Chapter

Toxic Effluent Treatment by Membrane Based Ultrafiltration and Reverse Osmosis for Sustainable Management and Conservation of Ground Water in Industrial Clusters

Biman Gati Gupta

Abstract

The present study attempts to assess the nature of effluents generated from textile bleaching and dyeing units located at Kalikapur area under Maheshtala region, West Bengal, India and to provide a sustainable management of ground water resources through installing CETPs with zero liquid discharge system. Effluent from medium, small and tiny units of this region is estimated at 2000 MLD. Studies with 40 units for 4 years (2012—2016) located in this area exhibited following mean values of different physic-chemical variables: pH (9), Biological Oxygen Demand (610 Mg/L), Chemical Oxygen Demand (1827 Mg/L), Total Dissolved Solids (6411 Mg/L), Total Suspend Solids (927 Mg/L) and toxic metals such as lead Pb (0.43 Mg/L), Chromium (0.031 Mg/L), Zinc (0.74 Mg/L), Nickel (0.07 Mg/L) and Cadmium (0.03 Mg/L). These finding of results surpass the standard allowable limits qualify by FAO (1985) and World Health Organization (2003). The waste water loaded with toxic trace metals is adversely affecting the environmental pollution and anthropomorphic eudemonia and also pollute the quality of both surface and ground water and consequently degraded agricultural and plant yield, vegetable and fruits and causes impairment to aquatic lives. Four to five Common Effluent Treatment Plants are urgently required to install at different areas of the Maheshtala cluster with a capacity of 500 MLD each, so that one in Kalikapur area, to manage sizeable volume of waste water (2000 MLD) and sustainable management of ground water resources in a thickly populated urban area near Calcutta, a principal city of India.

Keywords: textile, toxic, effluent, water, contamination, treatment, membrane, ultrafiltration, reverse osmosis

1. Introduction

The main aim of the study is to assess the nature of waste water generated and to provide a realistic sustainable groundwater management by installing common effluent treatment plant with zero liquid discharge system through implementation of membrane based ultra-filtration, reverse osmosis with recourse to recycling of bleaching and dying effluent at Kalikapur, West Bengal, India to save groundwater, environment and human health of a thickly populated area and 15 KM from Calcutta, a premier city of India. It revealed during study that the contamination level of surface water including canal water running in the cluster is highly contaminated. The waste water discharged into the nearby canal water is the main source of contamination as most of the units do not treat the waste water due to lack of treatment facilities in their own. The soil profile of the area is also degraded in the locality. Hence, the only way left behind is to treat the waste water to a level which can be reused in textile units through recycling. Membrane based treatment of waste water is found suitable in this circumstances to treat the toxic waste water as well as recycling of the treated water to the textile units to save groundwater paucity of the area. The water requirement in these industries is very high compare to any other industries in the world. The area Maheshtala, Chatta, Kalikapur, Mahishgot lie in South 24 Parganas district of West Bengal (**Figures 1** and **2**) between 10.45^0 N latitude to 75.90^0 E longitude having more than 1400 small and tiny bleaching and dying units as per Economic Survey (2014), Govt. of West Bengal where groundwater table is shrinking day by day as per SWID, Govt. of West Bengal survey.

Figure 1.
Map of Maheshtala region.

Figure 2.
Map of Chatta Kalikapur.

2. Assessment of waste water quality

The overall mean concentrations of different physico-chemical parameters studied (pH, TDS, BOD, COD, NO3, hardness, Fe, F, Pb, Cd, Cr and Na) showed distinct seasonal trend in the following order of variation: pre-monsoon (April, May and June) > monsoon (July, August September and October) > post-monsoon (November, December, January and February) ($P < 0.05$). The physicochemical profile of waste water reflects that highest concentrations of both metals and organic loading are associated with the quantum and quality of bleaching and dyeing effluents released from the units studied. For the Maheshtala textile units the manufacturing processes like cutting and stitching activities of cloths start in the pre-monsoon season whereas the bleaching and dyeing processes starts in June continues till August stretching pre-monsoon to monsoon to meet the demand in festival season, which have significant implications in both metal and organic loading in the wastewater effluents. The present findings on high metal concentration and deteriorated physicochemical parameters are similar in other studies on textile industries waste water [1–3].

