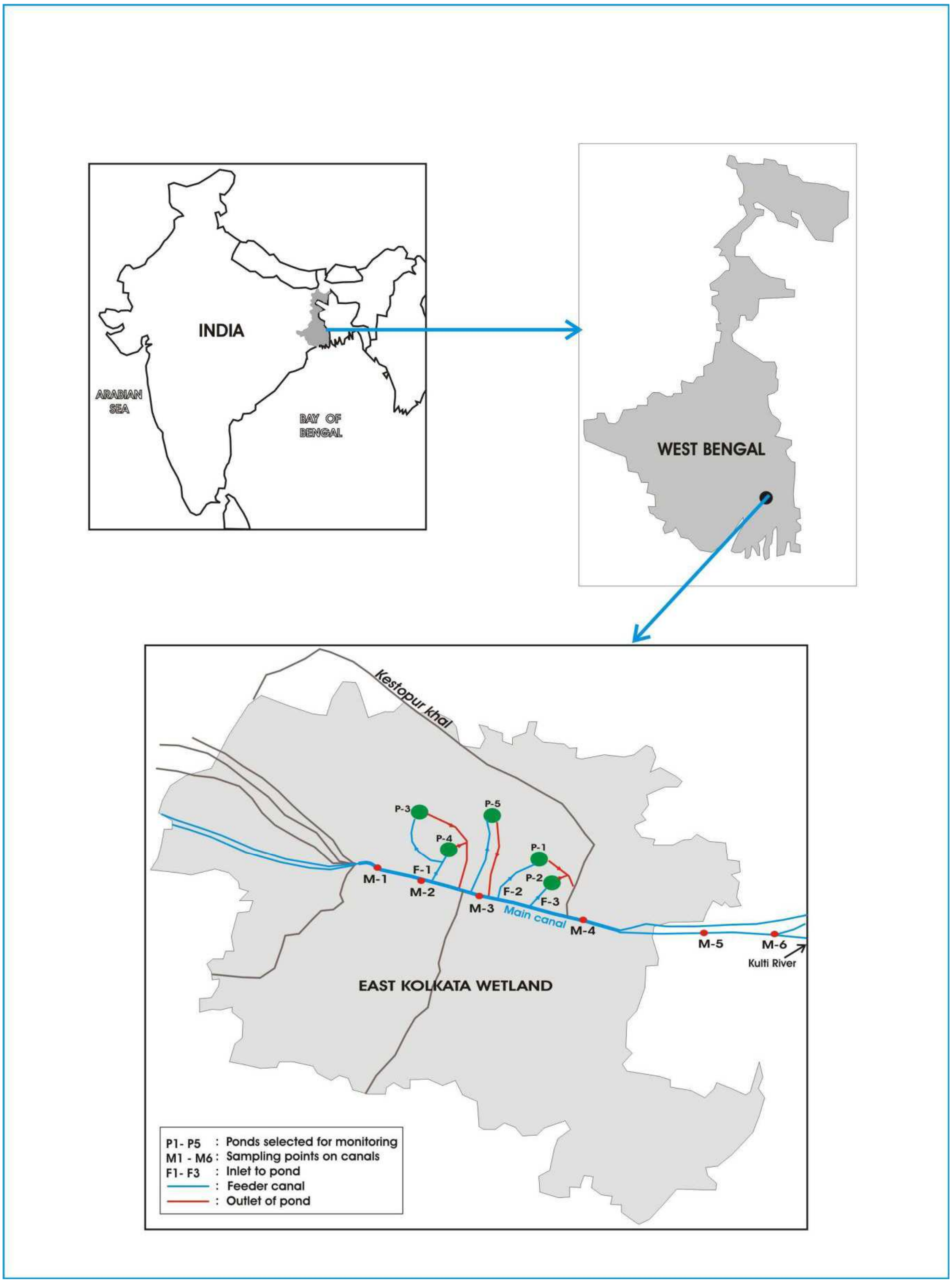


Figure 1: Sampling Location

has two holes (one extra hole as air outlet) fitted with stainless steel pipes to attach two 500-ml plastic containers or if necessary one plastic container and one DO bottle inside the container. Sample of one container was used in field analysis and sample of other container was preserved and transported to the laboratory as per standard methods [27]. The water samples were collected at 20 cm below the water surface during 10 am to 11 am from all the selected sampling points. The samples of the Canal and ponds were taken once a month for analysis during August to February over a period of three years (2002-2005). During heavy rain sample was not collected on the stipulated day because water quality on that day was more or less uniform over the entire stretch due to huge surface runoff. Sampling day has been postponed for 2-3 days. An electrochemical portable device (handheld WTWMulti 350i) was used for in situ measurements of temperature, pH, DO and conductivity. The sulfide was determined at the time of collection at each sample location by titrimetry method. Samples from each location were filtered in the field using a 0.45 µm filters to assess the partitioning of few pollutants between dissolved phase and particulate phase.

Standard methods [27] were used to analyze TSS(2540 D), TDS(2540 C),Alkalinity(2320 B), Total Hardness(2340 C), Calcium(3500 Ca, B), Magnesium(3500, Mg B), Nitrate(4500, NO_3 B & 4500, NO_3 B), Phosphate (4500-P-D), Chloride(4500 Cl B), Total Kjeldahl Nitrogen(4500-N_{org} B & 4500-NH_3 B & C), Ammonia (4500-NH_3 B & C), BOD(5210 B), COD(5220B), DO(4500 O C), Sulfate(4500-SO_4 E), and Oil & Grease(5520 B). For TSS, approximately 50-100 ml samples (depending on visual assumption) were collected in 100-ml polyethylene bottle and filtration was done by transferring whole aliquot to filtration funnel fitted with filter paper. The particles adhered to the wall of the container were transferred to the funnel by rinsing with distilled water. Before transferring the sample, meniscus of the container was marked. Then volume of sample taken for filtration was measured by filling the container with distilled water carefully up to the mark for calculation of analytical results. In addition to above parameters, the bacteria, Total Coliform and Fecal Coliforms, were assayed according to the multiples tubes technique based on standard methods - 9221 and 9221E respectively. Samples from all the ponds were collected at 5 am and 11 am to estimate phytoplankton. Chlorophyll and zooplankton was collected once during 10 am to 11 am. The standard methods[27] were applied to estimate plankton (10200B and F) and chlorophyll (10200H). The sample analyses were performed by the Zonal laboratory of Central Pollution Control Board recognized under Environment Protection (Act), 1986 by Ministry of Environment and Forest (MOEF), Govt of India and also accredited by National Accreditation Board of Laboratory (NABL), India. The biodegradability (BOD rate constant) was estimated as per the method recommended by Chin(2006)[28].

