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WATER QUALITY IN A SUBURB OF CHENNAI HOUSING A LARGE INDUSTRIAL COMPLEX

by

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Abstract

An extensive survey of the quality of groundwater and surface water has been carried out at the suburb of Manali, Chennai, which houses a cluster of several large industries. The cluster is called 'Manali Industrial Complex' and typifies the Indian situation wherein hazardous industries exist cheek by jowl with residential colonies, commercial hubs and public amenities. Industries also exist within directly impacting distance of water bodies and other neutral resources. The studies reveal the kind and the extent of adverse impacts that is possible under such situations. A stretch of Buckingham Canal, which receives effluents from some of the industries, has been modeled for its water quality. The impact of different extents of effluent input and of canal flow have been forecast.

1. Introduction

India's is one of the most rapidly advancing economies in the world. India is also consolidating and enhancing its thrust in science and technology which, even otherwise, has been quite strong.

The upward zoom of Indian economy began during the 1990s and by mid-1990 it was going full throttle. It was also the period during which environmental consciousness grew very rapidly. But has the increasing concern for protecting the environment translated into better environmental management of the rapidly developing India?

To seek an answer to this question the authors have carried out what has become one of the first 'regional' environmental impact assessment studies conducted in India. The studies cover the area of Manali, a Northern suburb of the Chennai metropolis (Figure 1). The area houses Manali Industrial Complex which incorporates a large petroleum refinery – the Madras Refineries Limited (MRL), now known as Chennai Petroleum Corporation Limited (CPCL) – and several major downstream petrochemical industries (Table1). The industries exist shoulder to shoulder with residential colonies, shops, hospitals, schools and various public amenities. There are also several surface water-bodies all around which are freely used by people for cattle, fishing, bathing, and laundry (Plates 1-4). Solid waste can be seen anywhere and everywhere — on open land, near water bodies, by the roadside — just as one can see plumes of gaseous pollutants rising on the horizon. Besides suburban sprawl, villages and slums exist right next to the industrial complex. In many ways Manali Industrial Complex typifies the way Industrial growth has occurred in India – industries have either come up in very close proximity with densely populated neighborhoods or townships have grown around industrial establishments to take advantage of the opportunities of employment and commerce that arise due to the industrial activity. By either mechanism, distinction between designated industrial areas and residential–commercial localities often gets quite blurred. This can have tragic consequences of catastrophic proportions, as has happened at Bhopal (Abbasi and Abbasi, 2005) and elsewhere (Abbasi and Abbasi, 2007 a,b,c; 2008; Tauseef*et al.,* 2011 a,b,c).

In the Manali Industrial Complex, each of the industries has been established on the basis of individual environmental impact assessment (EIA), including risk assessment (RA), and each is supposedly meeting with the stipulated standards of air, water, and solid waste discharges arising from its operations. But the collective impact of the industries is far from benign. Indeed Manali has been regarded as one of India's most polluted areas since several years and is currently among the top 20 'critically polluted areas' in India as per a list released by India's Central Pollution Control Board (CPCB, 2011).

In the present paper, the gist of findings of very comprehensive year-round surveys of water quality is presented.

2. Water–bodies in the study area

2.1 Ponds

Considering the high density of industries and of people living in and around Manali Industrial Complex, the study area still has a surprisingly large number of ponds. These ponds fill up during the monsoons and the water-spreads gradually shrink in size during the post-monsoon months. Due to this, the water-spread areas of the ponds cannot be precisely defined, but a fair indication is presented in Figure 2.

The largest of these ponds (Madhavaram Tank) has an approximate water-spread of 10000 m^2 and a maximum depth of 2 m when full. Most other ponds have water-spreads of 2000-3000 m^2, and maximum depths close to 1m.

Usage: The ponds are used extensively for bathing, washing clothes, and by cattle. Eventhough none of the ponds is used to draw drinking water for humans, there is a clear link with humans of the water quality of the ponds via the cattle, fishing, and the other forms of contact usage (Plates 1 and 2).

2.2 Dug-wells and borewells

The dug-wells and borewells form the principal source of water for most villages around the Manali Industrial Complex.

Indeed, for most people living in the study area these wells provide the *only* source of water – either directly or through municipal water taps.

2.3Rivers and canals

A creek passing through Amulavoil near the Manali Industrial Complex (MIC), and a stretch of the historical Buckingham canal are the two major lotic water bodies in the study area (Figure 3). Of these, the latter one is by far the most prominent and important.

The Buckingham Canal is a coastal channel running through the backwaters, depressions, and low-lying areas for 419 km between the towns of Peddagangam and Marakkanam situated at the east coast of the Indian peninsula. The canal runs close to the coast and is not more than one to two km away from the sea at any point along its length.

The canal was completed in 1897 and was the main means of communication between the rich deltaic areas of Coramandal coast and erstwhile Madras all through the later part of the 19th century and the early 20th century, when rail and road transport facilities were not well developed. Subsequently as the other modes of transport came up, the traffic in the Buckingham canal gradually declined.

Now, due to improper maintenance, effect of cyclonic storms, and high level of siltation hastened by pollution, the canal is in disuse at several places. It now exists in bits and pieces serving small stretches, notably in the city of Chennai (Madras).

One of the still useful portions of the Buckingham canal is running through the Manali industrial area, for a length of ~10 km (latitude 80.33°, longitude 13.13°). In this region the canal carries run-off water which is occasionally used for irrigation, laundry, and other domestic purposes by economically weak population living near its banks. They also occasionally fish in the canal waters.

From the foregoing it is evident that in spite of being located in a semi-arid region, Manali Industrial Complex and its surroundings has a large number of important water bodies. These water bodies continue to be used by people for both contact and non-contact purposes. It was thus considered very important to assess the status of the water quality of these resources, in terms of their fitness for various uses (Abbasi and Abbasi 2011).

3. Experimental

3.1 Sampling sites

Water samples were collected from surface water bodies (Figures 2 and 3), water taps and groundwaters (Figure 4) during three different seasons: pre-monsoon (April – July), monsoon (August – November) and post-monsoon (December – March).

3.1.1 Ponds

All the sampled ponds are used by humans for washing and bathing, and by cattle (Plates 1 and 2).

The choice of sampling sites was also based on their proximity to solid waste disposal sites and industrial or municipal wastewater streams (Plates 3 and 4). Representative sites were chosen within and away from residential houses. Brief description of sampling locations is presented in Table 2.

The sampling sites P1-P4 are in the vicinity of solid waste dumpings. Effluents of some of the industries are received by P6 and P7 sampling sites. The site P11 belongs to a pond near a graveyard in Thiruvottriyur. It receives municipal and slaughterhouse wastes.

3.1.2 Canals

One of the stretches of Buckingham canal which has appreciable flow atleast during some months every year passes through the Manali Industrial Complex (MIC), running a length of 10 Km. This canal was monitored extensively and a model was developed to assess and forecast the self-purifying capacity of the flow and the impact of increase or decrease of pollutant inputs on its capacity. A creek passing near MIC through Amulavoil was also monitored. Eighteen sampling stations were set up (Figure 3, Table 3). The sites were chosen on the basis of use of the canal water and different wastewater inflows coming into the canal. The samples at sites CA1, CA2 and CA3 were collected from the Amulavoil canal. The site CA3 is located below Sadayankuppam bridge. Solid waste dumps are located near this site, and the canal water is used for drinking and bathing by the cattle. The site CA4 represents the location where an effluent stream enters the Buckingham canal. The samples CB13 and CB14 were collected from upstream and downstream of the industrial wastewater discharged into the canal. Other sites in the canal represented the gradual change in the canal water quality as it flows towards the Ennore creek. All samples were collected from the middle of the canal, in conformity with Standard Methods.

3.1.3 Ground water

The majority of people at Manali draw water for their essential needs either from dug wells or bore wells. The water supply aspect has been dealt in more detail elsewhere (Abbasi et al. 2012). Twenty nine sampling points were set for these sources; the sites were chosen, once again, to cover all representative situations vis-a-vis use-pattern, and proximity to industrial sources of pollution (Figure 4, Table 4).

Of the bore wells, which provide most of the irrigation and domestic water needs in the area, seven were sampled.Two of the water taps provided by the municipal corporation were also sampled (Table 5).

All-in-all, 50 locations were sampled covering all types of water sources presented in Figures 2-4.

3.2 Methods of analysis

The collection and analysis of samples was done in strict confirmity with the standard methods (Abbasi, 1998; APHA 1995). Such of the parameters, which must be done *in situ,* were analyzed there and then with field equipment set up at our field station.

The physical parameters for each sample that were analyzed include colour, odour, temperature and turbidity. The physico-chemical and chemical parameters include pH, electrical conductivity (EC), total dissolved solids (TDS), alkalinity, acidity, total hardness, calcium hardness, total iron, ammonia (NH_3), nitrite (NO_2^-), nitrate (NO_3^-), chloride (Cl^-), fluoride (F^-), sulphate (SO_4^{2-}), phosphate (PO_4^{3-}), total kjeldahl nitrogen (TKN), chemical oxygen demand (COD), and biochemical oxygen demand (BOD). In addition some of the samples were analysed for trace metals and organics.

4. Results and discussion

The sample-wise results of the entire water quality survey, recording the levels of various variables at given location and given season for each and every sample, have been archived elsewhere (Abbasi*et al.,* 2012a). The gist of the findings are summarized below.

4.1 Major findings: surface water

The results have been discussed in the context of the following water quality standards.

1. Domestic water (For use as raw water for public water supply and bathing ghats) specification: IS 2296 (1974)
2. Drinking water: IS 10500 (1991)
3. Freshwater for fish culture: IS 13891 (1994)

The analysis has been aimed to ascertain: a) the present status of the quality of water resources in the context of the typical features of the study area; and b) the extent of resource degradation vis-à-vis different types of water use.

It may be emphasised that the compliance with respect to standard for fish culture (IS 13891) has been assessed together with the other two standards for the following reasons : a) some of the ponds are used for fishing and b) the fish culture standard is more liberal than the other two standards and non-compliance with this standard is an indicator of the extent of poorness of the given water, and c) compliance with IS 13891 would indicate that the water body is capable of supporting fisheries, in turn reflecting utility value of the water body.

4.1.1 Pre-monsoon

Most of the samples either had offensive colour, or odour, or both (Table 6). Three in every four samples had offensive colour and 41% had odours (Table 7). The levels of electrical conductivity, phosphorous and total dissolved solids were above the tolerance limit for domestic water and drinking water in most of the samples (Table 8). In more than 75% of the samples the free ammonia levels exceed the tolerance limit for fresh water fish culture. In all samples atleast one parameter is outside the acceptable limits; in several samples more than one parameter is failing to comply.

4.1.2 Monsoon

During monsoon, 90% of the samples had offensive colour and 36% had unpleasant odours (Tables 9 and 10). The levels of electrical conductivity and phosphorus were above the tolerance limit for domestic water in more than 80% of the samples. In more than 60% of the samples the levels of alkalinity, ammonia and nitrate exceed the tolerance level for fresh water fish culture. Total iron exceeded the tolerance limit for drinking water in more than 80% of the samples. The results are summarized in Table 11.

4.1.3 Post-monsoon

During this season, most of the samples (94%) had offensive colour and 47% had odours (Tables 12 and 13). The electrical conductivity exceeded the tolerance limit for domestic water in all the samples and 69% of the samples exceeded the tolerance limit for the water used for fish culture. The levels of total dissolved solids and phosphorus, too, were above the tolerance limit for domestic water in more than 85% of the samples. In a similarly large fraction (80%) of the samples, the levels of total dissolved solids, total iron and chloride were above the tolerance limit for drinking water. Here again, none of the samples complied with the requirement of water quality for any use (Table 14).

4.1.4 Heavy metals, arsenic and boron

The results are summarized in Tables 15 and 16. The fractions of samples containing higher-than-permissible metal levels vis-a-vis drinking and fish culture were computed. It was seen that in case of surface water, 96% samples had mercury above tolerable level and 40% had excessive cadmium. In nearly all the samples one or more metals were present above permissible limits.

4.2Major findings: ground water

4.2.1 Pre-monsoon

Of the ground water samples, 45% were coloured and 13% were odorous (Tables17 and 18). In all samples atleast one, but often more than one, water quality parameter was above tolerance limits for drinking water, domestic usage and fresh water for fish culture, thereby making all samples below acceptable quality (Table 19). Phosphate was the main pollutant, found to cross the tolerance level for domestic water in 93.5% of the samples.

4.2.2 Monsoon

It was observed that 42% of the samples had colour and 6% had offensive odours during this season (Tables 20 and 21). More than 50% of the samples had total dissolved solids, total iron and chloride above levels tolerable for drinking water. The levels of electrical conductivity, total dissolved solids and phosphorus exceeded the tolerance level of domestic water in more than 70% cases. All the samples exceeded the tolerance level for ammonia. The results are summarised in Table 22. All-in-all none of the samples indicated suitability of water for any use: drinking or domestic.

4.2.3 Post-monsoon

Among these samples 45% were coloured, and 16% had odours (Tables23 and 24). The levels of electrical conductivity, phosphorus and total dissolved solids were above the tolerance limit for domestic water in most of the samples. Total dissolved solids, nitrate and hardness exceeded levels acceptable for drinking water in 77%, 77% and 65% of the samples. In most of the samples the levels of electrical conductivity, alkalinity and ammonia exceeded the tolerance limits (Table 25). Overall 100% samples were found to be unfit for use as drinking or domestic water.

4.2.4 Heavy metals, arsenic and boron

Each and every sample contains one or more metals above permissible limits (Tables26 and 27). Several of them have been proved to be toxic at these levels (Abbasi, 1979; 1987; 1988a; 1988b; 1989).

Therefore in terms of heavy metal and metalloid contamination, too, nearly all the samples are unfit for human use.

5. Modelling of Buckingham canal water quality

The computer-automated tool QUAL 2E-UNCAS, developed for the United States Environmental Protection Agency (USEPA) was employed. The tool belongs to a series of such tools beginning with QUAL I developed by F.D. Masch and Associates and the Texas Water Development Board (Abbasi and Abbasi, 2012b). QUAL 2E-UNCAS can handle upto 15 water quality constituents including DO, BOD, temperature, algae as chlorophyll a, various forms of N, P, coliforms, upto three conservative and an arbitery non-conservative, constituents. It can be used to model dendritic streams that are well mixed. As the Buckingham canal is shallow (maximum water level ~ 2.0 m during rains) and turbulent, the assumption of well-mixed stream is justified in this case. QUAL 2E-UNCAS further assumes that the major transport mechanisms, advection and dispersion, are significant only along the main direction of flow (longitudinal axis of the stream or canal). It allows for multiple waste discharges, withdrawals, tributary flows, and incremental inflow and outflow.

Hydraulically QUAL 2E-UNCAS can be operated in steady state and dynamic modes. In the former it can be used to study the impact of waste loads on stream water quality and to identify the contributions to it of non-point source waste loads. In the dynamic mode the user can study the effects of diurnal variations in meteorological data on water quality (primarily dissolved oxygen and temperature) and diurnal dissolved oxygen variations due to algal growth and respiration.

The UNCAS facility allows the modeler to perform uncertainty analysis on the steady state water quality simulations. Three uncertainty options are available: sensitivity analysis, first order error analysis, and Monte Carlo simulation.

5.1 Model validation

Typical results validating the model are presented in Figures 5-9. Other validation curves are given in Figures 12-25. It may be seen that the observed values of temperature, BOD, nitrate nitrogen, nitrite nitrogen, organic nitrogen, total nitrogen, and TDS match well with the predicted values all the way.

In case of chloride, TDS (total dissolved solids), sulphate, and ammonical nitrogen, the observed values are 50% higher in summer than the predicted value after about 4.6 km from the reference point(Figures 12 – 25). This is due to the tidal influence from the sea.

The model was validated for the canal water quality for four seasons, post-monsoon (December-February), summer (March-May), pre-monsoon (June-August), and monsoon (September-November).

During summer the match between the observed and the predicted values is closest for temperature, BOD, nitrate nitrogen, nitrite nitrogen, organic nitrogen, and total nitrogen. For TDS, chloride, sulphate and ammonical nitrogen, there is a mismatch after about 4.6 km from the reference point, as mentioned above. We attribute this to tidal influence. Such an influence is noticed only during summer because the flow in the canal is at its lowest during summer allowing the tidal influence to penetrate deeper upstream than in other seasons. In some years in peak summer the flow even ceases leaving small puddles of water across the canal length.

During pre-monsoon, monsoon and post monsoon seasons, too, the trend is similar. The predicted values match with the observed ones all the way upto the point about 4.6 km downstream waste discharge point. Beyond this range the water quality is influenced by tidal inflows.

After the model was validated, it was used to simulate different situations of variations in flow, incoming water quality, and waste inputs. The impact of these variations on the assimilative capacity of the canal was then forecast. The salient findings are summarized below.

5.2 Important findings

1) The model was successful in predicting the water quality of Buckingham canal at 90-95% confidence levels across the 7.80 km stretch studied by us, throughout the year. The only exception was the mismatch between the observed and the predicted values of some variables in the third reach, about 4.6 km from the reference point (headwater) – this was due to the impact of tidal inflow which was particularly severe during summer when the flow in the canal was at its leanest.

2) The two variables of greatest concern in managing the water quality are total dissolved solids (TDS) and BOD; these are significantly higher than permissible for irrigation and non-consumptive domestic use throughout the year (except monsoon).

3) Simulations were carried out to forecast the impact of changes in the levels of one or more water quality variables, and of flow augmentation, on the canal water quality during summer, monsoon, and post-monsoon (Figures 10 and 11).

The aim of the simulations was to identify strategies for improving the water quality of the canal to the extent that it confirms to standards prescribed by the regulatory agencies for use in irrigation and non-consumptive domestic use. It is seen that:

a) several variables, notably TDS, suspended solids (SS), chloride (Cl), and temperature were not influenced by changes in other variables;
b) increase in temperature caused reduction in BOD, evidently by hastening microbial activity which in turn hastened BOD decay, but increase in headwater DO had no significant impact on BOD.
c) stepwise reduction in the inflows from two point sources (industrial effluents) down to zero, had only marginal impact on the canal water quality.

d) flow augmentation reduced pollutant levels down to permissible limits but the freshwater required to effect such flow augmentation is just not available in that region.