There appeared significant differences in metal concentrations in wastewater reflected in the following order: Na > Fe > Cr > Pb > Cd ($P < 0.05$). The metals in wastewater find their sources in the chemicals (like sodium hydrochlorides, sodium hydro-sulphites, optical brightening agent, caustic soda etc.) and dyes (mordant dyes, azo dyes, disperse dyes, vat dyes, indigo dyes etc.) used for the wet processing of textiles.

The heavy metal pollution index (HPI) for the wastewater studied is estimated as 926 which exceeds the critical level of 100 for drinking water as determined by Hakanson model [4] by about 9 folds. The study has shown similar HPI value for water of Jamuna river (near Delhi) obtained by [5, 6] following the same model (1492). Again the metal index (MI) in case of the studied wastewater is 4.68 which far exceeds than that of the threshold level of 1 for drinking water as prescribed by Hakanson model [4]. While assessing the water quality index (WQI) the results show that the wastewater poses severe potential ecological/health risk during all the seasons being maximum threat (WQI PRM-16) followed by (WQI M-19) and the minimum in post-monsoon (WQI PSM-31). According to Hakanson model (in the scale of 0–100) the present risk falls under the severe category in pre-monsoon and monsoon and critical in post monsoon with an annual average WQI being 22.

While comparing with the permissible limits for relevant parameters in case of wastewater discharge as per IS: 10500 (2012) it was observed that the values of the physico-chemical parameters and metals in the present study exceeded the respective limits.

All the physico-chemical parameters and metal concentrations in wastewater are very much higher than the permissible limits for drinking water of BS: 10500 (2012) and WHO (2003). These indicate that wastewater is critically contaminated compared to limits provided for drinking water. It finds conformity with observations of [7]. Due to higher level of TSS, TDS, BOD, COD and presence of very high concentrations of Pb, Fe and Na the wastewater becomes highly contaminated and often toxic, and there remains high chance of transfer of metals to soils and subsequently to crops, vegetables and fruits when irrigation contamination occurs due to advertent irrigation or inadvertent flooding of agricultural fields [8]. Wastewater also contaminates the water ways due to its direct discharge to the Chatta canal and damage aquatic ecosystem of canal, pond, watershed and ground water due to infiltration as shown by similar study conducted by [9].

Statistical correlation matrix shows that there is a significant positive correlation (r = 0.60) of Cd with TDS. Sodium has significant positive correlation with TSS (r = 0.78) and Fe (r = 0.56) and negative correlation with fluoride (r = −0.87).

3. Assessment of quality of canal water

The overall mean data of different physicochemical parameters of canal water indicate that TSS, TDS, BOD, COD, CaCO3, Na, Pb, Cd and Cr are higher than their permissible limits for drinking water prescribed by IS: 10500 (2012) and WHO (2003).

There appears a distinct seasonal trend in BOD, COD and metal concentrations in canal water in the following order of variation: PSM > M > PRM ($P < 0.05$). This finding can be explained by the fact that as the manufacturing as well as bleaching-dyeing activities become more intense during November and December to meet the demands of the Christmas and Ramjan festivals compared to the B and D activities in monsoon for meeting the demands of puja festive season the quantity of wastewater in the former becomes greater inclusive of its metal and organic load. Their concentrations fall during pre-monsoon due to reduced production and concomitant effluent discharge load.

There appeared significant differences in metal concentrations in canal water reflected in the following order: Na > Fe > Pb > Cr > Cd ($P < 0.05$). The metals in wastewater find their sources in the chemicals like sodium hydrochlorides, sodium hydro-sulphites, optical brightening agent, caustic soda etc. and dyes (mordant dyes, azo dyes, disperse dyes, vat dyes, indigo dyes etc.) used for the wet processing of textiles.

Further the overall mean values in mg/L of TSS (37), TDS (2150), BOD (60), COD (293), Na (669), metals (Pb, Cd and Cr) specify the canal water is very much contaminated similar to observations made by [10]. TDS in canal water appears due to presence of mostly dissolved inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates) and partly contributed by small amounts of organic matter dissolved in water [11].