5.0 Statistical techniques

The analytical results were processed using various statistical techniques such as mean, median, maximum, minimum, standard deviation, coefficient of variation, correlation coefficients etc. Factor analysis(FA) was performed by applying orthogonal varimax rotation and calculating the eigen factors higher than 1 [29] to evaluate association among the measured chemicals and to identify the parameters governing the variation of water quality of wastewater and pond water. The paired t-test was applied to assess the level of significance of difference among different parameters and among the stations. The mann-Kendall test was applied to evaluate the spatial and temporal trend of different parameters. The p values larger than the critical value of p at the 95% confidence level were considered significant.

6.0 Quality assurance and quality control programme

To maintain integrity of the analytical results, QA/QC protocol was implemented. QA/QC protocol for the sampling plan included duplicate samples for each sampling event for all analyses and rinse blank using decontaminated field equipment. The analytical results of the samples collected in duplicate did not exhibit any significant difference between two analytical results of individual sampling event. Results confirmed adequate precision and negligible cross-contamination. No attempt has been made for bacteriological parameters.

For Calibration, the standards traceable to NIST obtained from Merck, Germany were used to calibrate UV-VIS Spectrophotometer (Varian, DMS-100). Portable multiparameter instrument was calibrated in the field before putting them in use. The detection limit and determination limit were estimated in accordance with the recommended methods [27] to ensure the reliability of data. Recalibration check was performed at regular interval. Quality control was carried out using sample replicates, blank and certified reference materials (CRM). Inter-laboratory comparisons were carried out among the laboratories accredited by NABL and recognized by MOEF, India under EPA,1986 for better understanding of the possible dispersion. Recovery study of BOD and COD were performed using CRM of Glucose-Glutamic acid and potassium hydrogen phthalate respectively and percentage of recovery was 94 and 99 respectively. The percentage recoveries of TSS, TDS, Alkalinity, Total Hardness, Ca, NO_3-N, PO_4-P, NH_3-N, TKN, Cl, sulfide, SO_4, and oil and grease were performed by addition of CRM of known concentration to samples. The recovery varied from 91 percent to 102 percent. The measurement uncertainty (MU) of each parameter except coliforms, chlorophyll and plankton were estimated taking into account all relevant sources of uncertainty which might occur during the analytical process in accordance with guide to the expression of uncertainty in measurement [30-31]. The estimated measurement uncertainty ($C_{sample \pm UCsample}$) were 8.4± 0.24 pH , 330± 5.7 μmhos cond cm^{-1} , 1.4± 0.24mg S l^{-1}, 104± 2.5 mg TSS l^{-1}, 230± 3.4 mgTDS l^{-1} , 240± 4.1mg Alk l^{-1}, 214± 4.5mg TH l^{-1}, 34± 0.7mg Ca l^{-1} 2.1± .018 mg NO3 l^{-1}, 1.4 ±.012 mg PO4 l^{-1}, 245± 4.7 mgCl l^{-1}, 21± .72 mgTKN l^{-1}, 4.5± .32 mgNH3 l^{-1}, 58± 3.2 mgBOD l^{-1}, 87± 4.5mgCOD l^{-1}, 5.6± .2 mgDO l^{-1},5.8± .09mgO&G l^{-1}. Ionic balance of all the ions measured for few samples were estimated. It was noted that difference between cations and anions never exceeded 7 percent.

RESULTS AND DISCUSSION

7.1 Distribution and environmental behavior of pollutants in wastewater canal

The assembled analytical results were statistically processed and presented in Table-1 to compute average concentration and coefficient of variation (CV) of the chemical and microbiological parameters for evaluating spatial and temporal pattern of these parameters at five sampling sites in the canal. A perusal of results shown in Table-1 revealed that fluctuation of the average values of COD, Phosphate, Chloride, BOD, TSS, Sulfide, NH_3-N, TKN and Sulfate over the sampling sites were prominent. The spatial pattern of these parameters appeared to be associated with uncontrolled discharge of. wastewater at several infection points on this canal. The high average values of oxygen demanding substances, nutrients and chloride exhibited strong influence of urban pollution on deterioration of water quality. The fluctuation of average values of Total Hardness, Conductivity, TDS, Alkalinity, Ca-Hardness, Mg- Hardness and pH were relatively low. The spatial pattern of these parameters indicated the negligible influence of urban pollution on this canal. In terms of bacterial contamination, the entire zone under the study was largely infested with high counts of total coliform (TC) and fecal coliform (FC) reflecting fecal contamination originating from residences. The coefficient of variation (CV) at each sampling site revealed the pattern of temporal variability which is prominent for TSS, sulfide, TKN, NH_3-N, COD and BOD (Table-1). The CV rank of these parameters in descending order in M-1 station is- COD (91%) < BOD (71%) < S (59%) < NH_3-N (51%) < TKN (45%) < TSS (44%) < SO4 (35%).The variation of concentrations of the remaining parameters were relatively low because CV rarely exceeded 25 percent. The CV ranks of other sampling sites are similar to M-1. All these parameters in feeder canals (F-1, F-2 and F-3) had spatial and temporal pattern similar to main canal (Table-1).

The temporal variation due to months and years was investigated by a Two-way classified Analysis of Variance (ANOVA). The ANOVA exhibited significant variation over the months. The pattern of changes of these chemical substances over the months was tested by Mann-Kendall test. This test revealed no stable trend (inclined/declined) over the months in any sampling site. The explanation is that moderate rainfall during the study period in few sampling events increased the surface runoff to the canal and diluted the concentration of these chemicals substances. Therefore, emerged variation of all these parameters *at each site* (Table-1) can be attributed to seasonal changes influenced by influx of surface run-off.