4) Overall the modelling and simulation indicate that in order to manage the canal water quality the following steps are imperative.

a) Sources of BOD and TDS upstream must be identified and steps taken to reduce or eliminate their contributions;
b) The BOD and TDS levels of the effluents from two industries which join the canal in the study area should be reduced drastically by implementing appropriate treatment at the industries before disposal.

6. Summary and Conclusion

Extensive year-round surveys of surface water and ground water in the Manali area of Chennai, as impacted by the presence of a cluster of industries called Manali Industrial Complex have been carried out. Besides bulk parameters, trace constituents have also been analyzed. The findings reveal that for most times the quality of water sources is unfit for human consumption or fish culture. Often the incompatibility is so pronounced that the water carries offensive colour and odour.

The stretch of Buckingham Canal, which passes through the study area and which receives effluents from some of the industries, was modeled for its water quality. Simulations reveal that the carrying (assimilative) capacity of the canal is exceeded by the impact of the wastewaters discharged into it. Hence reduction in BOD and COD of the wastewaters being released into the canal to standards required for discharge into freshwater bodies is required if gross pollution of the waterway is to be controlled.

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Table 1: Madras Refineries Limited (now CPCL) and major downstream industries in Manali Industrial Complex, Chennai, India

SI. No	*Name of the Industry*	*Products manufactured tonnes/month*	*Manufacturing process inbrief*
1.	Madras refmeries Limited (now Chermai Petroleum-Corporation)	**Products** 1. LPG 2. Petrol 3. Diesel 4. Kerosene 5. Asphalt 6. Match wax 7. Par. wax 8. HSD 9. LDO etc. 10. Naphtha 11. Industrial fuel 12. Lube base stocks 1	Manufacturing process involves following stages: Crude tank - atmospheric Distillation unit - amine T reating unit - merox Treating unit - vacuum Distillation unit - fluid catalytic Cracking unit - final products.
2.	Madras Fertilizers Limited	**Products** Urea 38,500 NPK 7,000 Intermediate products Ammonia 28,875 **By products** CO2 24,100 Nm^3*!hr*	Ammonia is produced through naphtha steam reformation process, urea through total recycle process, NPK through DORR-oliver NPK granulation process
3.	Indian Additives Limited	**Products** FinisHed lubricating oil additives, 15,000 **Intermediate products** *Succinimides*: 6,300 Phenates : 3,000 Pibsa : 4,200	The process un its planned for additives manufacture are 1. Succinimide plant 2.Phenate plant 3.Pibsa plan t 4.Blending plant
4.	Manali Petrochemicals Limited	**Products** Propylene oxide : 1,000 Propylene glycol : 520 Polyols : 500	**Propylene oxide** *Propylene and chloride arereacted in water to form propylene*

		By products *di-chloropropane* : 120 di-propylene glycol : 40	*chlorohydrin. The propylene chlorohydrin* is saponified*with limeto form propylene oxide.* *Prooylenezlycol* *Propylene oxide* is *reacted with water to form mixture of mono, di and tri-propylene* glycols. *The mixture isconcentrated by triple effect evaporators and vacuumdistilled to produce pure pharmaceuticals grade* propylene *glycol and di-!propylene glycol*
5.	Madras Petro Chemicals Limited	**Products** 1. Transformer oil : 900 2. Petroleum specialities: 200 3. Oleum-sulphuric acid: 1200 4. Petroleumjellies: 40	Process involves following stages Raw oil storage – Retreat settler - Neutraliser - Oil still- Alcohol recovery - Percolation – Spent brine – Batch still - Drain – Desalter – Sulfonate still – Sulfarate – Miley retort - S02 purification - oleum Plant – oleumSulphuric acid

6.	Celex Petro Chemicals Limited	**Products** Methyl ethyl ketone 4000 T/Annum **By Products** *Secondary butyl ether* : 49 Heavy fraction : 66 Sulphuric acid :1097	Feed preparation, secondary butyl alcohol synthesis and secondary butyl ether recovery and methyl ethyl ketone synthesis.
7.	Sri Ram Fibers Ltd.	**Products** Nylonemoulding powder :2000T/A Nylone - 6!Nylone 6, 6 Polymer compounded and natural: 2000 *T/A*	The manufacturing process consists of mainly melting, prepolymerisation Granulation, extractions, drying and weaving
8.	Tramil Nadu Petro Products Limited	**Products** Linear alkyl benzene : 6667 Heavy normal paraffin : 1667 Heavyalkylate : 600 Intermediate products Normal paraffin : 5417	The manufacturing unit consists of refractionation, hydrotreator, mo1ex, pacol and detergent alkylation.
9.	Indian Organic Chemicals Ltd.	**Products** Polyester staple fibre : 2500 *TIM.* Ployester filament yarn: 1250 *TIM.* **By products** Methanol : 80 *TIM*	The manufacturing process involves melting, reaction, fractionation, polycondensation, extrusion, & spinning.
10.	Spic (heavy Chemicals Products Division) Limited	Caustic soda - 5500 *Tim* Liquid ammonia -3333 *TIM* Hydrochloric acid - 412 *TIM* Ammonium chloride - 1788 *TIM* **By Products** Hydrogeh-137.5 *TIM*	Brine preparation, cell operation, chlorine preparation, caustic flakes preparation, hydrochloric acid preparation, ammonium chloride preparation

11.	Kothari Sugar and Chemicals Ltd.	**Products** Poly butene& light : 425 *TIM* Polmers : 120 *TIM*	Feed preparation, polymerisation of isobutylene, fractionation and storage.
12.	U.B. Petro products Ltd. Products	Polyols : 1000 *TIM* Propylene glycol : 659 *TIM* Tripropylene glycol : 10 *TIM* Propylene oxide : 1000 *TIM* **By Products** Propylene dichloride : 175 *TIM* Dipropylene glycol : 80 *TIM*	Hypochlorination, neutralisation, dehy-drochlorination, purification, reaction concentration and distillation, reaction neutralisation and fi Iteration .
13.	South India Carbonic Gas Industries Ltd.	**Products** Carbon-di-oxide liquid : 600 *TIM* Solid : 300 *TIM*	The manufacturing process consists of absorption, compression, coo ling, separation drying, liquefaction and storing.
14.	BalmerLawrie& Co. Ltd.	DrurniBarrel-700 *TIM* Lubricating grease specialities - 417 *TIM* Bituminous compounds - 83 *TIM* Di Tertiary butyl para cresol - 12.5 *TIM* Para tertiary butyl phenol - 25 *TIM* Leatherauxidemies 180 *TIM* HCL-120 *TIM*	Deceiting, shearing, levelling cutting grinding, welding, heating, agitati on saponification cooling direction heating distillation, filtration, washing, drying & packing primary reaction, secondary reaction tertiary reaction, & blending operation.

Table 2: Ponds sampled (cf Figure 2)

Sl. No	*Sample No.*	*Region*	*Water use*
1.	PI	Manali	Washing, bathing
2.	P2	"	Cattle use
3.	P3		"
4.	P4		Washing
5.	PS	Sadayankuppam	Cattle use
6.	P6		"
7.	P7	"	"
8.	P8	"	"
9.	P9		Washing, bathing
10.	PIO	Thiruyottriyur	No use
11.	PII	"	Cattle use
12.	PI2	Vaikkadu	Washing, bathing
13.	PI3	"	"
14.	PI4	"	Cattle use

Table 3: Canals sampled; the location of sampling stations in Buckingham canal, which was modelled, is given in Figure 3.

S. No.	*Sample No.*	*Region*	*Water use*
1.	CAM1	Amulavoil canal	Washing, bathing
2.	CAM2	"	"
3.	CAM3	Manali (wastewater effluent of MRL)	No use
4.	CS4	Sadayankuppam canal	Cattle li use
5.	CB1	Buckingham canal, Manali	Transport
6.	CB2	"	"
7.	CB3	"	"
8.	CB4	"	"
9.	CB5	"	"
10.	CB6	"	"
11.	CB7	"	"
12.	CB8	"	"
13	CB9	"	"
14.	CB10	"	"
15.	CB11	"	"
16.	CB12	"	"
17	CB13	"	"
18	CB14	"	"

Table 4: Dug wells sampled (cf Figure 4)

Sl. No.	*Sample No*	*Region*	*Water use*
1.	DW1	Amulavoil	Washing, bathing and drinking
2.	DW2	Chillilamathur	Washing, bathing
3.	DW3	"	Washing, bathing
4.	DW4	Madhavaram	Washing, bathing and drinking
5.	DW5	"	Washing, bathing
6.	DW6	Manali	Washing, bathing and drinking
7.	DW7	"	"
8.	DW8	"	"
9.	DW9	"	"
10.	DW10	"	"
11.	DW11	"	"
12.	DW12	"	"
13.	DW13	Sadayankuppam	Washing, bathing
14.	DW14	"	"
15.	DW15	"	"
16.	DW16	"	Washing, bathing and drinking
17.	DW17	"	Washing
18.	DW18	Tiruvottiyur	No use
19.	DW19	"	Washing, bathing and drinking
20.	DW20	"	Irrigation
21.	DW21	Vaikkadu	Washing, bathing and drinking

Table 5: Bore wells and municipal taps sampled (cf Figure 4)

Sl. No	*SampleNo*	*Region*	*Water use*
1.	BWI	Chinnamathur	Washing, bathing and drinking
2.	BW2	Madhavaram	"
3.	BW3	Thiruvottriyur	Washing, bathing
4.	BW4	"	"
5.	BW5	"	Washing, bathing and drinking
6.	BW6	"	Washing, bathing
7.	BW1	"	Washing, bathing and drinking
8.	TWI	Madhavaram	" .
9.	TW2	Vaikkadu	"

Table 6: Occurrence of colour and odour in the surface water samples during pre-monsoon

Source and Sample number	*Colour*	*Odour*
Ponds		
P1	Pale green	Nil
P2	Dark yellow	N il
P3	Pale yellow	N il
P4	Grey	Fishy smell
P5	Pale yellow	Nil
P6	Pale yellow	Garlic Smell
P7	Pale green	Garlic smell
P8	Pale green	Nil
P9	Dark green	N il
PlI	Pale yellow	Nil
Pl2	Nil	Nil
Pl3	Pale yellow	Nil
Canal		
CA3	Dark grey	Garlic smell
CA4	Pale yellow	Pungent smell
CBI	Pale grey	Oily smell
CB4	Nil	Organic smell
CB6	off-white	Pungent smell
CB7	off-white	Oily smell

Table 7: Percentage of surface water samples of unacceptable quality in terms of physical parameters – pre-monsoon

S. No.	Parameter	Percentage of samples unfit as per the limit set for	
		Drinking water	Fish culture
1.	Colour*	77%	---
2.	Odour@	41%	---
3.	Turbidity	95%	90%
4.	Temp	0%	0%
5.	Overall	100%	100%

***** Samples with colour other than of normal water
@ Samples with some or other unpleasant odour

Table 8: Percentage of surface water samples of unacceptable quality in terms of physico-chemical and chemical parameters – pre-monsoon

S No.	*Parameter*	Percentage of samples unfit as per the limits set for		
		Drinking water %	*Domestic use* %	*Fish culture* %
1.	pH	23.8	9.5	23.8
2.	EC	*	90.5	57.1
3.	TDS	81.0	81.0	*
4.	Alkalinity	42.9	*	57.1
5.	Turbidity	95.2	*	90.5
6.	Total hardness	61.9	*	*
7.	Total iron	81.0	*	38.1
8.	Ammonia	*	*	76.2
9.	Nitrate	14.3	*	47.6
10.	Chloride	57.1	57.1	*
11.	Sulphate	23.8	9.5	*
12.	Phosphate	*	95.2	*
13.	Copper	30.4	*	30.4
14.	Zinc	8.7	*	21.7
15.	Mercury	95.7	*	95.7
16.	Boron	13.0	*	*
17.	Lead	26.1	*	26.1
18.	Arsenic	30.4	*	30.4
19.	Manganese	47.8	*	*
20.	Cadmium	39.1	*	39.1
21.	Overall water quality	100.0	100.0	100.0

* Standards not set

Table 9: Percentage of surface water samples of unacceptable quality interms of physical parameters – monsoon

Sl. No	*Parameter*	*Percent samples unfit as per the limits set for*	
		Drinking water	*Fish culture*
1.	Colour *	90%	---
2.	Odour@	36%	---
3.	Turbidity	100%	86%
4.	Temperature	0%	0%
5.	Overall	100%	100%

* Samples with colour other than of normal water
@ Samples with some or other unpleasant odour

Table 10: Occurrence of colour and odour in the surface water samples during monsoon

Source and Sample number	*Colour*	*Odour*
Ponds		
P1	*Greyish green*	*Odourless*
P2	*Pale yellow*	*Odourless*
P3	*Pale grey*	*Odourless*
P4	*Pale yellow*	*Odourless*
P5	*Greenish*	*Odourless*
P6	*Greenish*	*Odourless*
P7	*Pale green*	*Odourless*
P8	*Pale green*	*Odourless*
P9	Dark green	Odourless
PIO	Pale yellow	Odourless
PlI	Pale green	Fishy smell
PI2	Pale yellow	Muddy smell
PI3	Pale yellow	Odourless
PI4	Pale green	Odourless
Canal		
CAM I	Pale green	Odourless
CAM2	Colourless	Rotten smell
CAM3	Colourless	Oily smell
CAM4	Pale yellow	Odourless
CBI	Black	Sewage smell
CB4	Black	Oily smell
CB6	Black	Sewage smell
CB7	Pale Yellow	Sewage smell

Table 11: Percentage of surface water samples of unacceptable quality in terms of physico-chemical and chemical parameters – monsoon

SNo.	*Parameter*	Percentage of samples unfit as per the limits set for		
		Drinking water %	*Domestic use %*	*Fish culture %*
1	PH	40.9	9.0	40.9
2	EC	*	81.8	40.9
3	TDS	59.1	59.1	*
4	Alkalinity	36.4	*	68.2
5	Turbidity	100.0	*	86.4
6	Total hardness	31.8	*	*
7	Total iron	81.8	*	40.9
8	Ammonia	*	*	68.2
9	Nitrate	0.0	*	63.6
10	Chloride	50.0	22.7	*
11	Sulphate	9.1	0.0	*
12	Phosphate	*	90.9	*
13	Overall water quality	100.0	100.0	100.0

Table 12: Percentage of surface water samples of unacceptable quality in terms of physical parameters – post-monsoon

Sl. No	*Parameter*	*Percent samples unfit as per the limits set for*	
		Drinking water	*Fish culture*
1.	Colour *	94%	---
2.	Odour@	47%	---
3.	Turbidity	100%	97%
4.	Temperature	0%	0%
5.	Overall	100%	100%

* Samples with colour other than of normal water

@ Samples with some or other unpleasant odour

Table 13: Occurrence of colour and odourinthe surface water samples during post-monsoon

Source and Sample number	*Colour*	*Odour*
Ponds		
P1	Pale yellow	Odourless
P2	Pale green	Oily smell
P3	Brick red	Fishy smell
P4	Pale yellow	Fishy smell
P5	Grey	Odourless
P6	Pale yellow	Odourless
P7	Pale yellow	Odourless
P8	Pale yellow	Odourless
P9	Pale green	Odourless
P10	Yellowish green	Odourless
P11	Pale green	Fishy smell
P12	Pale yellow	Odourless
P13	Pale yellow	Odourless
P14	Colourless	Odourless
Canal		
CAM1	Pale yellow	Odourless
CAM2	Pale yellow	Odourless
CAM3	Black	Oily smell
CAM4	prey	pdourless
CBI	Pale yellow	Oily smell
CB2	Pale grey	Rotten smell
CB3	Dark grey	Rotten smell
CB4	Dark grey	Rotten smell
CB5	Pale grey	Rotten smell
CB6	Dark grey	Rotten smell
CB7	Pale grey	Unpleasant smell
CB8	Pale grey	Odourless
CB9	Pale yellow	Odourless
CB10	Pale yellow	Odourless
CB11	Dark black	Rotten smell
CB12	Dark black	Unpleasant smell
CB13	lPale yellow	Unpleasant smell
CBl4	~olourless	OdoLirless

Table 14: Percentage of surface water samples of unacceptable quality interms of physico-chemical and chemical parameters – post-monsoon

S. No.	*Parameter*	Percentage of samples unfit as per the limits set for		
		Drinking water %	*Domestic use %*	*Fish culture %*
1	PH	3.1	0.0	3.1
2	EC	*	100.0	68.8
3	TDS	87.5	87.5	*
4	Alkalinity	56.3	*	65.6
5	Turbidity	100.0	*	96.9
6	Total hardness	65.6	*	*
7	Total iron	96.9	*	40.6
8	Ammonia	*	*	56.3
9	Nitrate	53.1	*	71.9
10	Chloride	81.3	31.3	*
11	Sulphate	25.0	0.0	*
12	Phosphate	*	87.5	*
13	Overall water quality	100.0	100.0	100.0

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Table 15: Trace metals* in surface (pond) water samples

SNo.	*Cu*	*Ni*	*Zn*	*Hg*	*B*	*Co*	*Pb*	*As*	*Mn*	*Mo*	*Cd*	*Be*
P2U	0.033	BDL	BDL	0.226	0.367	0.039	BDL	BDL	0.444	BDL	0.009	BDL
P2F	0.031	BDL	BDL	0.170	BDL	0.010	BDL	BDL	0.303	BDL	0.001	BDL
P3U	0.002	0.019	BDL	0.339	1.014	0.010	BDL	BDL	BDL	0.082	0.015	0.004
P3F	BDL	0.009	BDL	0.226	0.663	BDL	BDL	BDL	BDL	0.011	0.009	BDL
P4U	0.025	BDL	BDL	0.226	0.962	0.039	BDL	BDL	BDL	0.100	0.007	BDL
P4F	0.018	BDL	BDL	0.170	0.747	0.039	BDL	BDL	BDL	0.015	0.005	BDL
5U	0.021	BDL	BDL	0.226	BDL	0.010	BDL	BDL	0.677	BDL	0.008	BDL
P5F	BDL	BDL	BDL	0.170	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
P6U	0.023	BDL	BDL	0.339	1.411	0.059	BDL	BDL	2.486	0.272	0.009	BDL
P6F	0.021	BDL	BDL	0.113	BDL	0.029	BDL	BDL	BDL	BDL	0.007	BDL
P8U	0.045	0.028	BDL	0.283	BDL	0.039	BDL	BDL	BDL	BDL	0.021	BDL
P8F	BDL	BDL	BDL	0.113	BDL	0.010	BDL	BDL	BDL	BDL	0.004	BDL
P9U	0.037	BDL	BDL	0.170	0.169	0.049	BDL	BDL	BDL	BDL	0.004	BDL
P9F	BDL	BDL	BDL	BDL	BDL	0.029	BDL	BDL	BDL	BDL	BDL	BDL
P14U	0.033	0.028	BDL	0.396	BDL	0.029	BDL	BDL	BDL	BDL	BDL	BDL
P14F	BDL	BDL	BDL	0.056	BDL	0.010	BDL	BDL	BDL	BDL	BDL	BDL

