Wastewater Allocation and Pricing Model for the Efficient Functioning of CETP Serving a Textile Industrial Cluster

Bhoomi Shah, Deepak Chaurasia, and Ajit Pratap Singh

Abstract Textile industry produces a quarter of the global industrial wastewater effluent, and most of the pollutants get added in the dyeing and printing processes of fabric production. Due to improper disposal and non-stringent policies, there is visible pollution of river bodies, degraded environmental flows and groundwater contamination. Since the cost of treatment to acceptable quality standards is high, industries operate by using cheaper water sources like lifting groundwater or bypassing the common effluent treatment plants (CETPs). Also, industries with small-scale production cannot bear the high cost levied on them by the authorities to recover the collective cost incurred by CETP. Thus, it is necessary to ensure that discharge and concentration of effluent sent to CETP by member industries are manageable, and industries pay as per their effluent quality and quantity. In this study, for the textile industrial cluster in Balotra, Rajasthan, in India, the zero liquid discharge (ZLD) technique has been proposed. Subsequently, the optimal allocation of effluent discharges for member industries in study region has been formulated. Using the industrial outflow data obtained from government agreements, the optimization relation between concentration, flow and cost has been implemented. The result obtained is the number of industries and their full or fractional wastewater share depending upon the value of fractional allocation (25, 33, 50, 66, 75 or 78%). This study can serve as an alternative to the existing ad hoc method of taxing member industries for wastewater treatment and lead to a win–win situation for industries, CETPs and the environment.

Keywords Textile industry · Wastewater · ZLD · Fractional allocation

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1 Introduction

Indian textile industry is the second largest in the world being the main producer of cotton, staple fibre and filament yarn. In ‘processing mills’, grey cloth is converted into fabric products by bleaching, mercerizing, dyeing, printing and washing. This is a water-intensive industrial sector since these mills consume 60–80% of total water used for cloth production. The World Bank estimates that almost 20% of global industrial water pollution originates from the treatment and dyeing of textiles. Not all the hazardous chemicals that are used in printing remain on the final fabric but get drained through the effluent discharged from the production factory into nearby river bodies and municipal sewers. Improper disposal of wastewater from textile industries due to inefficient treatment facilities and high cost of compliance to the treatment standards has largely contributed to the pollution of water bodies. This is observed mainly in the dyeing mills of Tamil Nadu, Rajasthan, Uttar Pradesh, Punjab, Gujarat and Maharashtra. To address this issue, the Union Ministry of Environment, Forest and Climate Change (MoEF&CC) [1] proposed the implementation of zero liquid discharge (ZLD) scheme, shown in Fig. 3. The non-uniformity in enforcement of ZLD scheme and the cost of groundwater extraction being cheaper than the salt recovery process of ZLD have led industries to find ways to escape the government regulations.

Rajasthan has emerged as a pre-eminent centre for the domestic textile industry covering the entire production chain, from spun yarn up to finished garments. At present, there are about 5000 composite and processing mills in Rajasthan. Rivers in Rajasthan are non-perennial and receive all kinds of pollutants annually. The ground water is also depleting alarmingly due to over-exploitation, population growth and pollution. This combined problem of water scarcity and pollution cannot be managed just by conventional treatment methods, i.e. physico-chemical and biological treatment. Therefore, there is a need to go beyond ‘treatment for disposal’ towards ‘treatment for reuse’. Zero liquid discharge (ZLD) is the way forward, and its adoption is becoming essential rather than an imposition. Though the initial cost of ZLD is high, but it can be offset by framing right policies. About a year ago, the major processing units in the state stared at the dire consequence of shutting down due to the environmental degradation they created. Finding a solution was urgent to create a win–win situation for all stakeholders—industries, investors, authorities and habitants.

2 Methodology

Keeping in view of above facts, this study presents a framework to address wastewater management issues, shown in flow chart in Fig. 2. The study objectives are as follows:

1. Identification of existing problems in wastewater management in study region
2. Case study of ZLD implementation: Tiruppur Industrial cluster

3. Optimal share of wastewater discharge of member industries to CETP
4. Pricing mechanism based on concentration and flow of effluent from industries
5. Application in study region to demonstrate the methodology.