The heavy metal pollution index (HPI) estimated for the canal water is 689 which has far exceeded (about 7 fold) the critical pollution value of 100 as per Hakanson model [4]. The metal index (MI) for canal water has been calculated as 6.90 which is about 7 times the critical pollution value considering all the metals present as per Hakanson model [4]. The water quality index (WQI) for canal water indicates that there appears potential ecological/health risk during PRM (49), M (39) and PSM (28) indicating severe water quality in pre-monsoon and monsoon, and critically deteriorated condition of water quality during post-monsoon season as per Hakanson model [4].

The high values of COD and BOD are attributed to the organic loading and oxidizable matter present in wasterwater discharged from the B&D units coming to the canal water and its mixing with the sewage coming from neighboring region. The very low level of dissolved oxygen (1.7 mg/L) is indicative of oxygen deficiency in the canal water which appears to be detrimental for sustenance of biota excepting a few indicator species [12]. During monsoon season as the canal overflows the canal water contaminates adjoining agricultural fields, it contaminates them due to presence of metals like Pb, Cd, Cr, Fe and Na. Such build-up of contaminants has serious adverse implications for severe contamination of the fields being almost agriculturally nonproductive; even the vegetables and fruits grown in selected residents of that area were found heavily laden with metals. The presence of total coliforms and fecal coliform indicates that the canal water was microbiologically contaminated, which may have their genesis from contamination of B&D wastewater with domestic sewage and fecal matters. The canal water can pollute the ground water due to presence of metals (Pb, Cd, Cr, Fe and Na) and inorganic chemicals due to long term infiltration [13]. These findings are similar in other studies on contamination of surface water due to textile industries [14–21].

The statistical correlation analyses show that COD has significant positive correlation with BOD (r = 0.98). Na has significant strong positive correlation with BOD (r = 0.91) and COD (r = 0.98) while Cr has positive correlation with Na (r = 0.47). Again nitrate has significant positive correlation with BOD (r = 0.91), Na (r = 0.73) and negative correlation with pH (r = −0.45).

4. Assessment of quality of soil

The overall mean data of different metals and chemical parameters of soil indicate that Pb, Cr, Cd, Zn, Fe, NO_3 are higher than the permissible limit of WHO (1996). The heavy metal concentrations in soil show the pattern in the following order: Zn > Pb > Cr > Fe > Cd ($P < 0.05$). These indicate that soil is contaminated with metals and not suitable for agricultural production [22]. The metal index for soil has been estimated as 336, which far exceeds the critical pollution value of 100 as per Hakanson model [4]. The soil quality index (SQI) indicates that it poses a potential ecological/health risk as reflected from its value (519), which is about five time the value of critical condition i.e. >100 due to presence of toxic metals. Among the metals highest ecologically risk is posed due to Cr and Pb followed by moderate risk from Zn and slight risk due to Cd. Considering the relative heavy metal concentrations in the canal water and soil the heavy metal concentration factors for different metals show the highest concentration in case of Cr (2325) followed by Pb (314) and Cd (44.24). Such metal concentrations in soil in course of time get transferred to vegetables and fruits grown in the locality and pose severe health risks to humans [23]. These results can be corroborated with the findings of several other studies [24–27]. Statistical correlations show that Cr is positively correlated with nitrate (NO3) (r = 0.57) while and F is negatively correlated with NO3 (r = −0.49).

Bleaching and dyeing units consume major quantities of water in textile industries, is the third largest user of water in the world. Wet processing is one of the major one in textile engineering. In all stages of wet processing large amount of water is used. Soft water is the major requirement of wet processing in textile industries for leading production quality.

5. Some important parameters of water for textile processing

5.1 pH

pH is the reference point of H+ ions concentration, its quantity indicates the quality of water,such as neutral, acidic or alkaline. .pH of neutral at 7, less than 7 indicates acidic and alkaline when above 7. The pH measurement scale is having value from 0 to 14.

5.2 Turbidity

Turbidity is reason by the scattering of light by suspended substance which may be organic or inorganic in universe. The turbidity of water is calculated against a standard solution having a standard turbidity value 1000 units.

5.3 Color

Color normally shows the presence of suspended and soluble matter, which affects the wet processing. The Hazen unit is the measurement of color of water and is comparing it with a color of a standard water solution. A colored Hazen unit is produced by liquefaction 1 ppm platinum in the form of chloroplatinic acid, in the impression of 2 ppm cobalt chloride.