U - Unfiltered
F - Filtered

* All the values are in mg/L

Table 16: Trace metals* in surface (Buckingham canal) water samples

SNo.	*Cu*	*Ni*	*Zn*	*Hg*	*B*	*Co*	*Pb*	*As*	*Mn*	*Mo*	*Cd*	*Be*
BC1	0.675	0.182	47.51	0.896	1.313	0.177	Nil	0.125	3.670	0.381	0.037	0.054
BC2	0.341	0.228	43.11	0.443	0.222	0.305	0.198	0.125	5.772	0.652	0.034	0.076
BC3	0.165	0.191	BDL	0.010	BDL	0.305	0.159	0.125	7.431	0.519	0.032	0.084
BC4	1.311	0.410	0.253	2.313	BDL	0.483	0.357	0.345	12.81	1.323	0.066	0.113
BC5	3.176	0.255	1.157	0.783	BDL	0.384	0.396	0.125	10.49	0.974	0.059	0.091
BC6	1.422	0.282	2.192	0.103	BDL	0.414	0.555	0.690	7.753	1.260	0.050	0.123
BC7	1.573	0.556	1.357	0.503	BDL	0.799	0.753	0.690	17.58	2.063	0.099	0.179

* All the values are in mg/L

Table 17: Percentage of ground water samples of unacceptable quality interms of physical parameters – pre-monsoon

Sl. No	*Parameter*	*Percent samples unfit as per the limits set for*	
		Drinking water	*Fish culture*
1	Colour *	45%	---
2	Odour@	13%	---
3	Turbidity	35%	29%
4	Temperature	---	0%
5	Overall	100%	100%

* Samples with colour other than of normal water
@ Samples with some or other unpleasant odour

Table 18: Occurrence of colour and odour in the ground water samples during pre-monsoon

Source and Sample l1umber	*Colour*	*Odour*
Dug well		
OWl	Colourless	Odourless
Dw2	Colourless	Odourless
Dw3	Pale green	Odourless
Dw4	Pale yellow	Odourless
Ow5	Colourless	Odourless
Ow6	Colourless	Odourless
Dw7	Colourless	Odourless
Dw8	Colourless	Odourless
Dw9	Colourless	Odourless
Ow10	Colourless	Odourless
Ow11	Pale yellow	Odourless
Ow12	Dark yellow	Rust smell
Ow13	Rusty red	Odourless
Ow14	Pale green	Odourless
Owl5	Pale yellow	Odourless
Owl6	Dark green	Odourless
Owl7	Dark green	Odourless
Owl8	Pale yellow	Odourless
Owl9	Colourless	Odourless
Ow20	Colourless	Odourless
Ow21	Pale yellow	Odourless
own	Colourless	Odourless
Bore well		
Bw1	Colourless	Odourless
Bw2	Colourless	Odourless
Bw3	Dark yellow	Pungent smell
Bw4	Grey	Oily smell
Bw5	Colourless	Odourless
Bw6	Colourless	Odourless
Bw7	Colourless	Odourless
Tap water		
Tw1	Colourless	Odourless
Tw2	Dark yellow	Fishy smell

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Table 19: Percentage of ground water samples of unacceptable quality in terms of physico-chemical and chemical parameters – per-monsoon

SNo.	*Parameter*	Percentage of samples unfit as per the limits set for		
		Drinking water %	*Domestic use %*	*Fish culture %*
1	pH	12.9	3.2	12.9
2	EC	*	93.5	54.8
3	TDS	80.6	80.6	*
4	Alkalinity	48.4	*	58.1
5	Turbidity	38.7	*	32.3
6	Total hardness	61.3	*	*
7	Total iron	35.5	*	22.6
8	Ammonia	*	*	51.6
9	Nitrate	0.0	*	64.5
10	Chloride	58.1	22.6	*
11	Sulphate	19.4	6.5	*
12	Phosphate	*	93.5	*
13	Copper	4.2	*	4.2
14	Zinc	0.0	*	0.0
15	Mercury	100.0	*	100.0
16	Boron	12.5	*	*
17	Lead	0.0	*	0.0
18	Arsenic	0.0	*	0.0
19	Manganese	25.0	*	*
20	Cadmium	25.0	*	25.0
21	Overall water quality	100.0	100.0	100.0

Table 20: Percentage of ground water samples of unacceptable quality in terms of physical parameters – monsoon

Sl. No	*Parameter*	*Percent samples unfit as per the limits set for*	
		Drinking water	*Fish culture*
1	Colour *	42%	---
2	Odour@	6.4%	---
3	Turbidity	64.5%	51.6%
4	Temperature	---	0%
5	Overall	100%	100%

* Samples with colour other than of normal water
@ Samples with some or other unpleasant odour

Table 21: Occurrence of colour and odour in the ground water samples during monsoon

Source and Sample number	*Colour*	*Odour*
Dug well		
DW1	Yellowish	Odourless
DW2	Colourless	Odourless
DW3	Colourless	Odourless
DW4	Colourless	Odourless
DW5	Colourless	Odourless
DW6	Pale yellow	Odourless
DW7	Colourless	pdourless
DW8	Dark yellow	Pdourless
DW9	Colourless	Odourless
DW10	Colourless	Ammonia smell
DW11	Green ish	Odourless
DW12	Pale ye llow	Odourless
DW13	Colourless	Odourless
DW14	Colourless	Odourless
DW15	Colourless	Odourless
DW16	Pale green	Odourless
DW17	Pale yellow	Odourless
DWl8	Pal e reddish	Odourless
DW19	Colourless	Odourless
DW20	Pale yellow	Odourless
DW21	Pale yellow	Fishy smell
DW22	Colourless	Odourless
Bore well		
BW1	Colourless	Odourless
BW2	Colourless	Odourless
BW3	Reddish	Odourless
BW4	Pale yellow	Odourless
BW5	Colourless	Odourless
BW6	Colourless	Odourless
BW7	Pale yellow	Odourless
Tap water		
TW1	Colourless	Odourless
TW2	Colourless	Odourless

Table 22: Percentage of ground water samples of unacceptable quality in terms of physico-chemical and chemical parameters – monsoon

Sno.	*Parameter*	*Percentage of samples unfit as per the limits set for*		
		Drinking water %	*Domestic use %*	*Fish culture %*
1.	PH	3.2	0.0	0.0
2.	EC	*	87.1	48.4
3.	TDS	74.2	74.2	*
4.	Alkalinity	45.2	*	54.8
5.	Turbidity	64.5	*	51.6
6.	Total hardness	38.7	*	*
7.	Total iron	64.5	*	25.8
8.	Ammonia	*	*	48.4
9.	Nitrate	35.5	*	100.0
10.	Chloride	54.8	16.1	*
11.	Sulphate	29.0	3.2	*
12.	Phosphate	*	95.2	*
13.	Overall water quality	100.0	100.0	100.0

Table 23: Percentage of ground water samples of unacceptable quality interms of physical parameters – post-monsoon

Sl. No	*Parameter*	*Percent samples unfit as per the limits set for*	
		Drinking water	*Fish culture*
1.	Colour *	45%	---
2.	Odour[@]	16%	---
3.	Turbidity	51.6%	48.3%
4.	Temperature	---	0%
5.	Overall	100%	100%

* Samples with colour other than of normal water
[@] Samples with some or other unpleasant odour

Table 24: Occurrence of colour and odour in the ground water samples

Source and Sample number	*Colour*	*Odour*
Dug well		
OWl	Colourless	Odourless
OW2	Colourless	Odourless
OW3	Pale green	Odourless
OW4	Pale yellow	Odourless
DW5	Colourless	Odourless
OW6	rColourJess	Odourless
OW7	~olourless	Odourless
OW8	Colourless	Odourless
OW9	Colourless	Odourless
' DWIO	Colourless	Odourless
DWII	Colourless	Odourless
DWl2	Pale yellow	Odourless
DWl3	Pale yellow	Odourless
DW14	Pale green	Odourless
DWI5	Pale green	Odourless
DW16	Grey	Odourless
OWl7	Grey	Rotten smell
OWI8	Pale grey	Oily smell
DW19	Colourless	Odourless
OW20	Brick red	Fishy smell
DW21	Pale yellow	Odourless
OW22	Colourless	Odopurless
Bore well		
BWI	Colourless	Odourless
BW2	Colourless	Odourless
BW3	Black	!Oil smell
BW4	Pale yellow	IOily smell
BW5	tolourless	!Odourless
BW6	,--olourless	IOdourless
BW7	Colourless	IOdourless
Tap water		
TWI	Colourless	Odourless
TW2	Pale yellow	Odourless

Table 25: Percentage of ground water samples of unacceptable quality in terms of physico-chemical and chemical parameters – post-monsoon

Sl. No.	*Parameter*	*Percentage of samples unfit as per the limits set for*		
		Drinking water %	*Domestic use %*	*Fish culture %*
1	PH	0.0	0.0	0.0
2	EC	*	100.0	58.1
3	TDS	77.4	77.4	*
4	Alkalinity	41.9	*	64.5
5	Turbidity	51.6	*	48.4
6	Total hardness	64.5	*	*
7	Total iron	51.6	*	22.6
8	Ammonia	*	*	3.2
9	Nitrate	77.4	*	90.3
10	Chloride	54.8	25.8	*
11	Sulphate	48.4	3.2	*
12	Phosphate	*	67.7	*
13	Overall water quality	100.0	100.0	90.0

Table 26: Trace metals* in bore well water samples

SNo.	*Cu*	*Ni*	*Zn*	*Hg*	*B*	*Co*	*Pb*	*As*	*Mn*	*Mo*	*Cd*	*Be*
BW3U	0.060	0.028	BDL	0.113	0.335	0.010	BDL	BDL	0.106	BDL	0.007	BDL
BW3F	BDL	BDL	BDL	0.056	0.210	0.010	BDL	BDL	0.081	BDL	0.002	BDL
BW6U	0.023	BDL	BDL	0.339	0.715	0.039	BDL	BDL	0.028	0.056	0.010	BDL
BW6F	BDL	BDL	BDL	0.283	0.549	0.029	BDL	BDL	BDL	0.032	0.001	BDL
BW7U	0.033	BDL	BDL	0.339	3.347	0.088	BDL	BDL	BDL	1.506	0.013	BDL
BW7F	0.002	BDL	BDL	0.170	BDL	0.039	BDL	BDL	BDL	1.393	0.010	BDL

U - Unfiltered
F - Filtered
* All the values are in mg/L

Table 27: Trace metals* in dug well water samples

SNo.	*Cu*	*Ni*	*Zn*	*Hg*	*B*	*Co*	*Pb*	*As*	*Mn*	*Mo*	*Cd*	*Be*
DW3U	0.037	0.009	BDL	0.056	BDL	0.020	BDL	BDL	10.21	BDL	0.013	BDL
DW3F	BDL	BDL	BDL	0.056	BDL	0.020	BDL	BDL	10.03	BDL	0.003	BDL
DW6U	0.019	BDL	BDL	0.679	BDL	0.079	BDL	BDL	BDL	BDL	0.007	BDL
DW6F	BDL	BDL	BDL	0.226	BDL	0.010	BDL	BDL	BDL	BDL	0.002	BDL
DW10U	0.025	0.019	BDL	0.283	BDL	0.020	BDL	BDL	0.512	BDL	0.009	BDL
DW10F	0.012	BDL	BDL	0.226	BDL	0.020	BDL	BDL	0.489	BDL	0.001	BDL
DW12U	0.002	BDL	BDL	0.170	0.016	0.049	0.119	BDL	0.258	BDL	0.005	BDL
DW12F	BDL	BDL	BDL	0.113	BDL	BDL	BDL	BDL	BDL	BDL	0.005	BDL
DW15U	0.029	BDL	BDL	0.170	BDL	0.039	BDL	BDL	BDL	BDL	0.010	BDL
DW15F	0.027	BDL	BDL	0.113	BDL	0.010	BDL	BDL	BDL	BDL	0.004	BDL
DW16U	0.033	BDL	BDL	0.283	2.165	0.049	BDL	BDL	BDL	0.976	0.005	BDL
DW16F	0.029	BDL	BDL	0.226	BDL	0.020	BDL	BDL	BDL	0.922	BDL	BDL
DW17U	0.021	BDL	BDL	0.226	0.295	0.079	BDL	BDL	BDL	0.244	0.008	BDL
DW17F	BDL	BDL	BDL	0.056	BDL	0.049	BDL	BDL	BDL	0.233	0.005	BDL
DW18U	0.041	BDL	BDL	0.113	0.416	0.148	BDL	BDL	BDL	BDL	0.007	BDL
DW18F	BDL	BDL	BDL	0.056	0.113	0.039	BDL	BDL	BDL	BDL	0.002	BDL
DW22U	0.018	BDL	BDL	0.170	1.249	0.010	BDL	BDL	BDL	0.054	0.006	BDL
DW22F	BDL	BDL	BDL	0.113	0.59	BDL	BDL	BDL	BDL	0.048	0.005	BDL

U - Unfiltered
F - Filtered

* All the values are in mg/L

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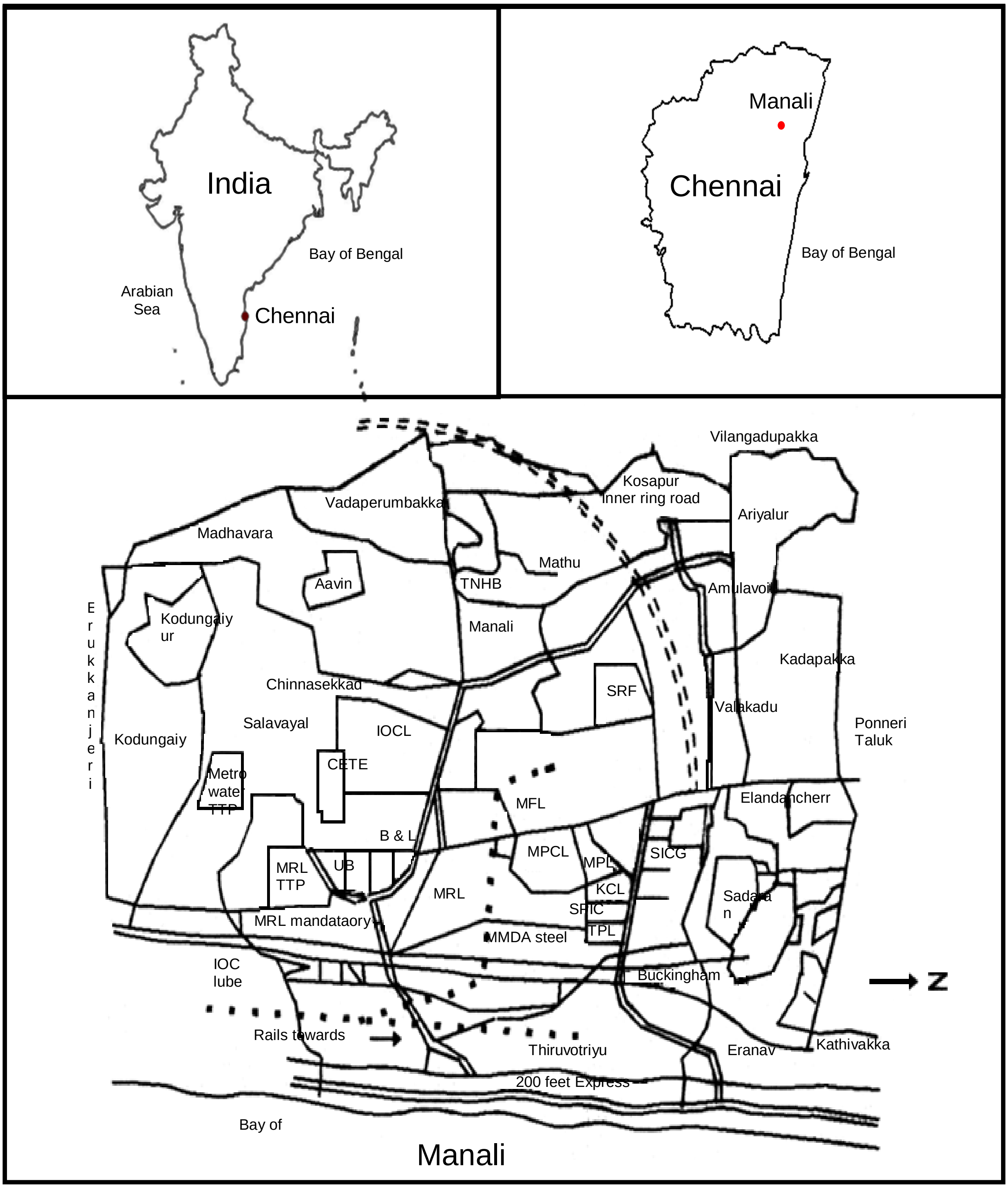