2.1 Identification of Existing Problems in Study Region

Our study region is the industrial cluster in Balotra city in Barmer district of Rajasthan, as shown in Fig. 1. There are 1500 cotton and synthetic cloth dyeing and printing units which release about 100 million litres of partially treated effluent per day into the Luni river [2]. The Balotra CETP serving the micro, small and medium enterprises (MSME) textile industrial cluster comprises 403 member industries carrying out dying and printing activities. During the initial visits, the following pollution-related problems were noticed [3]. Wastewater discharges from industries and CETP into Luni river, ad hoc method of wastewater allocation in which all member industries are permitted to send only an arbitrarily decided percentage of their total effluent to CETP irrespective of their size, smaller member industries bypass CETP and illegally discharge into nearby agricultural areas, leaching of untreated effluents causing contamination of underground wells and aquifers in the surrounding villages.

Fig. 1 Google map showing location of Balotra industrial cluster and the Luni river

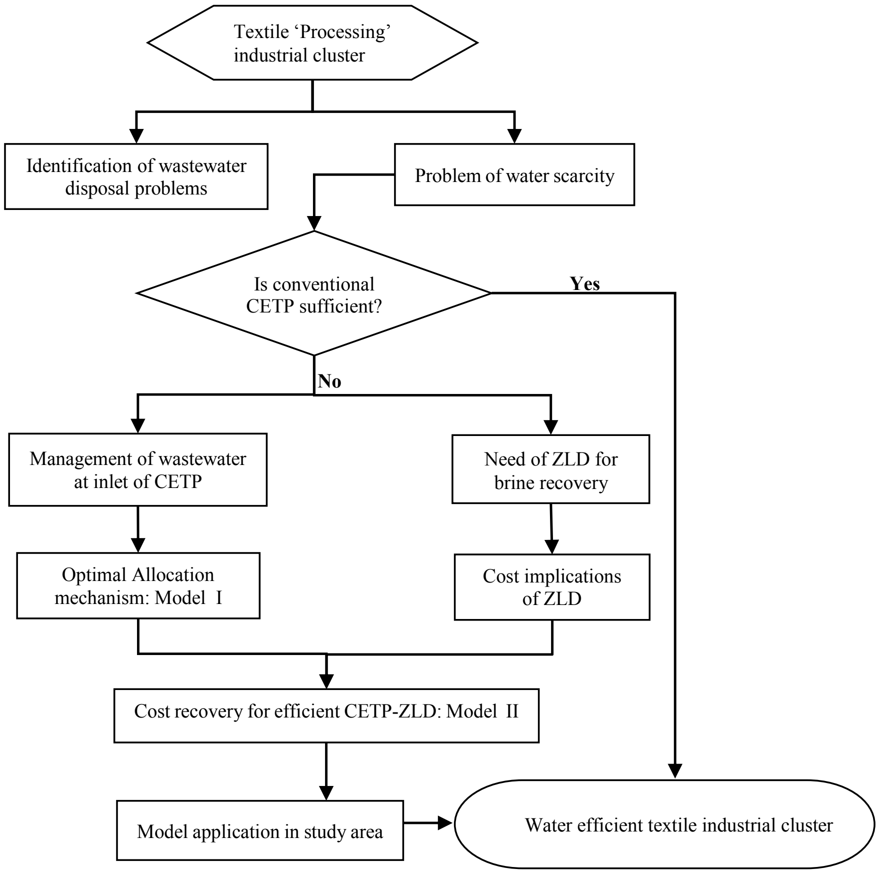

Fig. 2 Flow chart of methodology addressing environmental and operational concerns of CETP

2.2 Case Study of ZLD Implementation: Tiruppur Cluster, Tamil Nadu

ZLD refers to installation of facilities in a system which will enable recycling of permeate of membrane separation process of CETP and convert the solute of dissolved organics and inorganics into solid residue [4]. It can be achieved by adopting primary, secondary and tertiary treatment processes and polishing by filtration and sending treated water back into the process or domestic reuse (Fig. 3). The treated water is recovered from the membrane processes such as ultra-filtration (UF), nano-filtration (NF) and reverse osmosis (RO) during tertiary treatment phase, and salt is then recovered by increasing solid concentration in mechanical vapour recompressor (MVR) and then using multiple effect evaporation (MEE) with crystallization [5]. Ahirrao remarked [6] that the pollution arising from colour and high TDS brine