Now spatial trend was examined by Mann-Kendall test. This test revealed interesting spatial trend. Among all the parameters, pH, Conductivity, Cl, Total Hardness, TDS, NO_3-N, SO4 and Mg showed increasing trend. The COD, TKN, BOD, NH_3-N, Alkalinity, PO_4-P and sulfide demonstrated no stable trend. This can be attributed to the intermittent discharges from industries and residences to the main canal through tributaries suggesting further strong influence of urban pollution on water quality of of this canal in the study stretch.

Significance of the differences between different sites was tested by paired-t test and shown in Table-2. This test indicated no significant difference of conductivity, TDS, Alkalinity, total hardness, Calcium, magnesium, BOD, COD and sulfate among M1, M3 and M4 and thereby suggesting negligible influence of urban pollution on water quality. The prevailing concentrations of organic pollutants such as BOD, COD, and TKN at M3 exhibited significant difference in concentration of these pollutants at M1 and M2. This suggests fresh discharge of wastewater to the canal before M3. The uniform behavior of all the ions except chloride in the stretch between M1 and M4 indicated dominance of organic pollution and nutrients. Similarly behavior of sulfide between M1 and M3 exhibited onset of anaerobic process. The significant differences in pollutant concentrations between M-6 and the remaining sites (M2- M5) revealed influence of sea water intrusion in diluting the pollutant concentrations.

Prevailing concentration of pollutants (organics and nutrients) and their fluctuation over entire stretch of wastewater canal confirmed poor performance of the treatment plants (both Sewage Treatment Plants and Effluent Treatment Plants), imprudent waste water management and poor land uses, and ineffective enforcement of environmental acts and regulations. During inspection of various treatment plants located in this urban area, frequent failure of treatment system was observed.

Table - 1 : Chemical Characteristics of Wastewater in Main Canal and Feeder Canals (average values with coefficient of variation in the parenthesis)

	Main canal of 8 km stretch						Inlets to Pond		
	M1	M2	M3	M4	M5	M6	F-1	F-2	F-3
pH	6.1 (5.4)	6.2 (4.9)	6.4 (4.2)	6.7(2.9)	7.2 (2.4)	7.3 (3.1)	6.9 (1)	6.5 (2.3)	7.1 (3.1)
Temp°C	17.1(27)	16.8(26)	17.2(25)	17.3(22)	17.4(26)	17.5(24)	18.1(27)	17.8(26)	17.8(26)
Cond[5]	963 (22)	1060 (23)	1161 (27)	1138 (25)	1452 (35)	2160 (29)	1065 (14)	1074 (19)	1106 (19)
TSS[7] mg L^{-1}	280 (44)	180 (49)	212 (51)	246 (45)	58 (25)	24 (11)	234 (48)	284 (39)	312 (37)
TDS[7] mg L^{-1}	580 (24)	610 (21)	668 (24)	670 (19)	920 (22)	1230(31)	688(17)	576(16)	699(15)
Cl mg L^{-1}	95 (31)	107 (25)	121 (25)	132 (21)	188 (28)	350 (32)	138 (26)	133 (21)	141 (23)
Alk mg L^{-1}	248 (24)	237 (23)	248 (21)	235 (17)	295 (42)	310 (35)	241 (18)	264 (19)	259 (21)
Total-H[4] mg L^{-1}	226 (26)	234 (22)	241 (17)	245 (19)	282 (24)	298 (26)	208 (21)	263 (21)	261 (25)
Ca-H[4] mg L^{-1}	158 (19)	165 (21)	171 (18)	171 (23)	176 (31)	188 (33)	153 (22)	174 (21)	178 (26)
Mg-H[4] mg L^{-1}	68 (22)	69 (22)	70 (17)	74 (21)	105 (13)	110 (19)	55 (17)	87 (24)	83 (31)
SO_4 mg L^{-1}	30 (35)	35 (31)	37 (23)	35 (29)	45(24)	68(34)	39 (25)	41 (14)	43 (21)
Sulfide mg L^{-1}	1.9 (59)	2.3 (61)	2.2 (52)	3.2 (24)	0.8 (12)	0.7 (13)	1.9 (31)	2.2 (35)	1.7 (32)
NO_3-N mg L^{-1}	0.02 (19)	0.01 (34)	0.02 (35)	0.07 (19)	0.42 (62)	0.61 (19)	0.03 (146)	0.05 (79)	0.05 (81)
PO_4-P mg L^{-1}	1.7 (27)	1.1 (31)	1.2 (34)	1.5 (25)	0.85 (15)	0.23 (12)	0.9 (27)	1.2 (33)	1.6 (41)
TKN mg L^{-1}	38 (45)	29 (52)	39 (48)	57 (37)	22 (22)	17 (14)	42 (17)	29 (42)	35 (33)
NH_3-N mg L^{-1}	17 (51)	13 (41)	17 (39)	24 (42)	9 (31)	5 (23)	27.2(19)	19 (47)	23.5 (44)
DO mg L^{-1}	BDL[3]	BDL[3]	BDL[3]	BDL[3]	0.05 (99)	2.5 (11)	BDL[3]	BDL[3]	BDL[3]
COD mg L^{-1}	306 (71)	205 (69)	245 (73)	312 (69)	89 (27)	32 (29)	167(101)	232 (94)	208 (83)
BOD mg L^{-1}	108 (69)	72 (65)	81 (81)	132 (55)	21 (29)	12 (19)	57 (91)	91 (93)	65 (70)
O & G[6] mg L^{-1}	9.2 (31)	2.5 (41)	2.1 (14)	1.1 (31)	1.1 (21)	0.9 (15)	1.2 (51)	1.1 (34)	1.3(125)
TC[1]	$6.85X 10^7$	$8.4X10^6$	$3.7X10^6$	$17X10^5$	$1.8X10^5$	$1.2X10^5$	$9 X 10^7$	$10.8 X 10^7$	$10.4 X 10^7$
FC[2]	$3.77 X10^7$	$2.3 X 10^6$	$2.1X10^6$	$9X10^5$	$9.7X10^5$	$9.3X10^5$	$4.5 X 10^5$	$4.7X10^5$	$2.8X10^5$

[1] Total Coliform ml^{-1}; [2] Fecal Coliform ml^{-1}; [3] Below Detection Limit; [4] Hardness (as $CaCO_3$); [5] Conductivity($\mu S\ cm^{-1}$); [6] Oil and grease; mg L^{-1}