Figure 1: The study area

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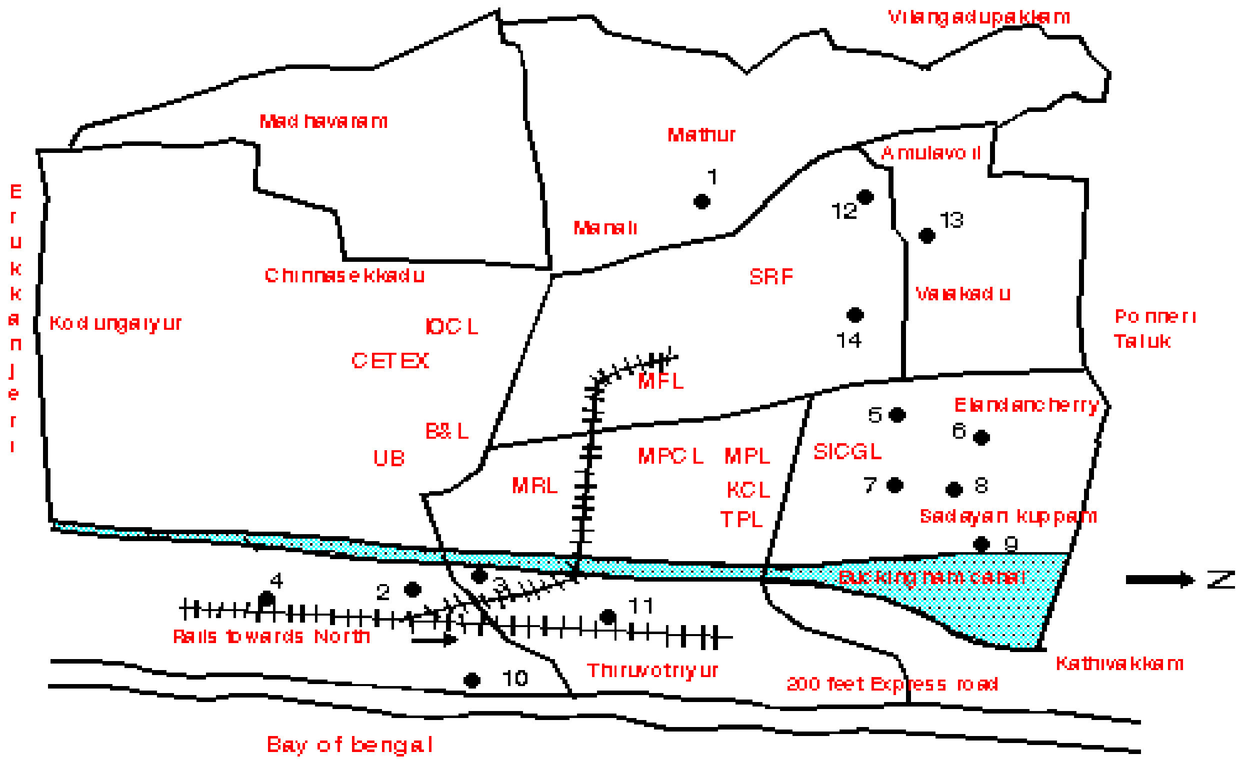

Figure 2: Location of pond-sampling sites [•]

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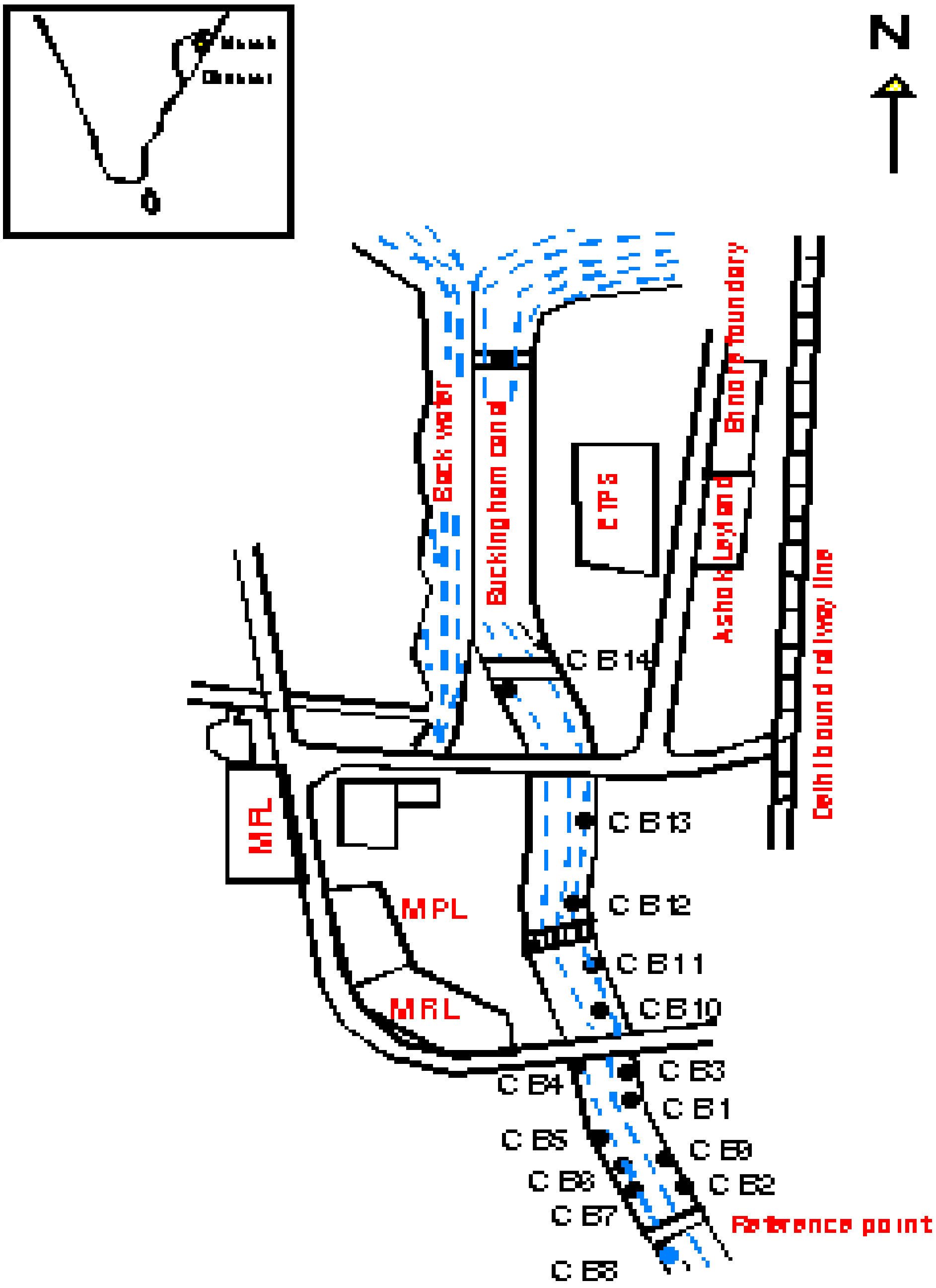

Figure 3: Sampling points in the Buckingham canal. All samples were collected from the middle of the canal, the sampling process strictly confirmed with the Standard methods.

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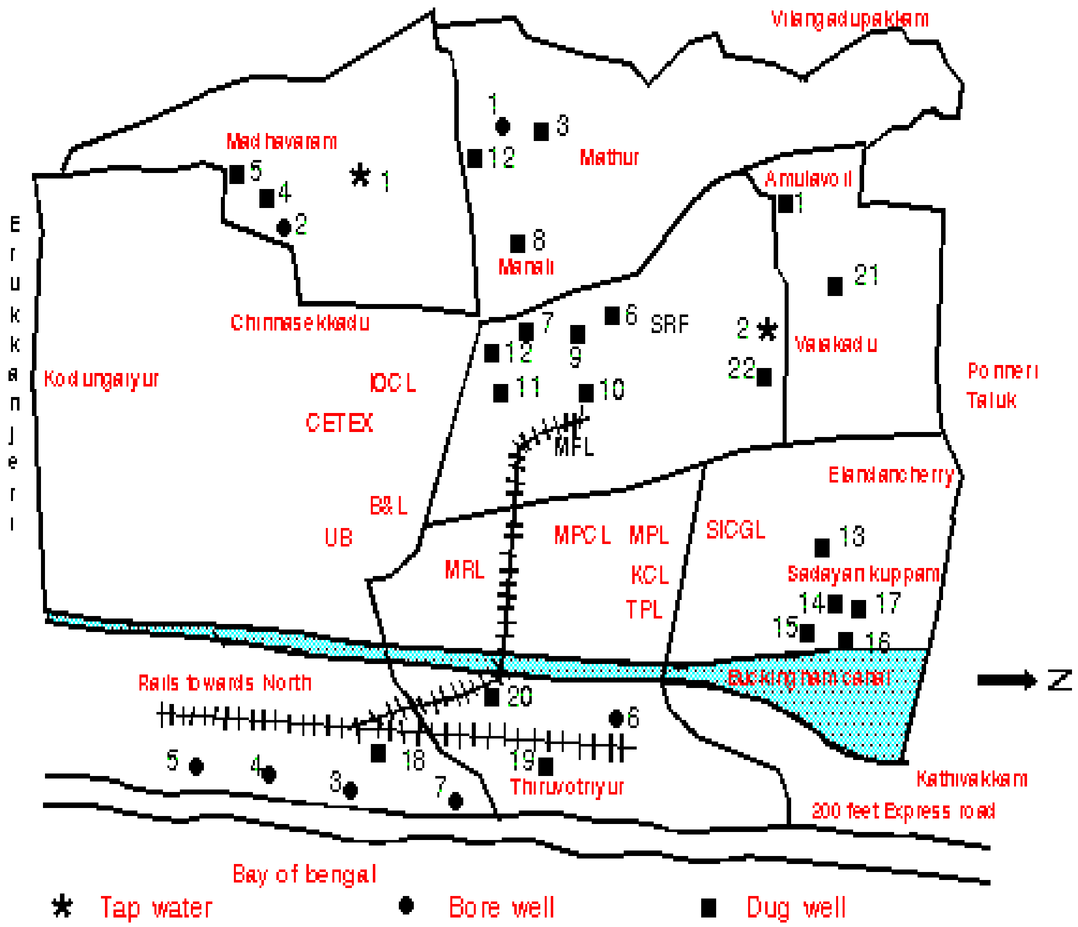