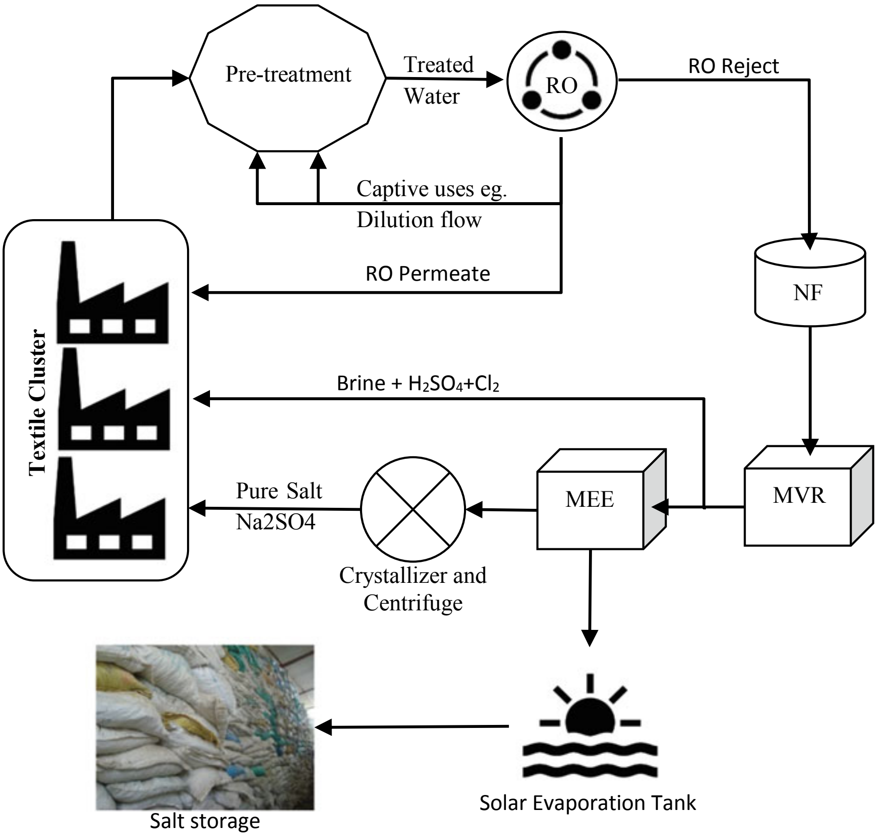

Fig. 3 Schematic diagram of unit operations and processes in ZLD treatment with proposed network for dilution flow

in the wastewater is solved by the ZLD technique of selective crystallization and recovery of Glauber's salt and mixed salt which can reused in dyeing process.

In Tiruppur industrial cluster, there were 760 dyeing units which discharged their treated effluent through CETPs into the Noyyal river till 1997. This conventionally treated effluent contained high TDS (900–6600 mg/l) and chloride (230–2700 mg/l) and did not meet prescribed quality standards. These pollutants containing heavy metals of chromium, copper, zinc and lead got accumulated 32 km downstream in the Orathupalayam dam reservoir. This prompted the High Court to direct the dyeing units to adopt ZLD concept for RO reject management in 2006 [4]. Currently, 450 textile units have collectively set up 20 CETPs while 150 units have their own individual effluent treatment plants (IETPs). The rest of the units is shifted to Karnataka where there are no such norms. The capital cost of ETP with ZLD facilities is around Rs. 12.0–15.0 crores per MLD, operation and maintenance (O&M) cost is Rs 3000–5000, and energy consumption cost is 50% of total O&M cost. Thus, the treated and recycled water costs approximately Rs. 120–150/cum, while the cost of water extraction from the ground or from the municipality would be between Rs. 30 and Rs. 60/cum [7]. So, to avoid migration of factories to areas where ZLD norms are not stringent, a uniform policy across different regions in India is key to the widespread adoption of ZLD if industries are to stay competitive in textile market.