7.2 Actual dynamics of pollutants and their influence on Wastewater canal

The factor analysis was performed to elucidate actual dynamics of pollutants and their interrelation in wastewater canal. The first four factors of wastewater canal explained 90.1% of total variance. The loading of 19 parameters for four factors are shown in Figure-2. Factor-1 explaining 38.5% of total variance revealed that both strong and moderate loadings highlighted bipolar nature of two groups- comprising BOD, NH_3-N, PO_4-P, and TKN in one group with positive loading and alkalinity-total hardness- calcium hardness-magnesium hardness-chloride-NO_3-N in other group with negative loadings. These two distinct groups mainly governed the variability of wastewater quality. The factor-1 exhibited the dominance of organic pollution due to uncontrolled discharge of urban domestic wastewater to canal. The high loadings on Cl and conductivity in opposite pole of the first group can be attributed to the influx of sea water. The strong positive loading on PO_4-P indicated influence of point (domestic) and non point (surface run-off) source pollution. Factor-2 explaining 30.8% of total variance revealed strong loadings on TSS, NH_3-N, COD, sulfide, TKN and moderate loadings on alkalinity and Ca-hardness. This pattern of loadings indicated the dominance of non-biodegradable substances originating from industrial sources. The tannery effluent may be the major source of these chemical substances. Moderate negative loadings on alkalinity and calcium indicate the influence of surface run-off on reducing the pollutants originating from the industries and residences. The moderate negative loadings on pH and temperature in factor-2 exhibited their inter dependence and influence of organic pollution in lowering the pH by anaerobic process. The factor-3 explaining 11.3% of total variance is characterized by positive loading on sulfate and temperature. The temperature plays important role in formation of sulfate. The factors-4 explaining 9.5% of total variance exhibited significant strong loading on TDS indicating influence of tidal water.

Table-2 : Paired-t test of different parameters between sampling stations in wastewater canal

	M1/ M2	M1/ M3	M1/ M4	M1/ M5	M1/ M6	M2/ M3	M2/ M4	M2/ M5	M2/ M6	M3/ M4	M3/ M5	M3/ M6	M4/ M5	M4/ M6	M5/ M6
pH		Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	
Temp															
Cond			Sig	Sig	Sig			Sig	Sig		Sig	Sig	Sig	Sig	Sig
TSS	Sig			Sig	Sig		Sig	Sig	Sig		Sig	Sig	Sig	Sig	Sig
TDS			Sig	Sig	Sig			Sig	Sig		Sig	Sig	Sig	Sig	Sig
Cl			Sig	Sig	Sig		Sig	Sig	Sig		Sig	Sig	Sig	Sig	Sig
Alk					Sig			Sig	Sig			Sig	Sig	Sig	
TH				Sig	Sig			Sig	Sig		Sig	Sig	Sig	Sig	
Ca					Sig										
Mg				Sig	Sig			Sig	Sig		Sig	Sig	Sig	Sig	
SO4				Sig	Sig			Sig	Sig		Sig	Sig	Sig	Sig	Sig
S			Sig	Sig	Sig		Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig
NO3	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig
PO4	Sig			Sig	Sig				Sig	Sig	Sig	Sig	Sig	Sig	Sig
TKN	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig
NH3	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig
COD	Sig			Sig	Sig		Sig	Sig	Sig		Sig	Sig	Sig	Sig	Sig
BOD	Sig			Sig	Sig		Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig
O&G	Sig		Sig	Sig	Sig		Sig	Sig	Sig	Sig	Sig	Sig		Sig	Sig

Sig – significance at 0.05 level(critical t-value-1.723)

The pattern of factor loadings on various pollutants clearly focused the combined influences of domestic and industrial discharges on deterioration of water quality by inhibiting natural purification in wastewater canal. Therefore uncontrolled discharge of Industrial wastewater to this canal play crucial role to maintain water quality in the canal. It may be inferred that this wastewater canal considered as natural reactor has lost its efficiency to purify the pollutants by various physical, chemical and biological processes.

7.3 Status of natural purification and reduction of pollutants

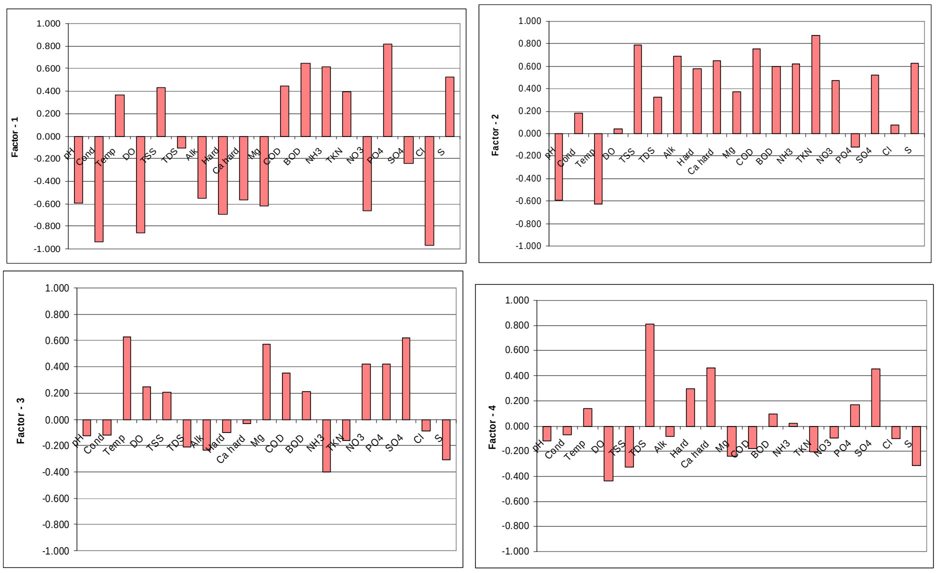
The discussion hereby is made to focus the status of natural purification based on the analytical results of wastewater canal (Table-1). The conversion of sewage into black color waste with strong sulfide odor indicated natural purification by anaerobic process. The perusal of analytical results shown in Table-1 revealed that pH was sub neutral and varied between 6.1 and 6.7 in the stretch between M1 and M4 with progressive increase to 7.3 at M-6. With the increment of pH, DO which was practically below the detection limit up to M-4, started to increase and reached to 2.5 mg L^{-1} at M-6. The average values of COD, Phosphate, Chloride, BOD, Sulfide, NH3-N, and TKN and TSS have been substantially reduced between M1 and M2 and then progressively increased and attained highest concentrations at M-4 and then turned to decline at M-5 and ultimately attained lowest concentrations at M-6 (Table-1). The changes of pollutant concentrations between M1 and M6 appeared to be the evidence of natural purification in this canal. Critical appraisal of these changes exhibited that removal of TSS (from 280 mg L^{-1} to 180 mg L^{-1}) enriched with BOD, TSS, COD and TKN from water column, reduced the level of oxygen demanding substances between M1 and M2. The concentrations of these pollutants and their association with TSS are discussed in Section 7.6. Little increase of NH3-N concentrations and decrease of TKN concentration exhibited partial onset of ammonification. But TKN concentration prevailed at M3 indicated incomplete ammonification and infection point before M3 The increase of pH with the increasing distance has made the requisite pH for ammonification. Intermittent discharge of wastewater to canal caused failure of self purification capacity of this canal between M1 and M3. The increment of sulfide at M-4 was the combined influence of sulfate reduction and industrial discharge from tannery. Interestingly distribution of alkalinity was found just reverse to that of sulfide. This relationship signaled that sulfide received from industrial discharge and produced by sulfur reducing bacteria (SRB) got precipitated with the increasing distance and diluted by tidal water. In contrary, alkalinity received by wastewater and developed by reduction of sulfate up to M-4 increased at M5. The abundant sulfate ions (35 mg L^{-1} to 48 mg L^{-1}) and organic substances rendered the wastewater favorable for the growth of SRB. These SRB facilitated the reduction of sulfate ions with the production of bicarbonate ions and hydrogen sulfide [32]. In natural wetlands, SRB generally prevails at the range of 105–107 CFU g^{-1} [33] , 1.5×107 MPN mL^{-1} [34], and 103–107 MPN g^{-1} [35]. These chemical processes increased alkalinity concentration from 235 mg l^{-1} at M-4 to 295 mg l^{-1} at M-5 and decreased sulfide concentration from 3.2 mg L^{-1} at M-4 to 0.8 mg L^{-1} at M-5. Further reduction of pollutants at M-6 may be attributed to mixing of sea water with wastewater. The increase of concentrations of Mg, Cl and SO_4 at M-6 authenticates the above statement.