Figure 4: Location o ground water monitoring stations

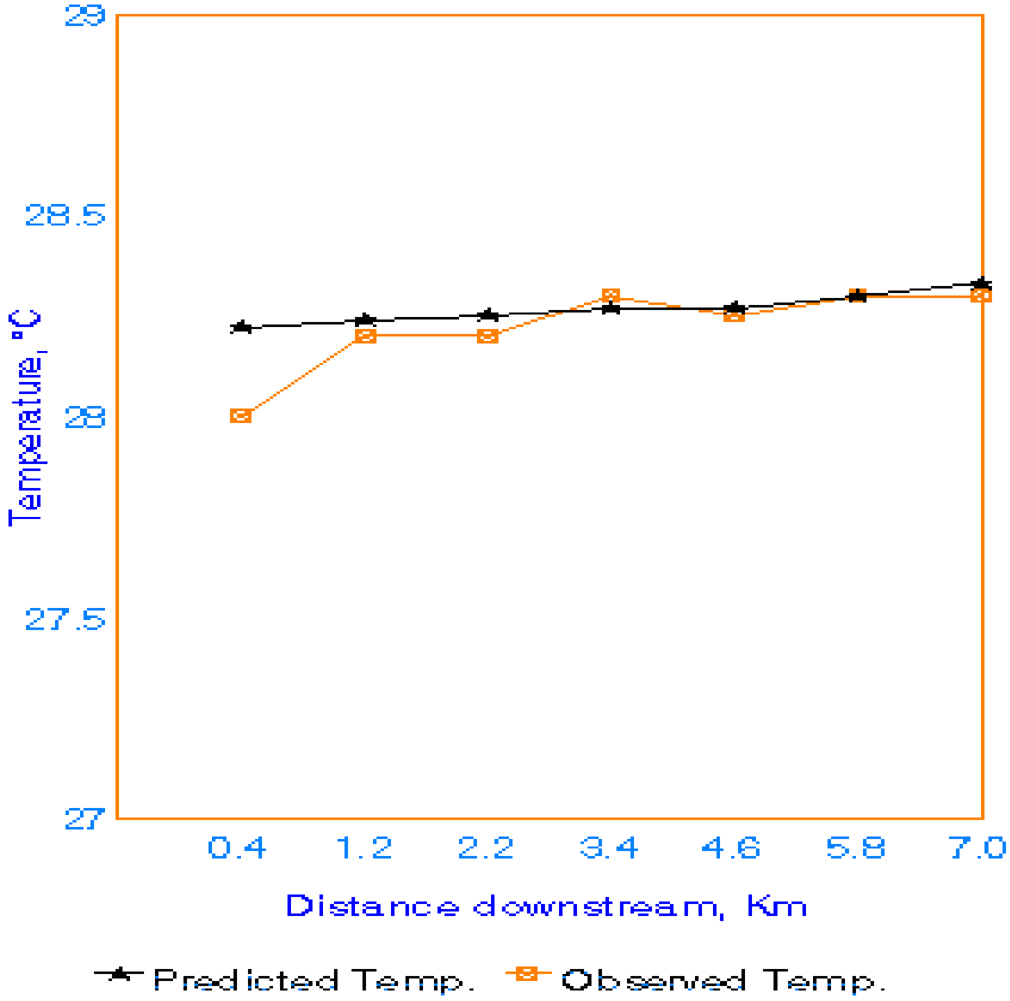

Figure 5: Validation curves for temperature during summer

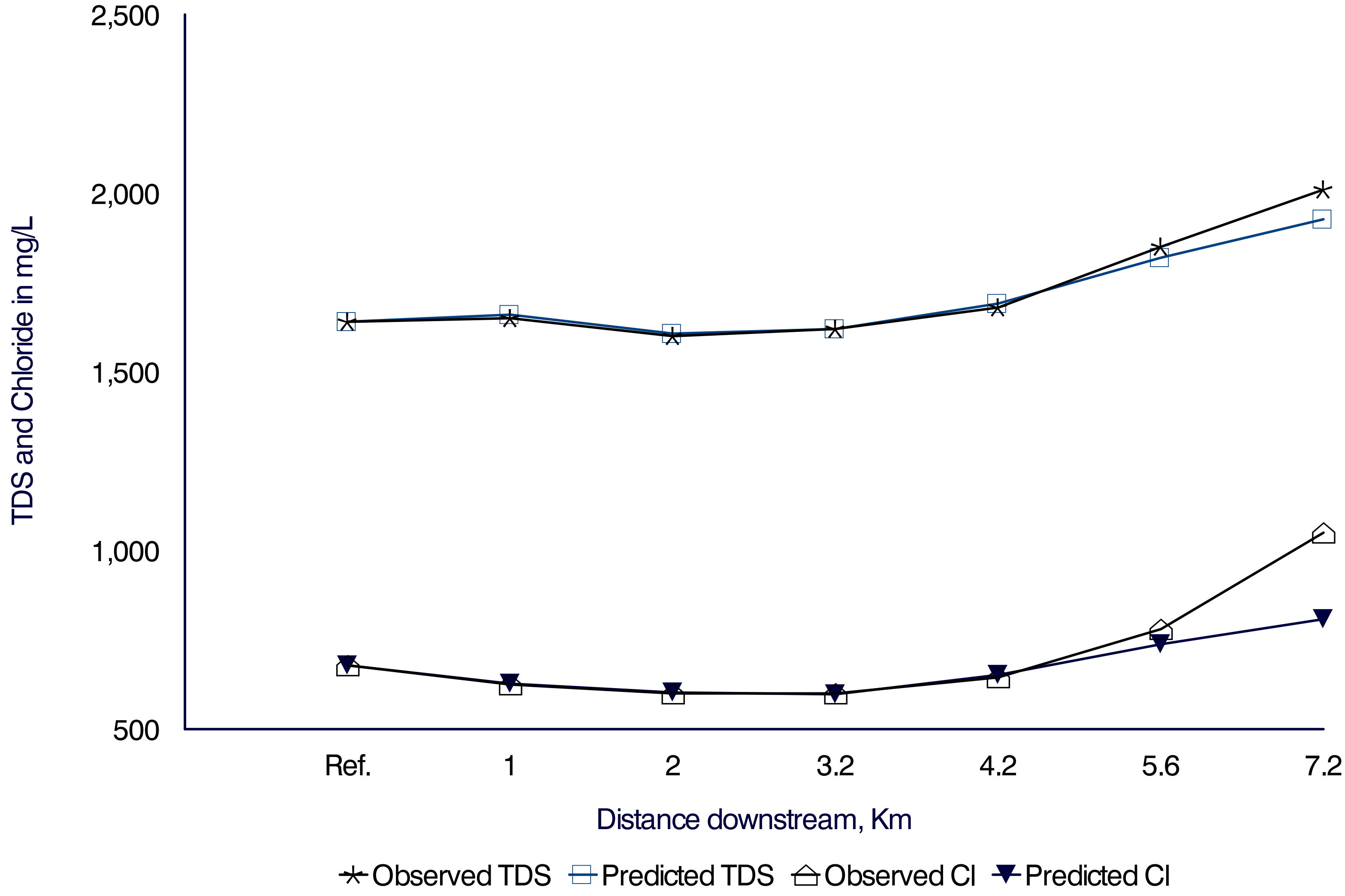

Figure 6: Validation curves for TDS and chloride during premonsoon

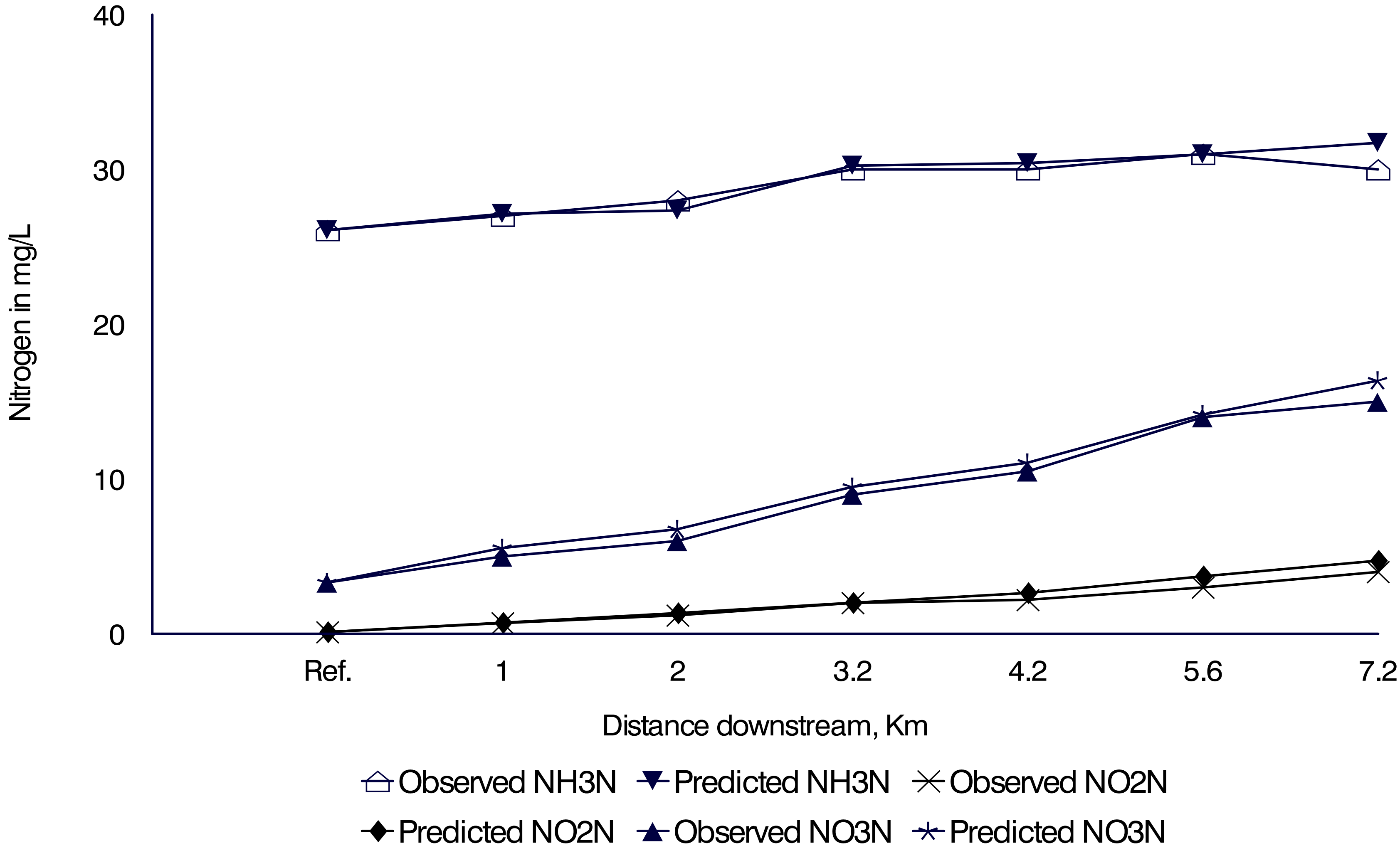

Figure 7: Validation curves for Nitrogen (NH_3, NO_2, NO_3) during premonsoon

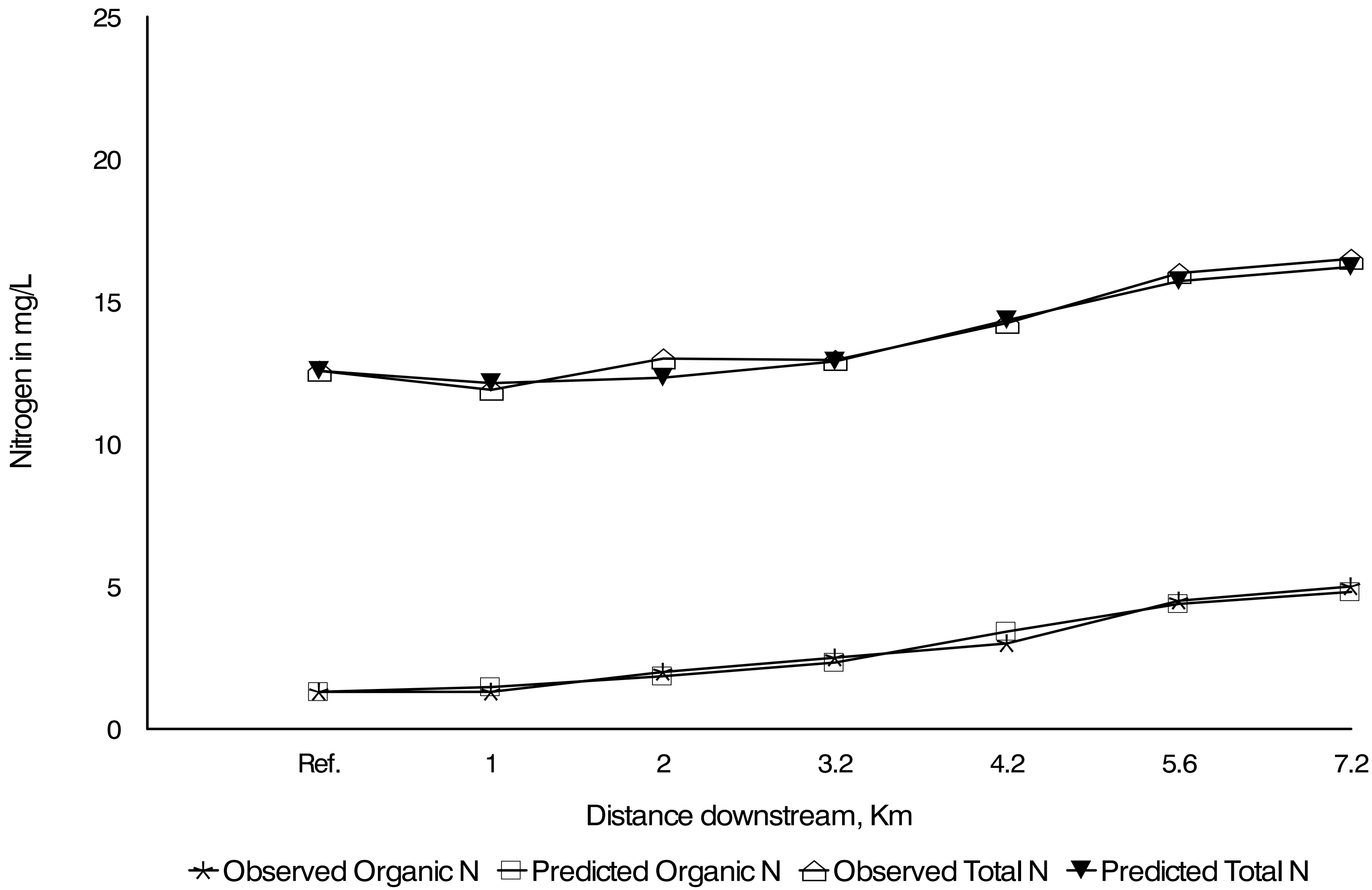

Figure 8: Validation curves for organic and total nitrogen during monsoon

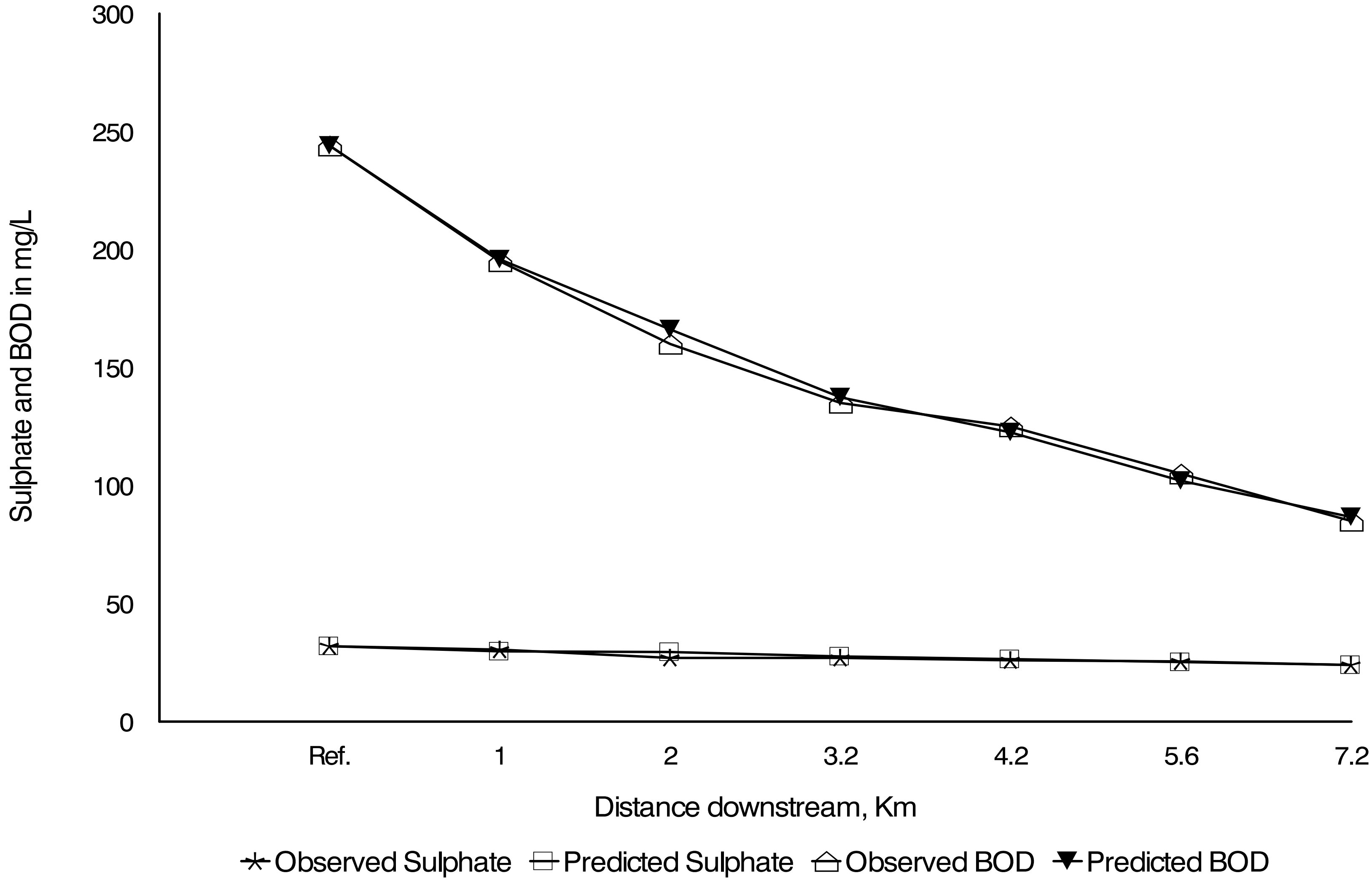

Figure 9: Validation curves for sulphate and BOD during postmonsoon

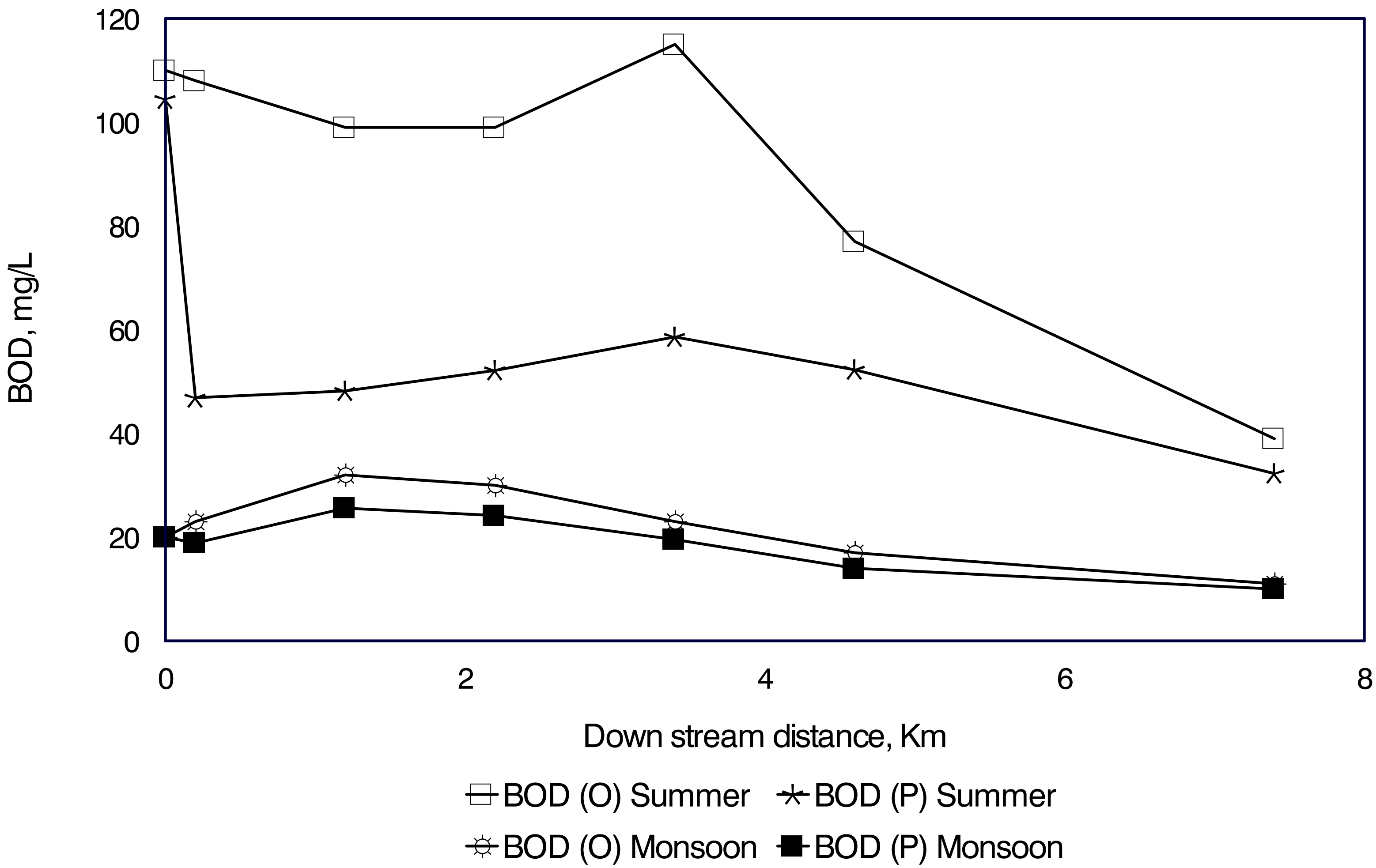

Figure 10: Impact of addition of fresh water stream ($3.5 m^3/s$ and $2.5 m^3/s$) and increase in head water DO (4 mg/L) on BOD of the canal during summer and monsoon seasons

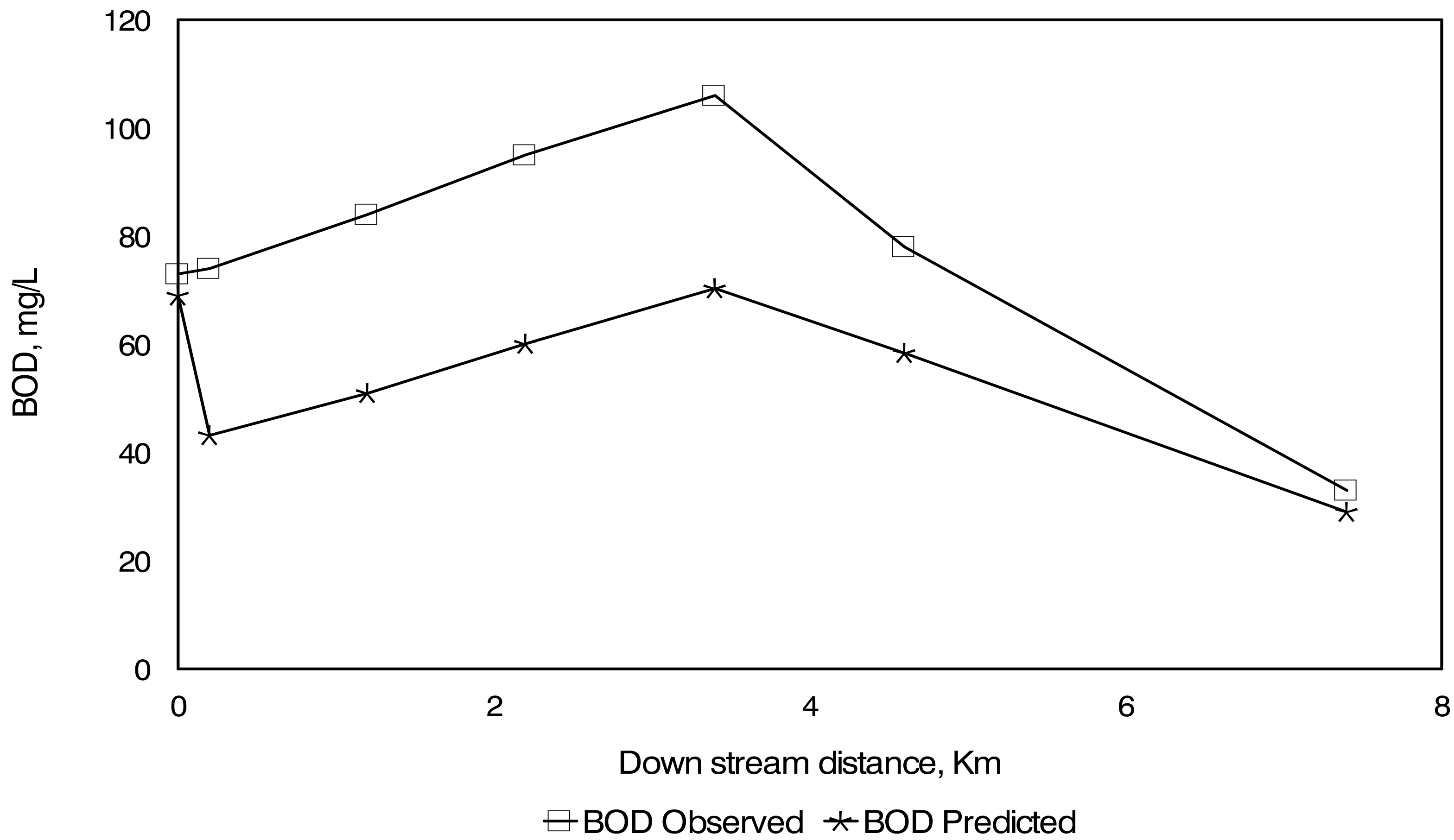

Figure 11: Impact of addition of fresh water stream (3.0m^3/s) and increase in had water DO (4 mg/L) on BOD of the canal during post monsoon season