5.4 Total dissolved solids (TDS)

TDS contain of small amounts of organic matter and inorganic salts that are change state in water. The TDS is calculated in ppm (Mg/L).

5.5 Total suspended solids (TSS)

The suspended solids are distinct particles which are not soluble in water. These can be separated by filtration and are also calibrated in ppm.

5.6 Acidity

Major natural waters are buffered by a HCO_3/CO_2 system. Carbon acid is not amply neutralized until a pH of 8.2 and will not depress pH below 4.5. CO_2 acidity is in the pH range of 8.2–4.5. The reason of mineral acidity caused in industrial waste having pH is below 4.5.

5.7 Alkalinity

The alkalinity is due to the existence of bicarbonates (HCO_3), carbonates or hydroxides. Alkalinity is separated into caustic alkalinity (above pH 8.2) and total alkalinity above pH 4.5.

6. Disadvantages of hard water in textile wet processing

Shade change caused due to formation of hard soaps with calcium and magnesium ions. Carbonates of calcium and magnesium precipitates iron (Fe) and aluminum (Al) black and essential cotton dyestuffs. Hard water creates dyes duller and even form scum. The metals Fe and Cu ion are known impurities, is a problem in the peroxide bleaching, Fe (iron) is responsible for reducing the brightness level of many dyes and is also objectionable in the washing off activities in wet processing.

Hard water is accountable for scaling in the boilers. When temporary hardness is high, the soft scales are formed in the boilers causing corrosion.

7. Tentative water quality parameters for wet processing in textiles

pH → in the scale 6.5–7.5.
TDS → 250–300 ppm.
Color → Hazen No. 4.5–5.5.
Residue on ignition → 245–250 ppm.
Total Hardness → 25–30 ppm.
COD → to be considered as nil.
Turbidity → to be considered as nil.

Suspended Solids → to be considered as nil.
Copper (Cu) → to be considered as 0.01 ppm.
Iron (Fe) → to be considered as 0.01 ppm.
Chromium (Cr) → to be considered as 0.01 ppm.
Manganese (Mn) → to be considered as 0.05 ppm.
Aluminum (Al) → to be considered as 0.2 ppm.
Chloride (HCl) → to be considered as 125–150 ppm.
Sulphate (H2SO4) → to be considered as 125–150 ppm.
Nitrite → to be considered as nil.

8. Membrane based filtration in wet processing

The membrane based filtration is increasingly being used in the manufacturing processes of various process industries. Filtration by membranes based technology is considered as a profitable one than other types of traditional methods now a days. Their capacity to separate impurities and specific natural essences at low or ambient temperatures makes more usable. The selection of membrane is an important constituent for better functioning and optimum result of the process. There are many types of membrane that adapt to different use according to the level of filtration required. Ceramic membranes, spiral membranes, tubular membranes, stainless steel membranes, hollow fiber membranes and plate and frame membranes are the most common ones. Generally, filtration by membranes is a pressure technology that is utilized to separate various contaminated liquids. Its different types are ultrafiltration, microfiltration, nanofiltration and reverse osmosis.

Reverse osmosis is the processes of treatment of residual liquids particularly appropriate to dehydration, concentration/separation of substances. It is very helpful for the concentration of dissolved or suspended solids on the one hand and for obtaining a rejected liquid that comprise of a very low concentration of dissolved solids on the other hand.

Ultrafiltration is a process of exclusive division that is normally used to separate milk, whey and proteins. It paradigm suspended solids and solutes with a molecular weight of greater than 1000. The rejected liquid contains organic solutes having low molecular weight and salt.

Application of nanofiltration is normally work for demineralization, desalinization and also for color removal.

Microfiltration is a low pressure based flow through a membrane for the separation of colloids and suspended particles in the range of 0.05–10 microns. For the clarification of stock, fermentations and the clarification and recuperation of biomass, membrane based microfiltration is used.

9. Applications in industrial activities

Membrane based filtration is applied to various number of chemical processes industries. Filtration by membrane is very useful for food industries, specially in the dairy and sugar, pharmaceutical, biotechnological and chemical industries.