7.4 Biodegradability of wastewater

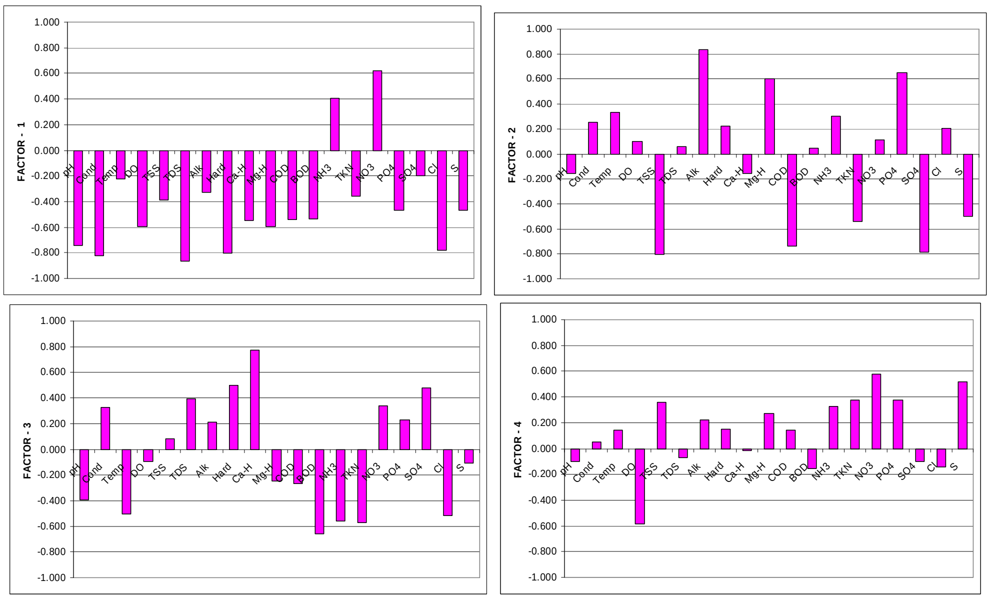
The above discussion clearly demonstrated the dominance of industrial discharge to wastewater canal. Therefore, biodegradability of organic substances is important factor to determine the fate of these organic substances. Natural purification is inhibited due to excedence of carrying capacity of the wastewater canal. Biodegradability was studied to evaluate the potential of removing the organic substances through natural purification. The value of the rate constant was varying between 0.14 day^{-1} and 0.24 day^{-1} with a mean of 0.18 day^{-1} and standard deviation of 0.028 day^{-1}. This result demonstrated that the rate of biodegradability for organic substances in wastewater canal is less than that of typical domestic waste i.e. k - 0.3 day^{-1} [36].

Figure-2 : Factor loadings on 19 parameters of four factors (Extraction: Principle Component)