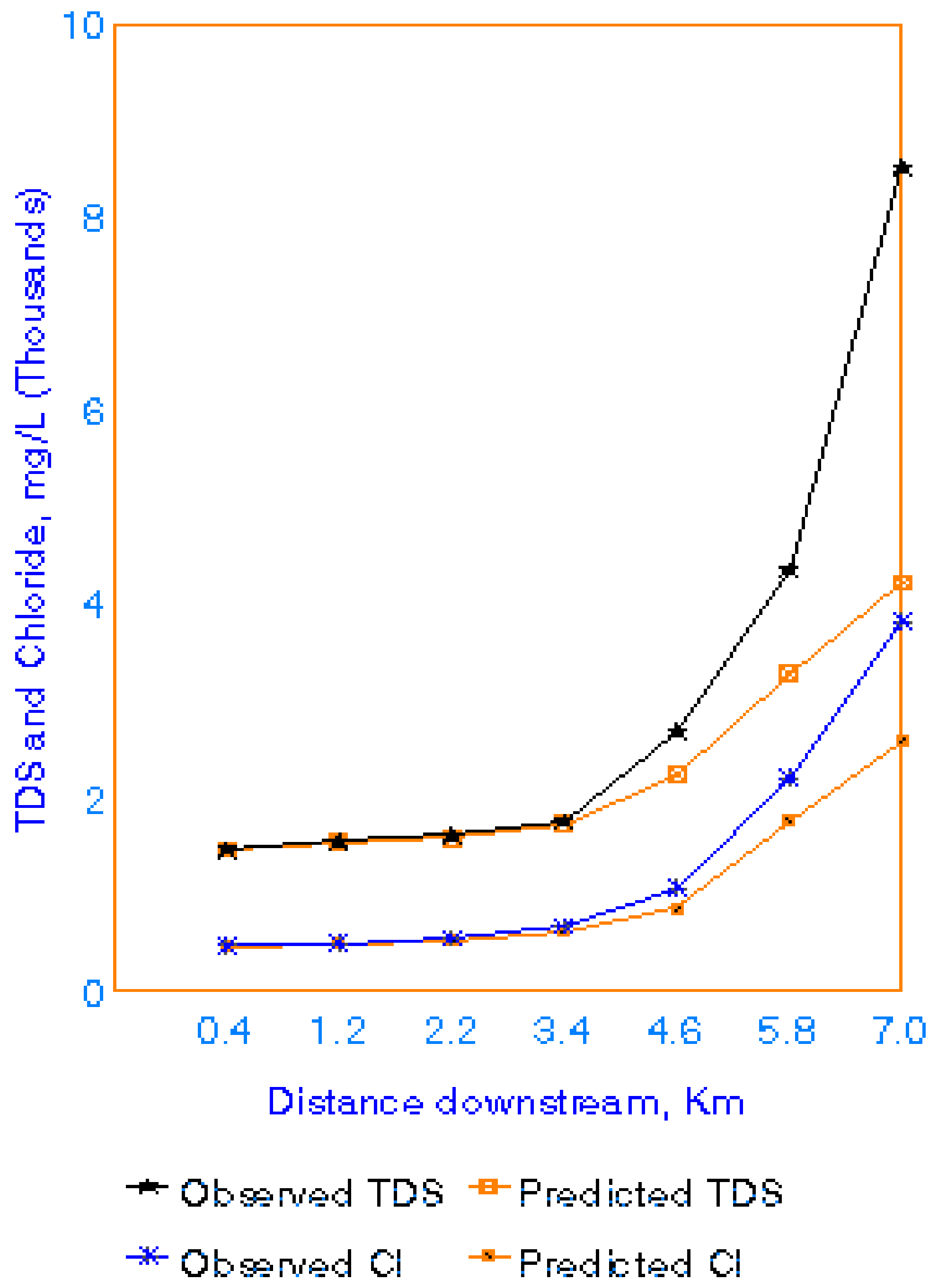

Figure 12: Validation curves for TDS and chloride during summer

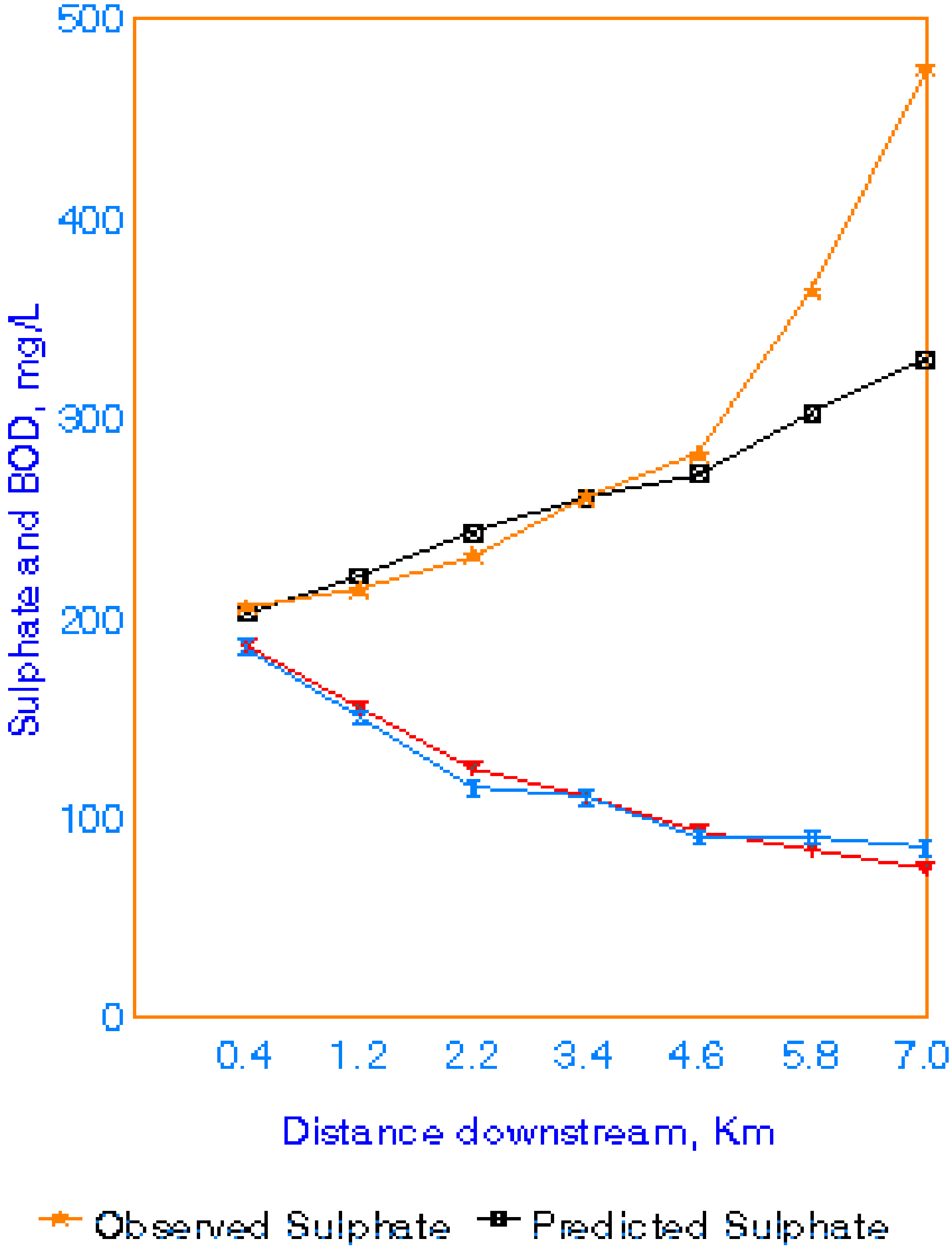

Figure 13: Validation curves for Sulphate and BOD during summer

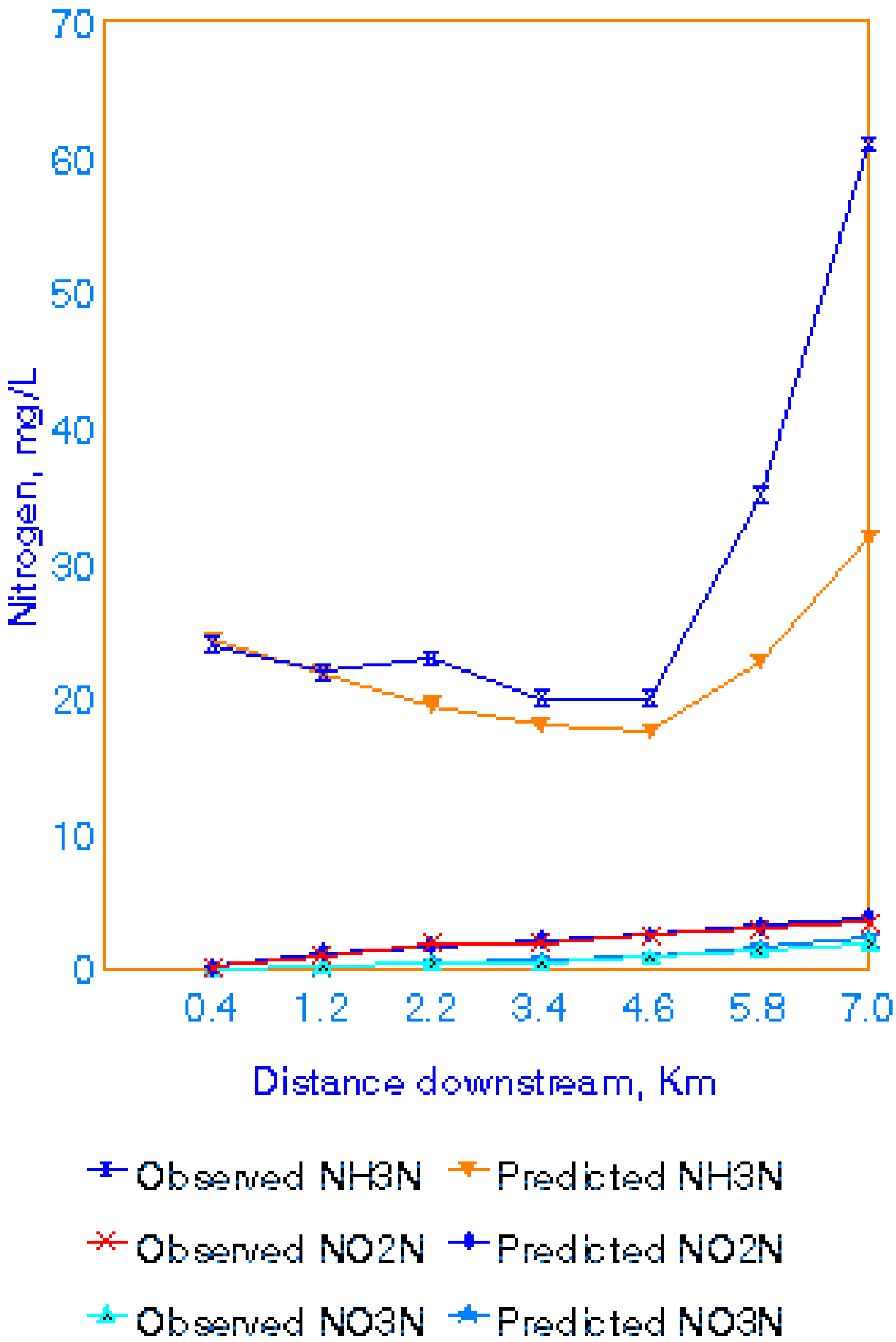

Figure 14: Validation curves for Nitrogen (NH_3, NO_2, NO_3) during summer

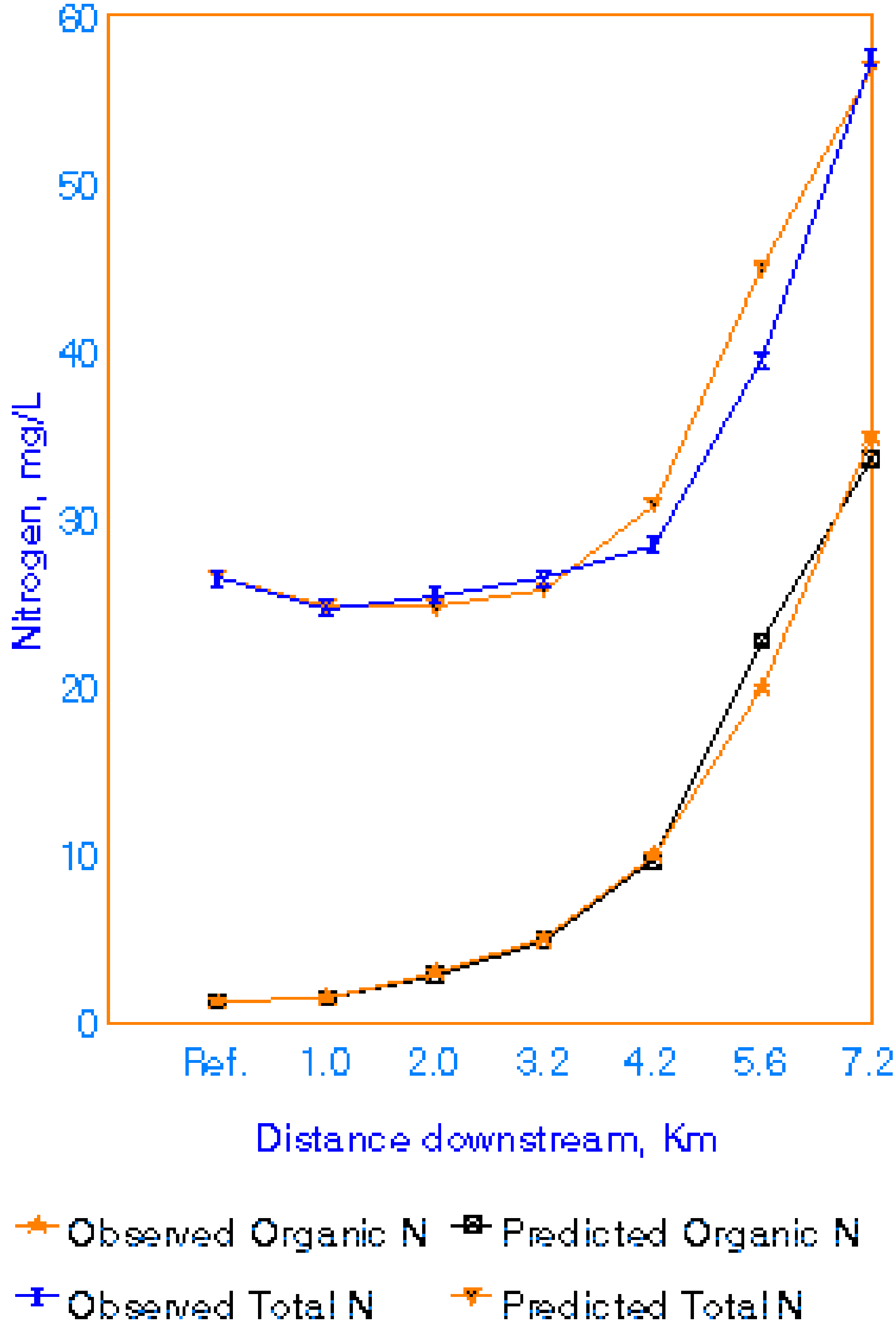

Figure 15: Validation curves for Organic and Total Nitrogen during summer

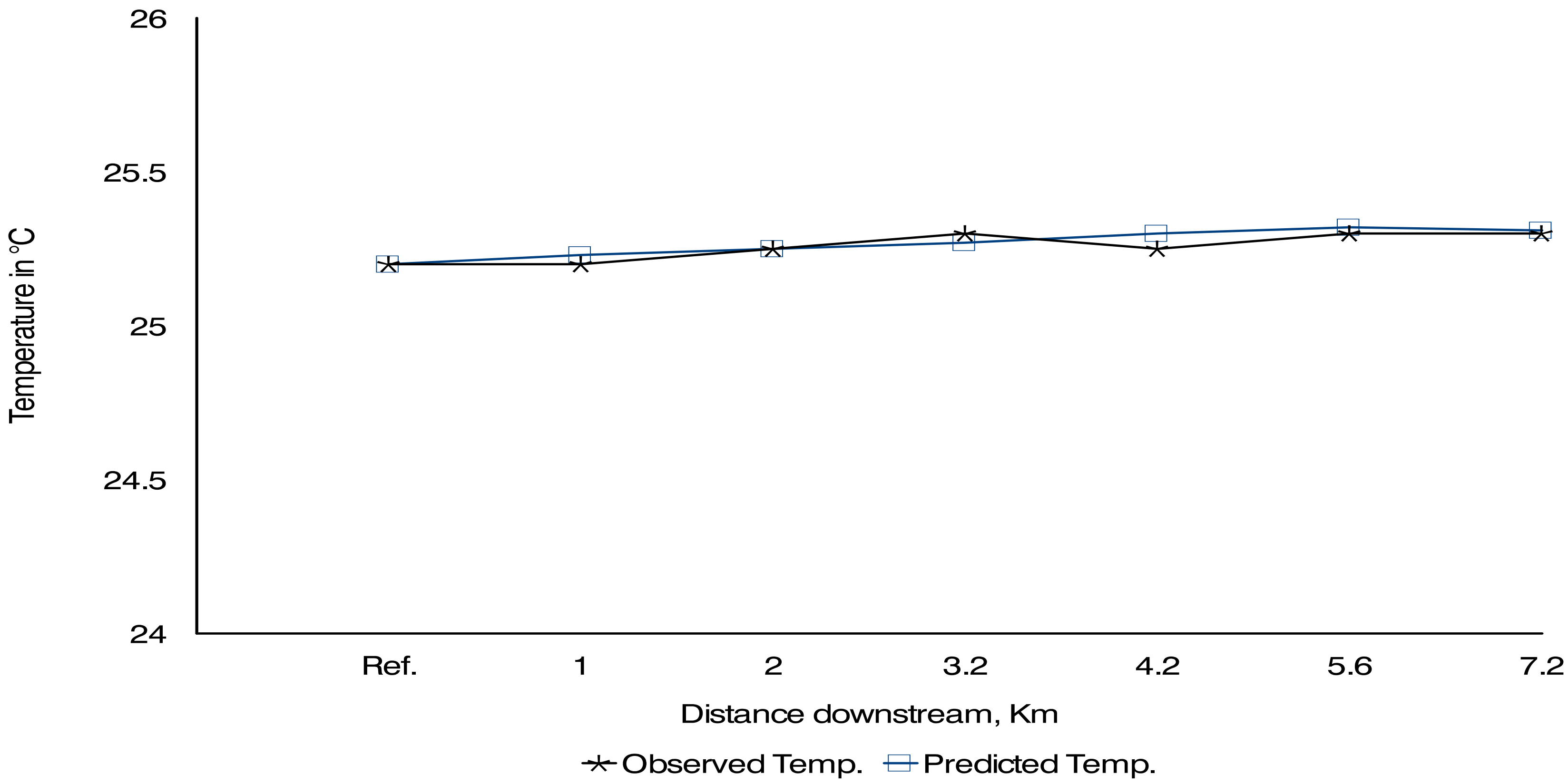

Figure 16: Validation curve for temperature during monsoon

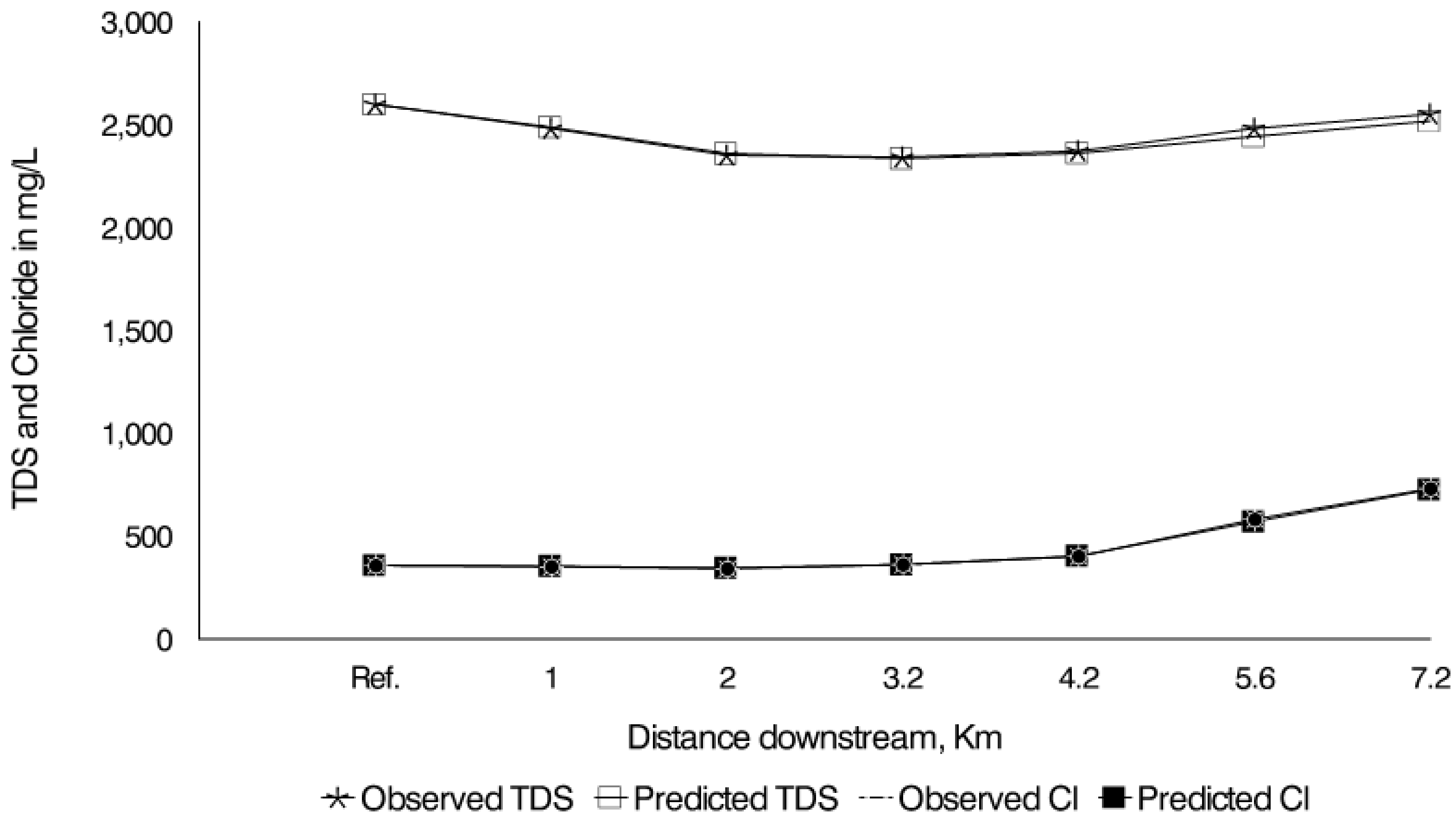

Figure 17: Validation curves for TDS and chloride during monsoon (observed curve for chloride totally overlaps the predicted curve)