The utilization of various filtrations by membrane techniques in the food industries sets an infinite number of areas. The most popular include the concentration of egg whites, the elucidation and pre-concentration of various fruit juices, the concentration and natural process of the ashes of porcine, bovine or bone gelatin, the clarification of meat brine for the re-motion of bacteria and reprocess of the brine, the spatial arrangement of vegetable and plants such as canola, soy and oats and the separation of alcohol from wine and beer.

Dairy industry: In the manufacture of dairy ingredients, filtration by membrane is a valuable part of the production process. Its work can be divided into three major categories such as applications to milk, clarified cheese brine and whey.

Starch and sweetener industry: the main gain is the increase in the quality of the products, including the manufacturing and quality of corn syrups such as dextrose and fructose, the separation and property of rinse water from starch, the enhancement sub-product of dextrose, the depyrogenation of dextrose syrup and the division/application of maceration water.

Sugar industry: filtration by membrane can be used to purify unprocessed juice without using primary clarifiers, thus obviate many ambient problems and rising the quality and the execution of other traditional methods. The membranes can also purify, separate and concentrate various sugar solutions in the production activities and processes.

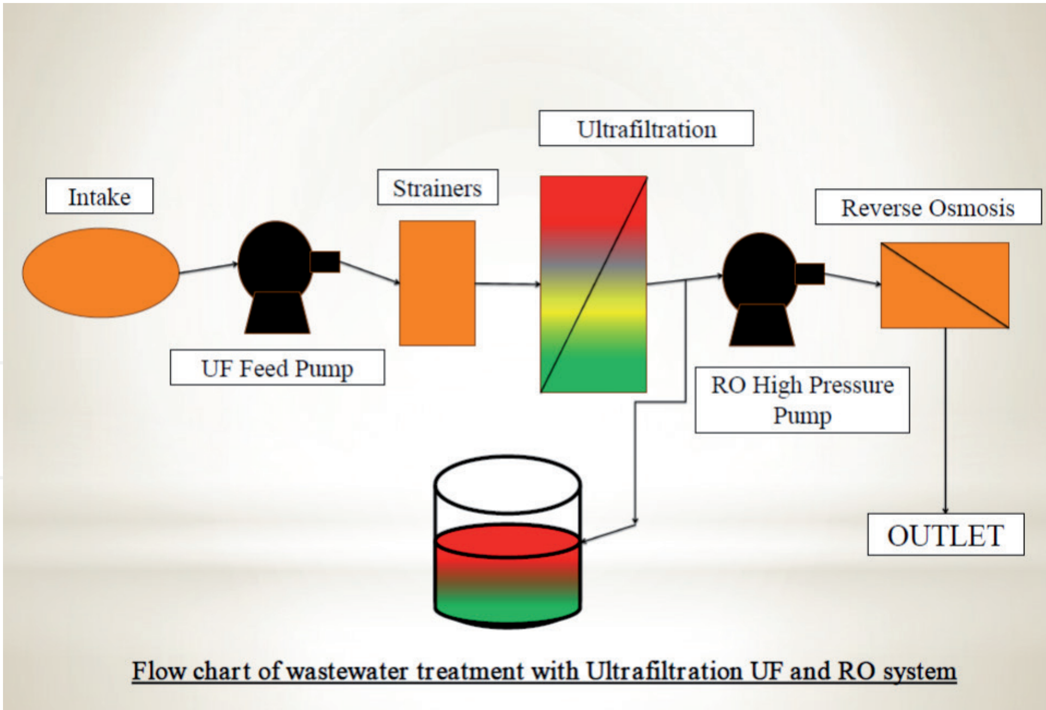
Chemical industry: many chemical processes use filtration by membrane. It works to desalinate, diafilter and purify dyes, pigments and optical brighteners. Filtration is also use to clean the waste water and rinse water currents. During the concentration and dehydration of minerals such as kaolin clay, titanium dioxide and calcium carbonate, during the clarification of caustic agents, the production of polymers or the recuperation of metals membrane based filtration process is used.

Pharmaceutical industry: the gathering of cells or the recovery of biomass is an essential part in the manufacturing process of fermentation, especially when manufacturing products such as antibiotics. Filtration process improves production as well as loss of the operator's workload and the maintenance reimbursement/cost. The membranes' filtration are also a standard part of the industrial manufacturing lines for enzymes, when concentrating enzymes prior to other processes.