Wastewater



Pond Water



7.5 Influence of wastewater on pond water

The assembled analytical results of pond water were statistically processed and presented in Table-3 to present average concentration of the chemical and microbiological parameters and their variation (CV) in each pond. The fluctuation of average values of all the parameters did not exhibit any consistent characteristics among the ponds. The alkaline nature (pH 7.9 – 9.2) and profuse algal growth (2500-8544 ml^{-1}) in pond water shown in Table-2 indicated high rate of photosynthesis using solar energy and CO_2 particularly during day time. The PO_4-P concentrations (0.2 mg L^{-1} to 0.41 mg L^{-1}) in the pond water accelerated the algal growth. According to Hundell (2008)[37], this eutrophication may support the freshwater harmful algal growth (FHABs) in these ponds. The low DO (2.1-1.1 mg L^{-1}) at 5 am is the clear indication of CO_2 production due to decomposition of algal cells and oxygen demanding substances during night time. The algal count (600-5251ml^{-1}) at 5 am revealed unutilized phytoplankton. The zooplankton counts varied from 2500 ml^{-1} to 8544 ml^{-1}. However marvelous achievement was noted in reduction of bacterial counts of both total coliform ($2.2x10^3$ ml^{-1} $0.65x10^3$ ml^{-1}) and fecal coliform ($1.5x10^3$ ml^{-1} $0.37x10^3$ ml^{-1}) with respect to the counts in wastewater canal. The microbiological quality of wastewater-fed ponds was reported to be satisfactory in India [38] and Egypt [39] than that of freshwater fish from many other water bodies. The prevailing NH_3-N concentrations (1.3 to 2.1 mg L^{-1}) above /close to the permissible limit in the ponds were not conducive for rearing the major carps such as Rohu, Catla , Mrigel. The elevated level of alkalinity, ammonia and pH indicated oxidation of organic nitrogen into NH_4OH during day time. Decomposition of algal cells in presence of sulfide in pond water inhibited nitrification that prevented conversion of ammonia into nitrate. Even there is formation of nitrate that will be loss to denitrification. The explanation to ammonia formation by another source is that the prevailing organic nitrogen available in the ponds encourages the heterotrophic bacteria like *Actinomycetes*, some Clostridia and Fungi to yield amines and subsequently ammonia by the process of mineralization as reported elsewhere [40]. Therefore nitrogen input to fish ponds through wastewater has become a key issue in management of fish pond ecosystem. The ratios of BOD to COD in unfiltered sample showed poor availability of biodegradable organic substances in the ponds. The major fraction (70%) of BOD and COD were strongly associated with TSS (as discussed in Section 7.6). As a result deposition of these suspended solids on bed developed anoxic condition and sludge built up at the bottom of the ponds. The accumulation of these organic matter along with phosphorus compounds in sediment accelerated the phosphorous release from the sediment to the water column [41] by controlling the oxidation state of iron and the mineralization of the organic matter. The dissolved phosphorous, in turn, stimulates the phytoplankton growth [42-43] and also blue green algae (cyanobacteria) responsible to produce cyanotoxin [37]. The excreta of zooplankton is also responsible to elevate Phosphate concentration (PO_4-P) in water [44]. The alkaline nature of pond water in presence of DO during day time oxidized the sulfide into sulfate, but availability of sulfide (0.4 mg L^{-1} to 0.7 mg L^{-1}) in all the ponds indicated re-formation of sulfide through natural phenomenon of sulfate reduction by SRB [45] because of anoxic condition at the bottom. This phenomenon was confirmed by visual observation of freshly deposited sediment with offensive odor. The concentration of chloride has considerably increased in all the ponds (except Naskar Pond) which may be due to subsequent evaporation of the water, leaving behind the salts.

In the backdrop of the above findings, factor analysis was performed to illustrate the nature of association of different pollutants in the pond water. The factor analysis of the raw data of pond water (Figure-2) revealed that first four factors of pond water explained 82.9% of total variance. Factor 1 explaining 33.1% of total variance demonstrated that strong association of pH, conductivity, TDS, total hardness and chloride indicating the dominance of dissolved solids. The regular use of wastewater with high TDS caused accumulation of salts by evaporation. The concentration of salt could not reach to alarming level because farmers pumped out the pond water at alternate year or two to get the sludge exposed to sunlight. Factor-2 explaining 22.5% of total variance revealed that the strong negative loadings on TSS, sulfate and COD were affirmative of the feeding of wastewater with high TSS enriched with non biodegradable substances. The alkalinity and phosphate was conversely related with TSS, sulfate and COD.

Formation of algal bloom sequestered phosphate from the water and then accelerated growth of organic substances associated with TSS . Factor-3 explaining 18.2% of total variance is characterized by moderate loadings on BOD and Ca-hardness suggesting moderate availability of biodegradable organic substances in fish ponds.The chemical behavior of pollutants in these ponds clearly supports the causes of exclusion of sensitive species particularly Indian major carps as reported by the farmers. The prevailing water quality of the ponds and the types of fish available in the ponds signals the lack of sustainable pond management. The prevalence of non biodegradable organic substances and excessive nutrients in wastewater has led to ecological crisis in pond ecosystem and adverse impact on socio-economic condition .

Table 3 : Physical, chemical and biological of water of different ponds (Average value with coefficient of variation in parenthesis)

		P-1	P-2	P-3	P-4	P-5
Temp		18.1(24)	17.9(26)	17.9(26)	17.5(25)	18.1(27)
pH		8.1(16)	7.9(13)	9.2(14)	8.3(10)	8.5(9)
Conductivity		705(40)	631(38)	874(12)	926(56)	896(31)
DO mg L^{-1}	11 am	7.5 (44)	8.1 (32)	7.2 (28)	7.9 (21)	7.8 (28)
	5 am	2.1(41)	1.7(45)	1.1(51)	1.9(32)	1.7(35)
TSS mg L^{-1}		53(27)	52(23)	107(69)	83(52)	99(18)
TDS mg L^{-1}		416(35)	327(24)	544(11)	589(47)	546(29)
Alkalinity mg L^{-1}		171(33)	149(12)	197(26)	240(20)	188(24)
T - H[1] mg L^{-1}		184(29)	166(42)	225(17)	256(51)	203(28)
Ca - H[1] mg L^{-1}		104(27)	101(31)	127(15)	167(41)	132(15)
Mg - H[1] mg L^{-1}		80(15)	65(26)	97(12)	89(32)	71(16)
COD mg L^{-1}		59(47)	173(27)	145(61)	82(36)	116(28)
BOD mg L^{-1}		30(50)	37(49)	59(25)	45(19)	46(17)
NH_3-N mg L^{-1}		2(51)	1.5(80)	2(24)	1.3(114)	2.1(57)
TKN mg L^{-1}		7(36)	7(38)	11(45)	8(60)	7(18)
PO_4-P mg L^{-1}		0.5(87)	0.5(60)	0.6(60)	0.6(18)	0.3(64)
NO_3-N mg L^{-1}		0.2(56)	0.2(38)	0.2(58)	1.3(21)	0.1(43)
SO_4 mg L^{-1}		30(29)	31(32)	73(81)	72(74)	63(56)
Chloride mg L^{-1}		160(15)	144(12)	176(17)	159(21)	171(7)
Sulfide mg L^{-1}		0.4(12)	0.6(9)	0.5(13)	0.7(17)	0.5(15)
Total Coliform ml^{-1}		2240	568	2080	652	1640
Fecal Coliform ml^{-1}		1520	448	1520	376	1056
Zooplankton ml^{-1}		3500 (12)	2500 (21)	5800 (13)	8544 (31)	7400 (21)
Phytoplankton ml^{-1}	2 PM	600 (40)	3250 (47)	5251 (51)	4030 (34)	-
	5AM	200(27)	1060 (25)	1204 (23)	2105 (31)	
Chlorophyll-a, µg l^{-1}		120 (22)	245 (34)	419 (34)	365 (31)	-