2.3 Mathematical Model Formulation

A rational approach of wastewater allocation that provides the benefit of economies of scale to smaller member industries is proposed in part I model. In part II model, treatment cost recovery from the members is proposed considering both wastewater flow and concentration at CETP inlet. Treatment cost is inclusive of ZLD cost, which is arrived at from the literature review. It is assumed the all industries operate during the same hours in a day.

Part I: Wastewater Allocation Optimization Model
Let n be the number of member units served by a CETP. Then, as per the existing practice, effluent flow from industries to CETP can be expressed as follows:

$$Q = \frac{\sum_1^n r * q_i}{100} = \frac{r}{100} * \sum_1^n q_i \le Q_0 \quad (1)$$

where r is the arbitrary allocation percentage as per ad hoc method, q_i is the effluent flow of ith industry, Q is the total inlet flow, and Q_o is the operating capacity of CETP.

Our aim is to find the optimum effluent allocations (${q_i}^*$'s) such that smaller players (x in number, $1 \le x \le n$) are allowed to release effluent at their full potential, whereas rest of the members (n–x) are allowed to release certain fraction f ($0 < f \le 1$) of their full potential. Thus, the objective to maximize value of x and subsequently obtain q_x is as follows:

Max x, subject to

$$\sum_{i=1}^{x} q_i + f * \sum_{i=x+1}^{n} q_i = \sum_{i=1}^{n} q_i = Q \le Q_0, q_i \le q_{i+1} \quad (2)$$

Solution of above fractional allocation optimization can be obtained by following a stepwise procedure as shown in Fig. 4.

The optimum allocation of ith industry ${q_i}^*$ will be as follows:

$$q_i^* = \begin{cases} q_i; 1 \le i \le x \\ f * q_i; x + 1 \le i \le n \end{cases} \quad (3)$$

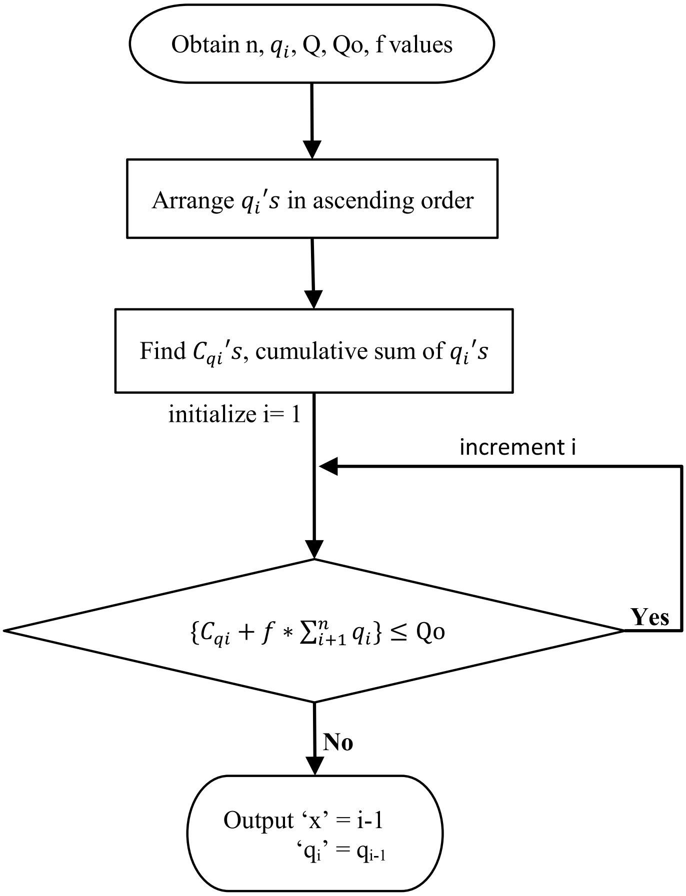

Fig. 4 Flow chart showing algorithm for finding the solution of fractional allocation equation (where, n = industries, q_i = flow of ith industry, Q = total input at CETP, Q_o = design capacity of CETP, f = percentage of fractunal allocation)

Part II: Pricing Model for CETP Based on Flow and Concentration

Following conditions shown in Table 1 can exist between cost, concentration and flow.

where C_o = input design concentration of CETP; C, Q = inputs to CETP at any time, C_{mix} = combined concentration at CETP inlet, q_i = flow of ith industry, c_i = effluent concentration of ith industry, Q_d = dilution flow = $Q_d = \frac{C*Q_o^*}{C_o} - Q_o^*$, k = normal cost factor (Rs/kl), p = penalty cost factor (Rs/kl).