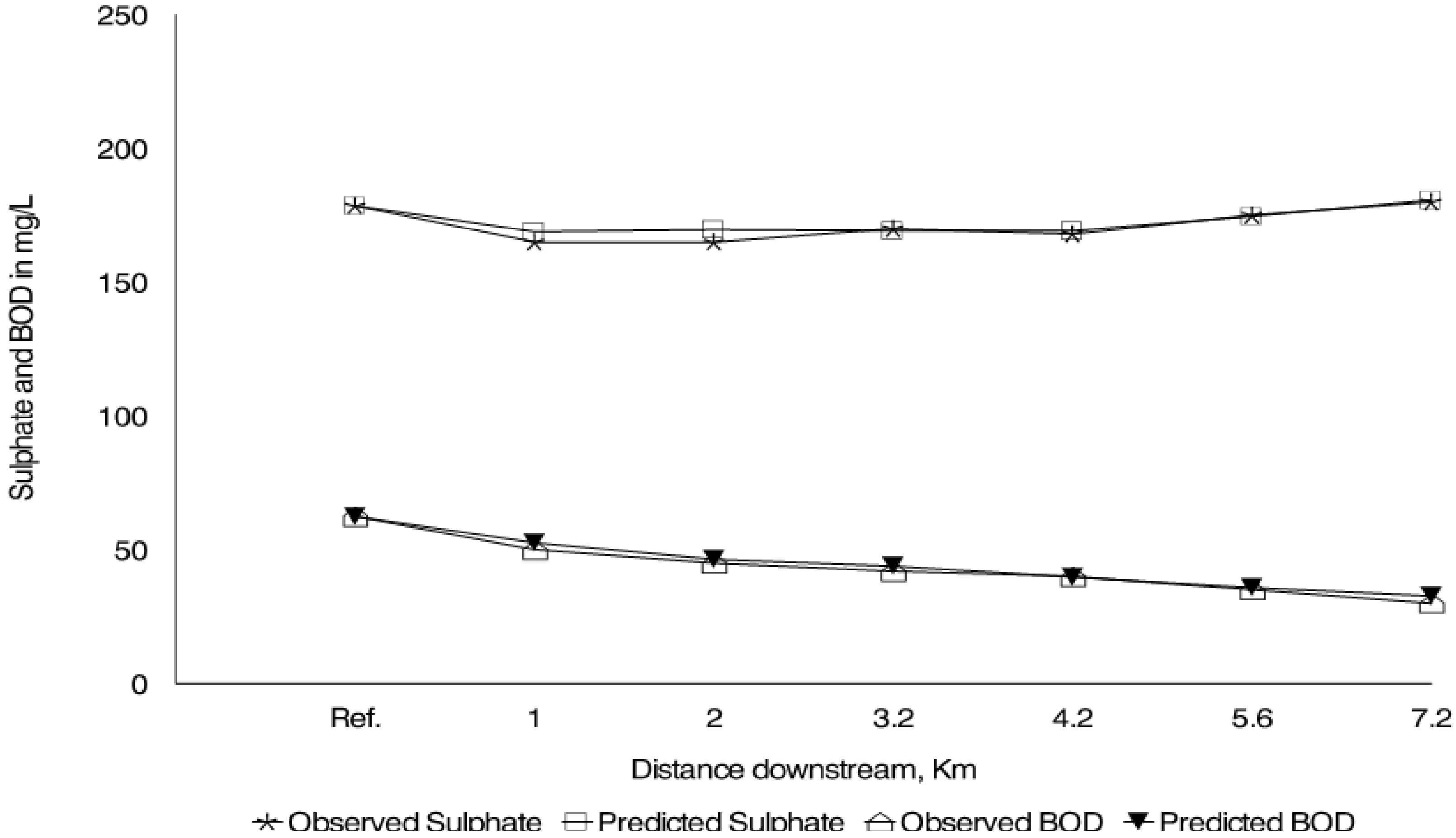
250
200
150
100
50
0
Sulphate and BOD in mg/L
Ref.
1
2
3.2
4.2
5.6
7.2
Distance downstream, Km
Observed Sulphate
Predicted Sulphate
Observed BOD
Predicted BOD

Figure 18: Validation curves for sulphate and BOD during monsoon

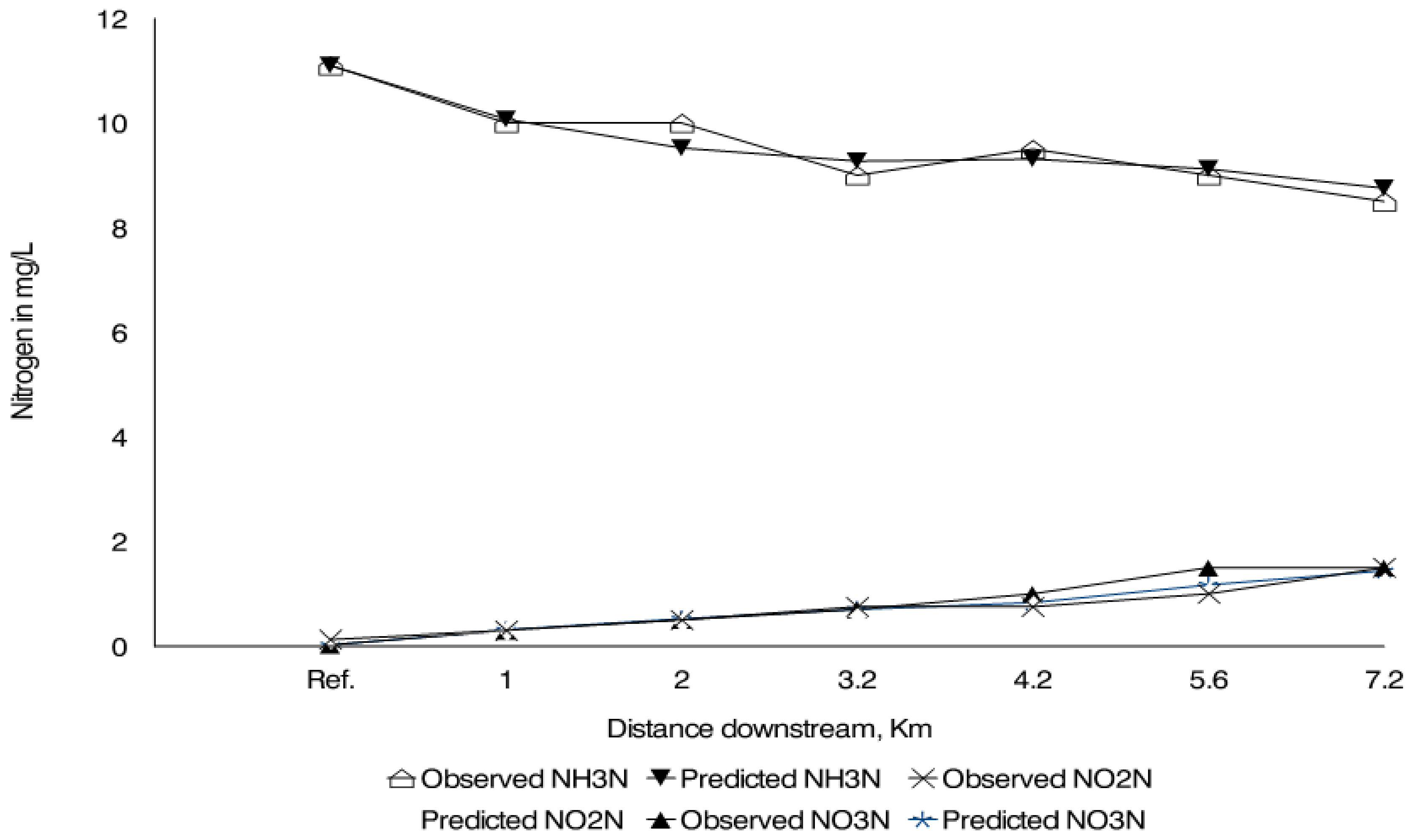
12
10
8
6
4
2
0
Nitrogen in mg/L
Ref.
1
2
3.2
4.2
5.6
7.2
Distance downstream, Km
Observed NH3N
Predicted NH3N
Observed NO2N
Predicted NO2N
Observed NO3N
Predicted NO3N

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Figure 19: Validaiton curves for nitrogen (NH_3, NO_2, NO_3) during monsoon