[1] *Hardness(as $CaCO_3$)*

7.6 Association of BOD and COD with TSS

The above discussion focused that suspended solids enriched with pollutants has adverse impact on fish pond management practice. The role of suspended solids in wastewater is poorly understood in impairment of pond water. Our improved understanding can address the role of absorbance of few pollutants on TSS in wastewater and pond water. The study has been made to explore the relation between concentrations of the oxygen demanding substances (ODS) and the amount of suspended solids termed as TSS and their impact on pond management. TSS are mainly originated from wastewater and erosion of soil [46]. TSS is also formed in aquatic phase either from the precipitation of minerals at the expense of soluble components or from the aggregation of colloids in the dissolved phase [47]. Apart from this, turbulence created due to increase of flow rate causes uplift of finer particles from the sediment bed and made them in suspension. The degree of association of ODS with TSS was tested by applying Pearson's correlation coefficients based on 21 observations.. Correlation coefficients revealed significant correlation of TSS with BOD (r - 0.87; p – 0.000), COD (r - 0.91; p – 0.000), and TKN (r = 0.84; p – 0.000) suggesting strong association of ODS in wastewater. The concentrations of BOD and COD in particulate phase and dissolved phase in wastewater and pond water were measured by analyzing filtered and unfiltered samples and the analytical results are given in Table-4. The BOD and COD in dissolved phase varied from 28% to 48% and from 20% to 27% respectively of the total concentration between M-1 to M-4. The percentage of dissolved BOD and COD sharply increased after M4 and reached to 44%-48% at M-6. In the feeder canal, percentages of dissolved BOD and COD were 30% to 35% and 14% to 20% respectively. It may be inferred that availability of the oxygen demanding substances in soluble form were relatively less in wastewater. Now, status of readily available biodegradable substances (in soluble form) in wastewater and pond water was evaluated. For this purpose the ratios of BOD to COD in filtered and unfiltered samples in wastewater canal and pond water were determined. The percentage of biodegradable substances were relatively high in filtered samples (50% to 60%) compared to the unfiltered samples (33% to 45%) in polluted stretch (M1 to M4). After M-4, ratio of BOD to COD was more or less similar in both filtered and unfiltered samples. In the feeder canals, the biodegradable substances in filtered samples were relatively high (77% to 92%) compared to the main canal. Holding of

Table-4 : Apportionment of BOD and COD between Dissolved and Total Concentration

	COD			BOD			BOD /COD	BOD/ COD	TSS
	mg L^{-1}			mg L^{-1}					mg L^{-1}
Station	F[1]	UF[2]	Ratio	F[1]	UF[2]	Ratio	F[1]	UF[2]	
M -1	68	276	0.25	34	91	0.37	0.50	0.33	234
M - 2	46	211	0.22	28	67	0.42	0.61	0.32	168
M - 3	47	174	0.27	29	61	0.48	0.62	0.35	142
M - 4	63	320	0.20	41	144	0.28	0.65	0.45	198
M - 5	44	103	0.43	25	54	0.46	0.57	0.52	58
M - 6	21	44	0.48	16	36	0.44	0.76	0.82	41
F - 3	45	314	0.14	38	126	0.30	0.85	0.40	347
F -1	42	267	0.16	39	117	0.33	0.92	0.44	311
F -2	44	225	0.20	34	98	0.35	0.77	0.44	259
P - 4	29	109	0.27	16	68	0.23	0.53	0.62	89
P- 3	39	136	0.29	16	68	0.24	0.41	0.50	161
P - 2	28	114	0.25	11	42	0.26	0.39	0.37	123
P - 1	32	51	0.63	16	47	0.33	0.49	0.92	64

[1] Filtered Sample; [2] Unfiltered Sample

wastewater in feeder canal that is a normal practice adopted by fish farmers, improved the availability of biodegradable organic substances in soluble form. Still wastewater fed to fish ponds contained substantial amount of suspended solids. The feeding of this wastewater containing high TSS non-biodegradable substances to fish ponds does not help to utilize optimum biomass production in a sustainable manner. On the contrary, these substances are liable to be accumulated in the sediment leading to anoxic condition.

7.7 Barriers to sustainable development

Wastewater canal thought to be the vital component of ecological security to natural water body has lost its efficiency of natural purification. The major causes of this impairment is imprudent watershed management due to poor planning, designing and construction of engineering projects such as roads, housing complex , shopping mall , small-scale industries etc, poor maintenance of wastewater canal (siltation), inadequate trained and organized fish farmers' group to properly maintain fish pond and lack of institutional support. The other major barriers are lack of implementing appropriate legislation to control at source and lack of environment policy specifically framed to restore this wetland in local level. Attitude (personal responsibility to perform the work) and awareness (policies, procedure, objectives etc) of concerned personnel impede restoration of sustainable pond management. The most pressing problem is financial constraint and management impassivity in top level officials to implement sustainability programme. One example can authenticate the management impassivity to solve this problem. The freshly deposited sediment and their re-suspension increased TSS concentration because depth at each point hardly exceeded 1 m as observed during the survey. The farmers are utilizing this wastewater without any suitable treatment before feeding to the ponds. TSS enriched with substantial amount of non biodegradable substances created anoxic condition at the bottom. The raw data (not shown here) revealed that the profuse algal growth rendered the pond water super-saturation of oxygen (13 mg L^{-1}) during day time and almost anoxic (0.3 mg L^{-1}) during night time. In this condition, farmers fail to maintain the major carps in sustainable manner. Tilapia is practically dominating because each catch demonstrated about 60% Tilapia observed during field study. The bad to worse condition of waste water is determined by visual perception of fish farmers based on their organoleptic experience of color and odor. Farmers have frequently complained about loss of biodiversity (non availability of major carps). The major problems are non-availability of requisite quantity and quality of wastewater. Government is reluctant to make the canal eco-efficient by removing the sludge at regular interval. The pollutant concentration prior to utilize in aquaculture is reduced by passive treatment (holding in the feeder canals for few hours) but its effectiveness was not evaluated in a systematic manner. Rational design for treatment of variety of contaminant suggested by Bunting (2007)[24] cannot be implemented in the current socio-economic condition.