Textile industry: many textile production processes exercise filtration by membrane to diafilter and purify dyes, desalinate, pigments and optical brighteners. It also uses to clean the waste water and rinse water currents, again for the concentration and dehydration of minerals such as titanium dioxide and calcium carbonate, the clarification of caustic agents, the manufacturing of polymers or the recovery of toxic metals such as Pb, Cr, Cu, etc.

10. Method

Samples were collected from different units in the study area at regular intervals during 2012–2013. Samples brought to the laboratory where they were analyzed using the standard method defined and suggested by American Public health Association (APHA, 1998). Temperature and pH were calculated by a mercury thermometer having scale from 0–100°C and with digital movable pH meter respectively at site. Total dissolved solids (TDS), dissolved oxygen (DO), salinity and turbidity were ascertained by Water Quality Analyzer PE- 371 (Systronic). Alkalinity of samples was calibrated by titrametric method. For analysis of COD, samples were stabilized by acidifying with H_2SO_4 below 2 and it was evaluated by dichromate titration method (APHA, 1998). The concentration of nitrate in the samples was ascertained by UV spectro photometric screening method with Zuconyl indicator. Sodium, potassium and calcium were calculated by Flame-photometric method. Heavy metal samples were analyzed after filtration by Whatman filter–paper no. 40 and then acidified samples were digested with concentrated HNO_3 (0.1%) acid. The metal ions were determined by atomic absorption spectrophotometer (OMA 300 process analyzer).



11. Results and discussion

The value of pH indicates the effluent before treatment is alkaline, substantial chemicals and dyes in solid form available in TDS, and trace metal concentration indicates that the raw effluent is hazardous for ecological systems in the region and required immediate treatment. The physicochemical parameters of wastewater generated from the bleaching and dyeing units after primary treatment found under limits as pH (7.7), BOD (20 mg/L), COD (120 mg/L), TDS (2234 mg/L), TSS (22 mg/L) by WHO (2003) and FAO (1985) [28–31] and trace

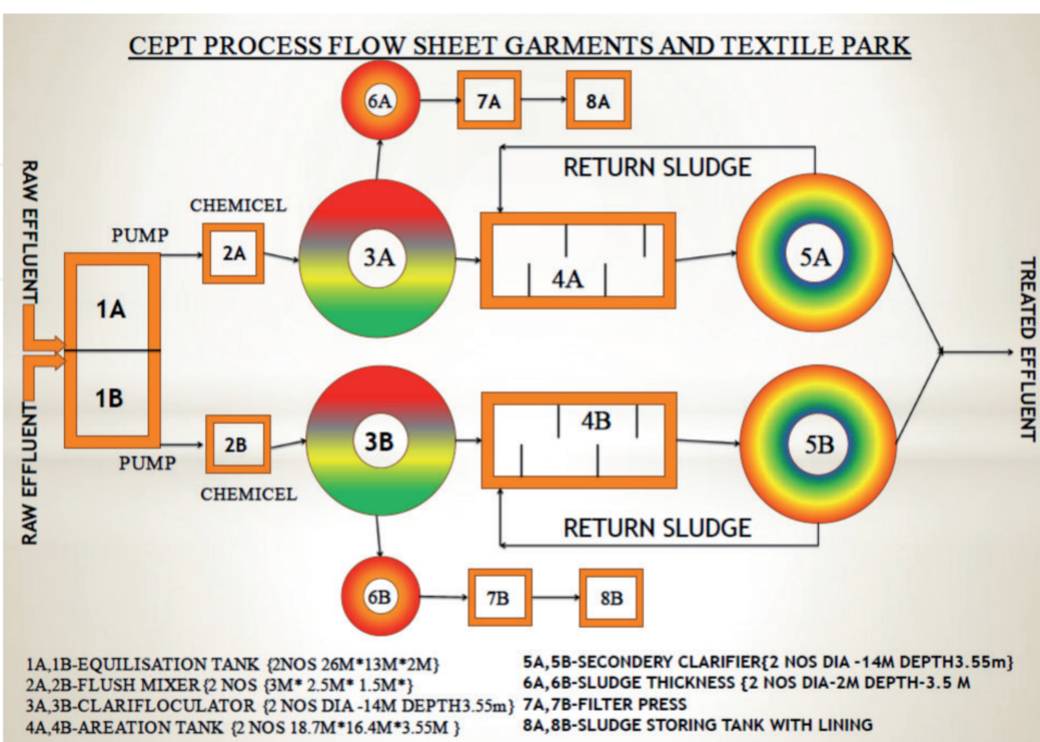


Figure 3.
CEPT PROSS flow chart: 500 MLD capacity.