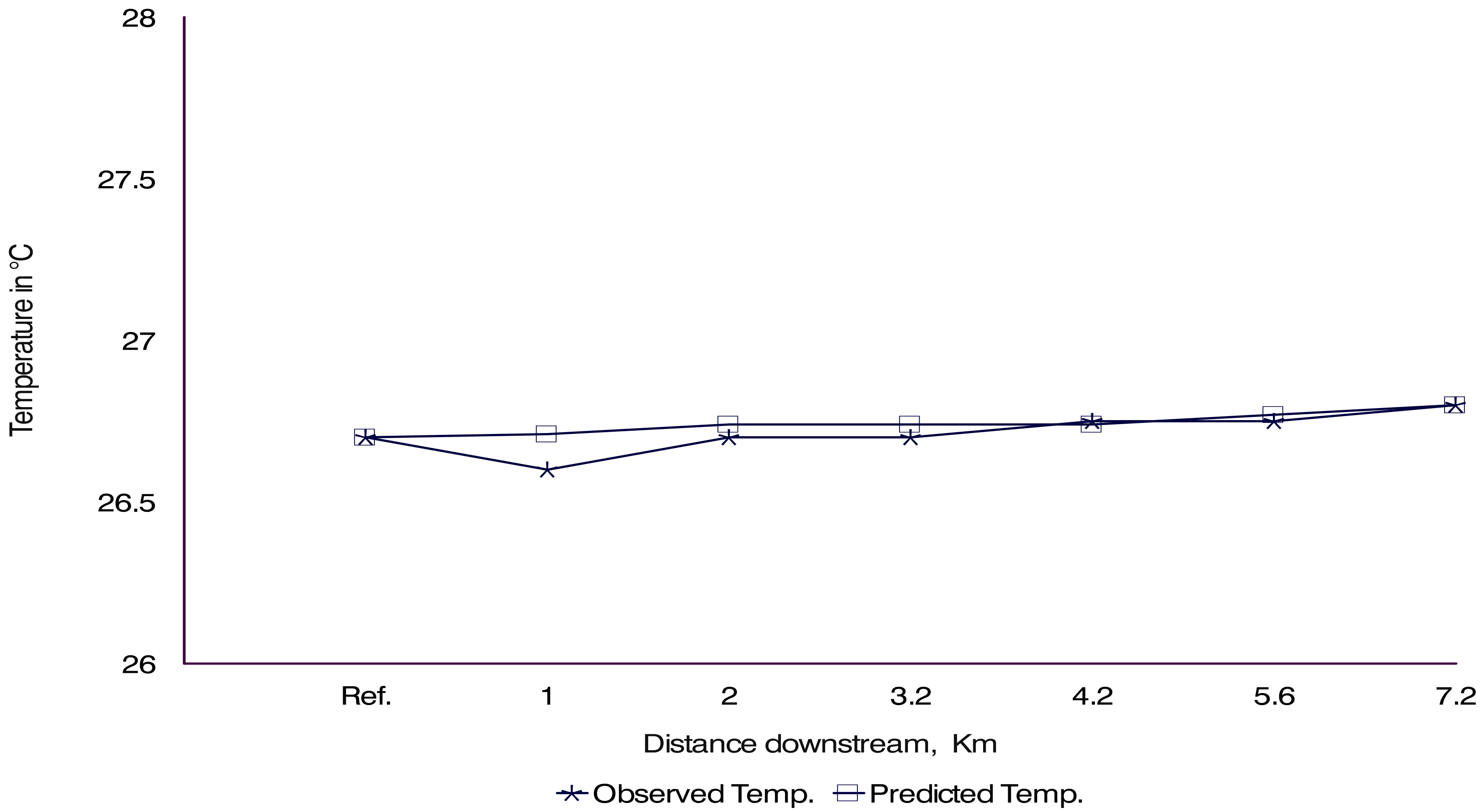

Figure 20: Validation curves for temperature during premonsoon

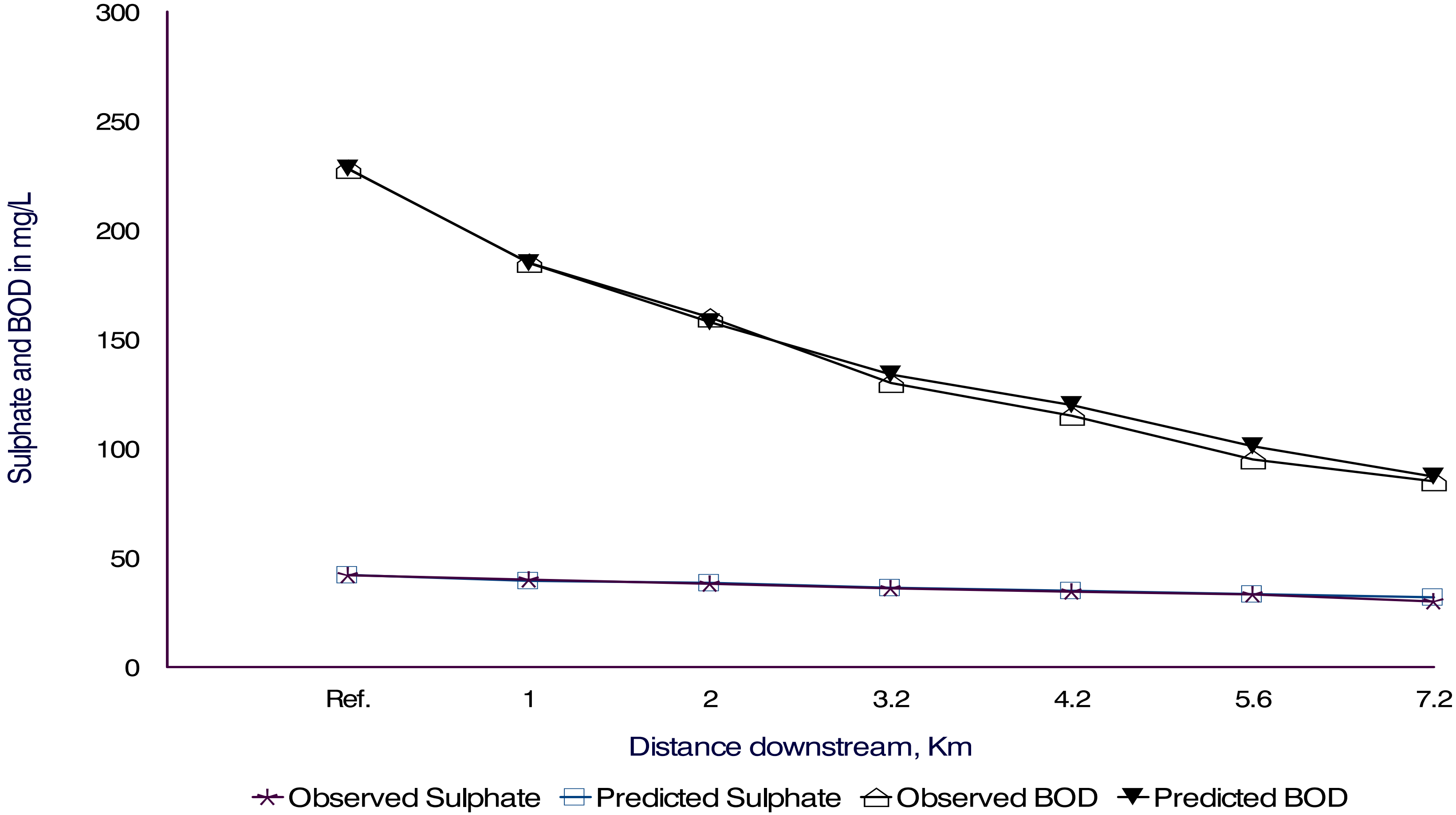

Figure 21: Validation curves for sulphate and BOD during premonsoon

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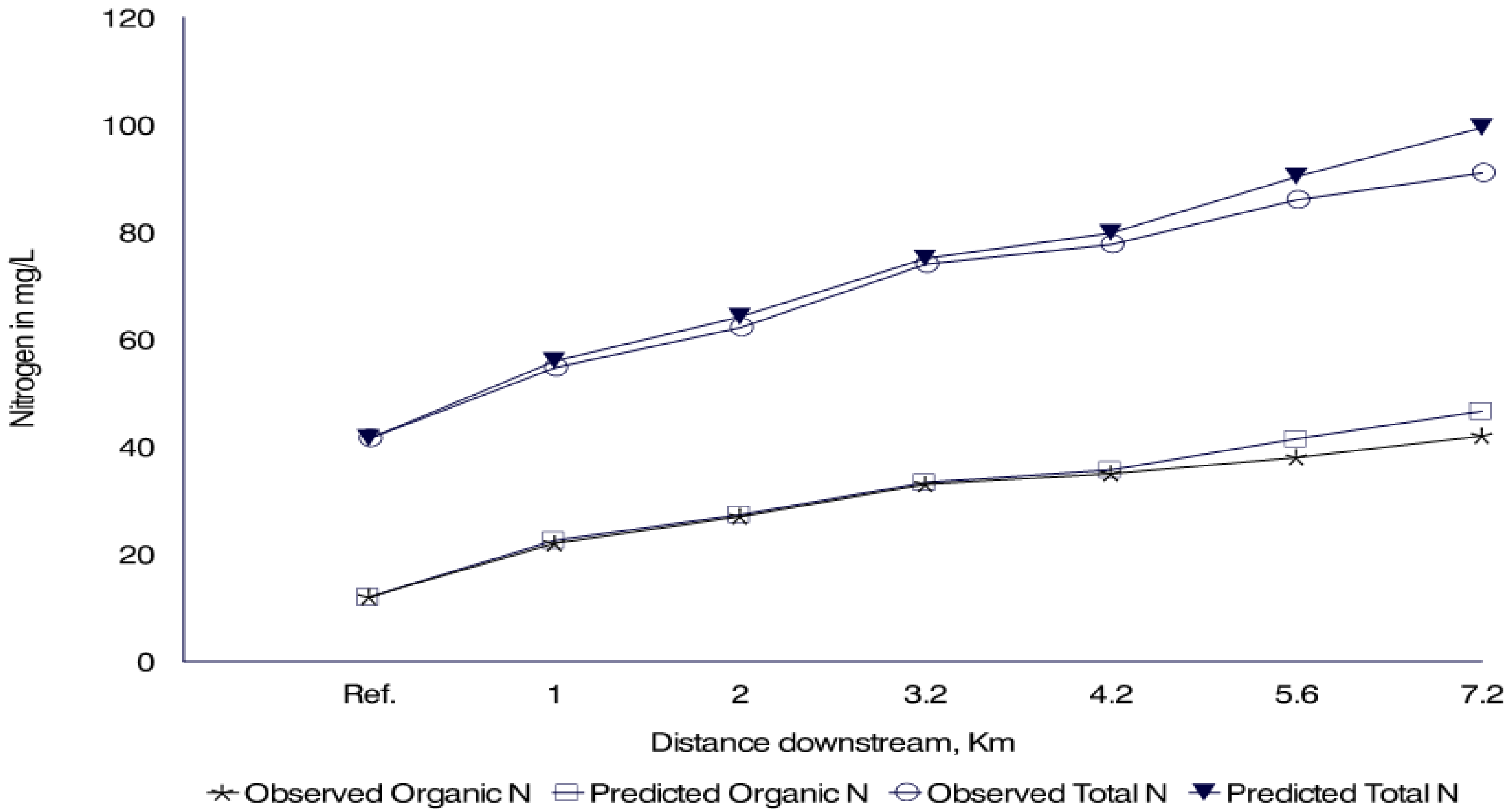

Figure 22: Validation curves for organic and total nitrogen during premonsoon

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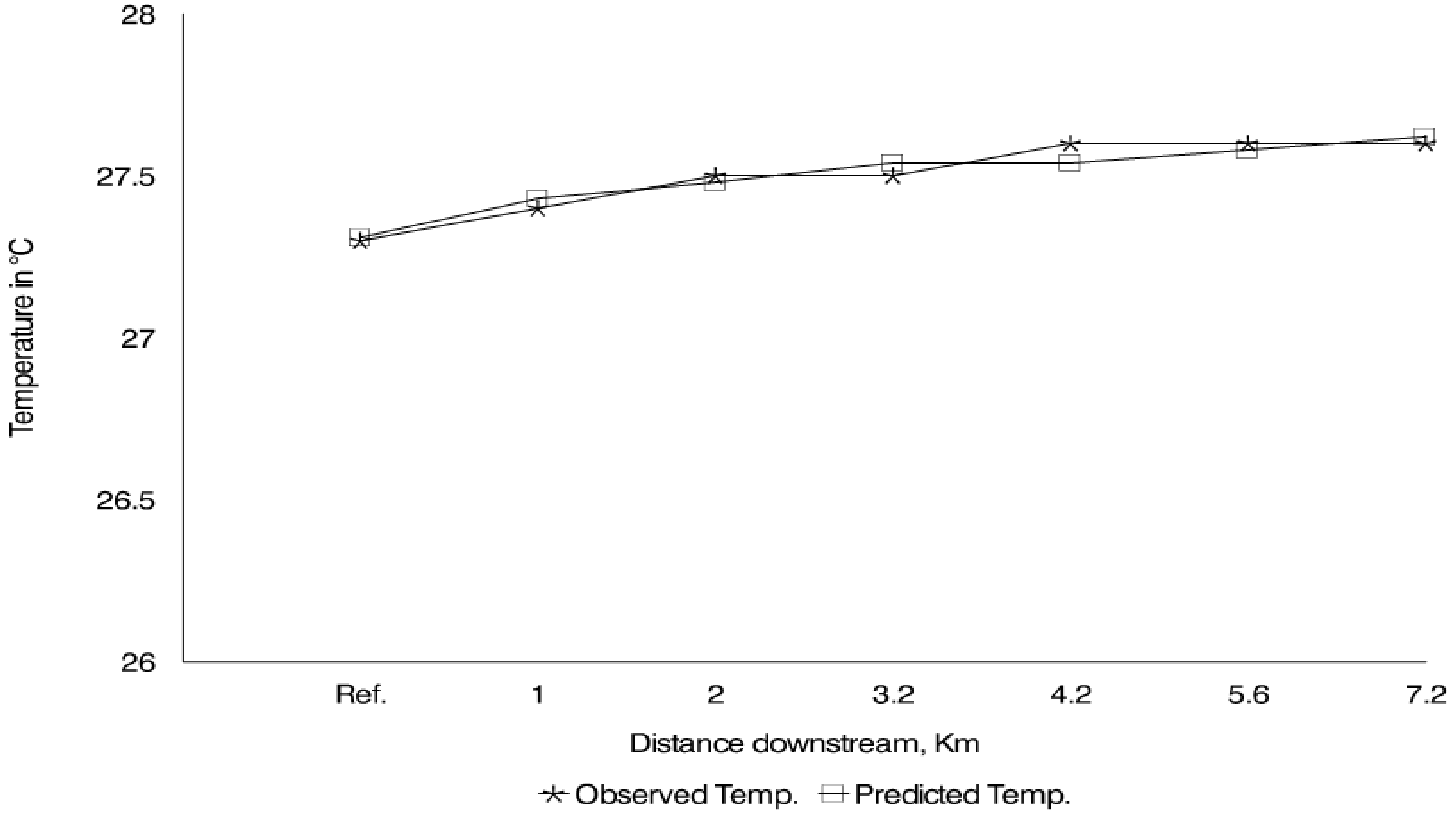

Figure 23: Validation curves for temperature during postmonsoon

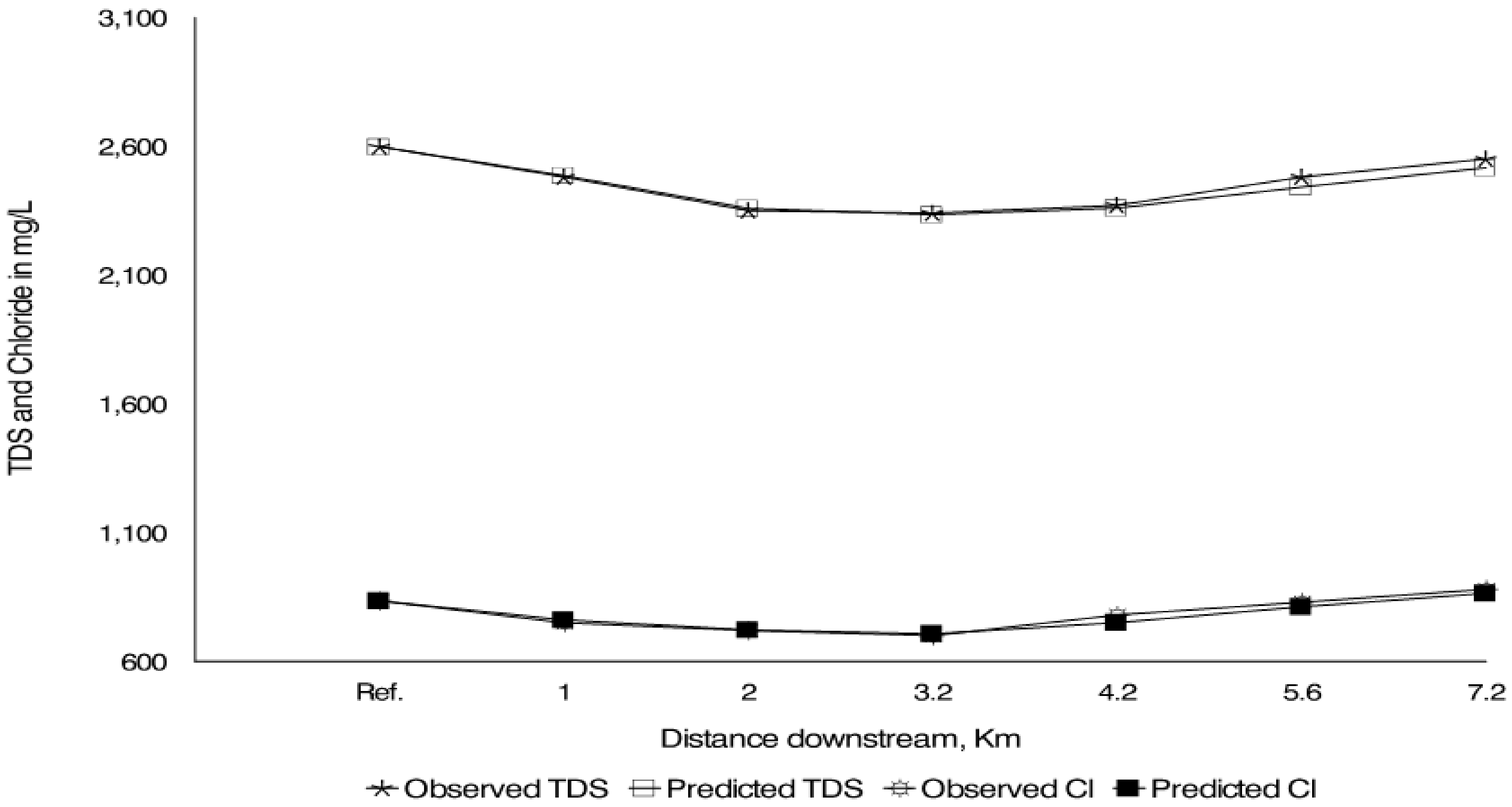

Figure 24: Validation curves for TDS and chloride during postmonsoon (the observed and the predicted curves for chloride almost totally overlap)

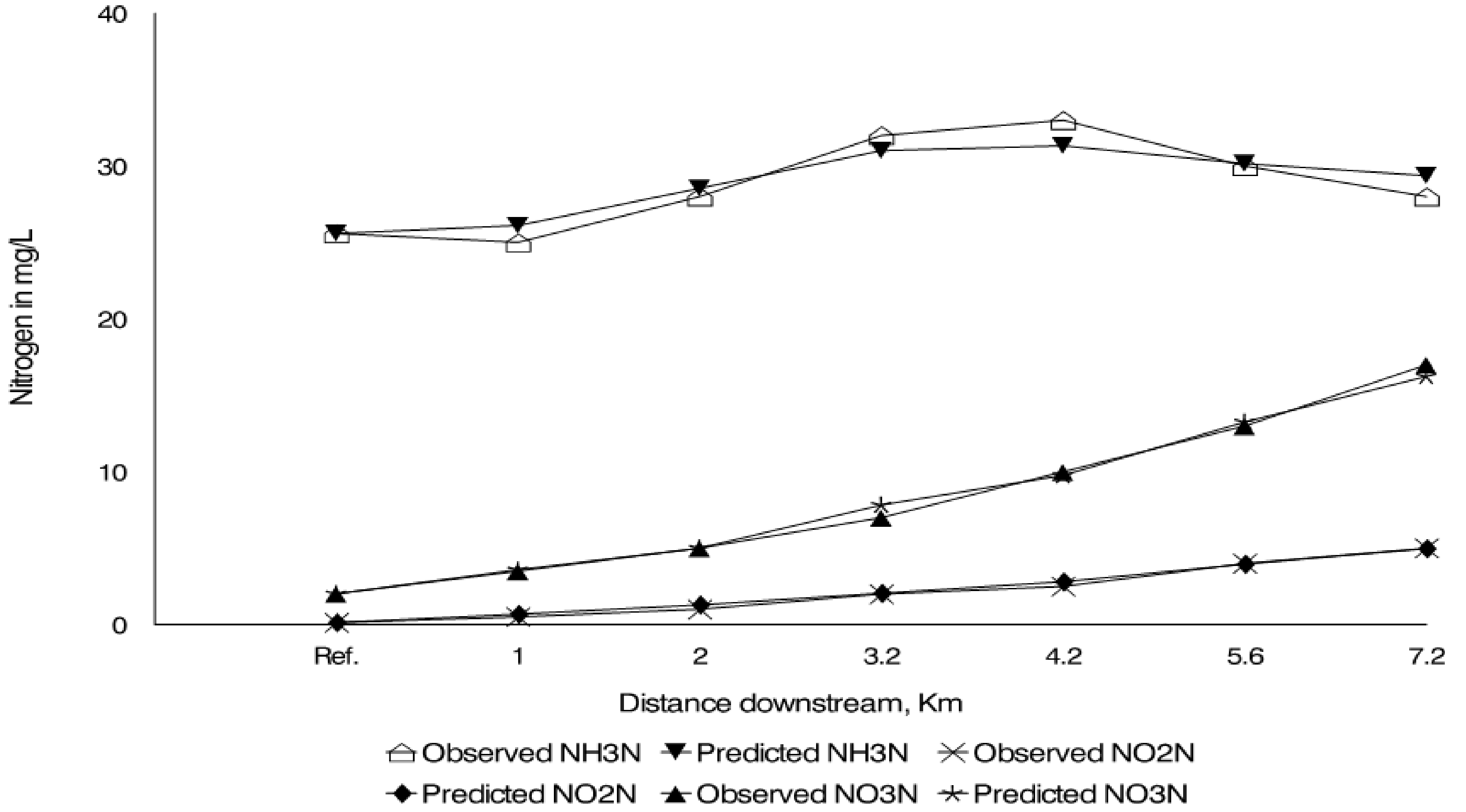

Figure 25: Validation curves for nitrogen (NH_3, NO_2, NO_3) during postmonsoon

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Plate 1: Cattle wallowing in and drinking water from one of the ponds in the study area

Plate 2: Fishing in a pond close to several industries

Plate 3: Solid wastes dumped close to a pond (above), and near residential houses

Plates 4: Solid waste dumped all round houses: persistent source of groundwater contamination through leaching.