7.8 Possible opportunities to improve ecosystem function

The concept of self maintaining pond ecosystem utilizing solar energy and culture of variety of species to cover all the ecological niches is the best option to restore the functionality of pond ecosystem. The profuse algal growth (Table-2) is a clear indication of solar energy utilization and CO_2 sequestration. Artificial circulation of water between hypolimnion and surface water using appropriate technology powered by solar panel and batteries can transform anoxic condition into oxic condition[37] that can suppress FHABs and reduce the pollutants. The utilization of rich solar energy in tropical countries like India not only reduces pollutants in the ponds and creates robust fisheries but also helps in sequestering CO_2. This measure can easily enable the nutrients to move up the food web from edible, chlorophyta(green algae) to zooplankton to filter feeding and carnivorous fish [37] . This ecological function will prevent deterioration of water quality and maintain sustainable resource recovery from the waste by channeling the nutrients and organic substances to highest trophic level. Further continuous exposure of surface water to sunlight containing UV-light will deactivate the pathogens and transform the hydrogen sulfide, TKN, ammonia to less toxic compounds. The prevailing surface water temperature in this country will stimulate the microbial activity both in wastewater canal and in the ponds and enhance the self purification capacity of the wastewater canal and the carrying capacity of the fish ponds. Therefore composite fish culture and introduction of suitable submerged macrophytes [48] would accelerate restoration of ecosystem function. Adoption of these measures needs adequate institutional support to maintain water quality of wastewater canal. The regulatory authority must take proper initiative to control the pollutants at the source of wastewater and to accelerate the rate of natural purification. Few traditional ecological measures [49] must be applied. For example introduction of macro vegetation in the feeder canals can easily arrest the suspended solids enriched with organic substances as well as to enhance natural processes of pollutant removal. Excessive accumulation of salt can be avoided by abstracting the wastewater during ebb tide. Regular harvesting of macro vegetation and removal of sludge must be carried with a provision to prepare organic manure for utilization in the nearby agricultural field. But composition of sludge and plants must be free from the metal and other persistent organic pollutants. Proper co-ordination between the concerned government authority (responsible for treating and discharge of wastewater) and farmers must be initiated for availability of good quantity and quality wastewater. In the present situation, the success of resource recovery (fish yield) depends on shifting of environmental policy to environment management system both in the watershed and within water body by incremental technological changes. Assessment of past performance and current management practice must be carried out to eliminate the barriers towards sustainable pond management anf to reframe the environmental policy. The reframing of the environment policy definitely change the prevailing environmental process and their negative impacts on fish farming into sustainable development and clean production.

In addition to above an emergent need is to have the cost-effective and logistically sound water quality monitoring programme to evaluate the prevailing water quality and their suitability for the intended use because reliability of data collected by different agencies is questionable. Author observed that quality control/ quality assurance protocol has not been properly implemented in most of the laboratories engaged in generating the data. As aresult , monitoring agencies are unable to provide relaiable information to policy makers. In this study, achievement made by implementing QA/QC helped to provide confidence on acceptability of analytical results and subsequent interpretation of data to evaluate environmental process of wastewater and pond water.

CONCLUSION

The characterization of wastewater and pond water clearly revealed the strong influence of urban pollution on wastewater canal and fish ponds. The deterioration of water quality in canal and ponds caused irreparable loss of pond ecosystem in terms of poor fish yield, loss of biodiversity and inefficient nutrient recovery. Good quality sewage, which is a critical component for sustainable resource recovery, was practically lacking for fish pond management. The imprudent practice of watershed management and within water body management inhibited the natural purification process of the canal and carrying capacity of the ponds. Water pollutants masked by the TSS have unknown fate and sometimes actual pictures of spatial and temporal trends of the pollutants remain elusive. It is also pertinent to note that certain percentage of wastewater is utilized to manage the fish ponds but no significant improvement of water quality of this canal through fish farming was observed. The magnitude of natural purification and use of wastewater in fish pond cannot provide the environmental security to the receiving water body (Coastal zone) for maintaining its unique and inherent characteristics. The impairment of water quality may be attributed to the major barriers highlighted in this study but these barriers can easily be overcome by changing attitude (performance of individual responsibility) and awareness (policies, objectives, procedures, instructions etc.) of concerned officials including top management. No major radical change is necessary at huge financial investment. The integrated management of aquaculture, watershed and within water body management can make this largest natural wetland ecosystem a very valuable and productive resource without threatening their sustainability. Sometimes interpretation of data creates an illusion that pollutants in wastewater canal has been gradually decreased with the distance but critical evaluation reveals that dilution of wastewater by sea water intrusion reduced the level of pollutant concentration. But this study clearly indicated that prevailing nutrients and oxygen demanding substances in this canal ultimately reach to the coastal zone via Kulti river. This is obviously matter of serious concern in developing countries like India. This study also explores an opportunity to gain a better understanding of water quality of wastewater canal and its impact on fish ponds and natural water body. The management of waste-fed aquaculture is also suffering due to lack of appropriate policies, legislation, institutional frameworks and regulations at the national and local levels. Therefore developing a national policy framework is an emergent need to facilitate safe waste-fed aquaculture based on the WHO Guidelines [15]. On restoration of this wetland, it may be unique and largest natural ecosystem in the world that can convert the wastewater into free wealth and this framework may be an unique example in the world. The complexity of watershed management questions has remained a key issue for managing the water quality of wastewater canal.

Acknowledgement
Author expresses his sincere gratitude to Prof S.P. Gautam, Chairman and Sri B.R. Naidu, then Incharge of Zonal Office, Central Pollution Control Board for their continuous encouragement and to provide all facilities to carry out the above work. I am grateful to Dr M.N. Das, my teacher, for his guidance in statistical interpretation of data and laboratory staff of Zonal Office , Kolkata to assist in carrying out the sampling and analytical work and Mrs Aparna Bagchi of Zonal Office , Kolkata for her assistance in editing and typing.

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