Sr.no.	Parameters	Feed[a]	Permeate from	Concentrate from	Reverse osmosis
Ultrafiltration				Reverse osmosis	
1	Appearance	Clear	Clear	Clear	Muddy
2	pH	7.7.	7.7	6.0	7.8
3	Alkalinity	345(±15.2)	325(±14.1)	12(±1.4)	1100(±51.7)
4	Suspended solids	22(±1.6)	ND	ND	ND
5	Total dissolved solids	2234(±57.7)	2196 (±53.0)	40(±1.8)	7584(±195.4)
6	COD	120(±1.6)	20(±1.2)	ND	68(±2.3)
7	BOD	20(±1.2)	3(±1.2)	ND	11(±1.2)
8	Total Kjeldahl nitrogen	ND	ND	ND	ND
9	Phosphate	1.1(±0.08)	0.066(±0.05)	ND	0.22 (±0.06)
10	Sulphides	1.6(±0.20)	ND	ND	ND
11	Oil and grease	1.4(±0.20)	<1(±0.1)	ND	3.3(±0.40)
12	Chlorides	494(±29.1)	483(±28.4)	12(±0.80)	1653(±97.8)
13	Calcium	330(±11.1)	325(±11.0)	3(±1.1)	1125(±112.90)
14	Magnesium	164(±14.6)	143(±12.7)	2(±0.60)	493(±42.5)
15	Sulphate	350(±37.0)	307(±32.7)	ND	1070(±114.1)
16	Sodium	289(±14.0)	264(±12.9)	3(±0.9)	917(±122.9)
17	Potassium	15(±2.00)	<1(±0.20)	<1(±0.20)	1(±0.200)

All values are expressed in mg/L except pH; values in parenthesis are standard deviation; ND: not detectable.
[a]Tertiary treated effluent from feed tank of ATP, Source: Nandy et al. [32].

Table 1.
Efficacy assessment of advance treatment processes (ATP) after primary treatment.

metals Pb (0.33 mg/L), Cr (0.021 mg/L), Zn (0.54 mg/L), Ni (0.00 mg/L) and Cd (0.02 mg/L) will be cleaned after membrane based advance treatment processes (ATP) (**Figure 3** and **Table 1**).

The Common Effluent Treatment Plant (CETP) in Maheshtala cluster with advanced method of treatment containing of primary, secondary treatment, ultra-filtration and membrane based reverse osmosis, comparatively energy-efficient membrane based crystallization and distillation units and evaporation would yield premier quality water maintaining the qualifying standards of Central Pollution Control Board, New Delhi, India for industrial areas/clusters [33].

12. Conclusion

The CETP plants can thus save surface and ground water from depletion and degradation. Transfer of contaminants to agri-horticulture produces through the food chain would be curtailed and thus human health risk would be minimized. The entire treatment and reusing of treated water will help to preserve 2000 MLD groundwater in the cluster area to save water and save life as the entire world is moving towards water paucity due to climate change.

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Conflict of interest

The author does not have any types of financial and non-financial conflict of interest with any other person.

Abbreviation

APHA	American Public Health Association (1998). Standard methods for the examination of water and wastewater, WEF and AWWA, 20 th edition, USA
CPCB	Central Pollution Control Board (2007). Advance method of treatment of textile effluent
FAO	Food and Agriculture Organization, (1985). FAO guidelines of water quality for agriculture, Ministry of environment and forest, New Delhi
WHO	World Health Organization, (2003), Standard for quality of water for irrigation purpose
SWID	State water Investigation Department, Government of West Bengal

Author details

Biman Gati Gupta
Civil Engineering Department, Elitte College of Engineering (B. Tech), India

*Address all correspondence to: bimangupta@yahoo.in; civil.ece@petindia.com

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