Table 1 Four possible conditions at CETP inlet and associated cost

Sr	Influent conditions	Cost	Remarks
1	If $C \leq C_o$ and $Q \leq Q_o$	$k \bullet Q$	Normal CETP operation cost
2	If $C \leq C_o$ and $Q \geq Q_o$	$k.Q_o$	Individual $q_i's$ checked against the $q_i^{*\prime}s$ and violators are identified. To manage the excess flow (Q-Q_o), each industry will have to store flow equal to $(q_i^* - q_i)$
3	If $C \geq C_o$ and $Q \leq Q_o$	$k \bullet Q + p \bullet Q_d$	Individual $c_i's$ checked against C_o, and penalty will be levied on violators in proportion to $c_i - C_o$ CETP will provide additional dilution flow Q_d such that, $Q_{mix} = Q + Q_d$, $C_{mix} = C_o$ and excess flow, $Q_{mix} - Q_o$ will be managed by CETP
4	If $C \geq C_o$ and $Q \geq Q_o$	$k \bullet Q_o + p \bullet Q_d$	Combined application of condition 2 and 3. Q_d with concentration C_o will be managed by CETP

3 Results and Discussion

Model Part I Application

For Balotra CETP, the values of variables are as follows: $n = 403$, $Q = 15.34$ MLD, $Q_o = 12$ MLD, $Q_D = 18$ MLD, $f = 0.75$, q_i values were obtained from Balotra CETP authorities. The result is 187 industries, generating wastewater below 18KLD shown in Fig. 5b, will be permitted to send discharge at full potential, while the remaining 216 industries will be permitted to send 75% of their full potential as shown Fig. 5a.

Model Part II Application

The value of k is Rs. 200/kl [7]. Value of p consists of two components, one the treatment component (=k) and other is the storage component corresponding to

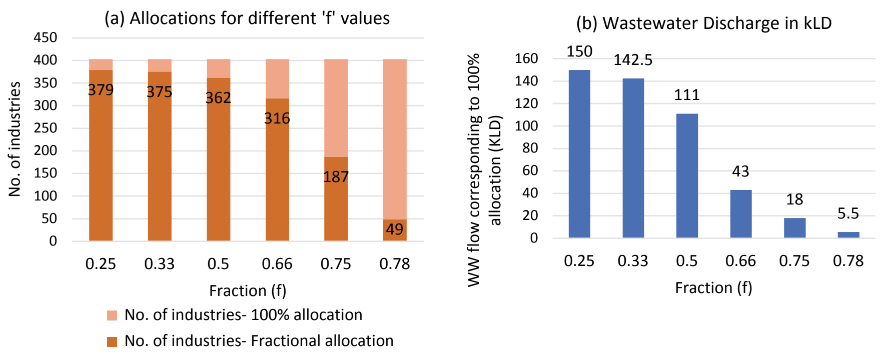

Fig. 5 Graphical representation for different f values **a** no. of industries given full allocation and **b** corresponding wastewater flow

(Q_{mix}–Q_o). Storage cost corresponding to this value can be taken as Rs. 50/kl, so that p = Rs. 250/kl. The Balotra CETP design concentration for COD parameter alone was taken, i.e. $C_o = 2200$ mg/l. For example, Industry PI-3 had sent 172.5 kld of effluent at 2349 mg/l COD concentration. Firstly, the allocated flow for PI-3 is 129.4 kld after applying model I, therefore the industry will be allowed to send only 129.4 kld to CETP, and the remaining 43.1 kld must be stored by the industry itself. As c_i–C_o = 149 mg/l, it violates condition 4 of Table 1. Q_d = 809 kld. Thus, PI-3 will incur per day penalty cost of Rs. 250 × 809 = Rs. 202,250, in addition to the normal ZLD treatment cost of Rs. 34,500 at Rs 200/kl.

4 Conclusion

ZLD is an 'end-of-pipe' concept to mitigate the impact of wastewater pollution on the environment. The cost of the treated water recovered in the process is always higher than the cost of freshwater used from other. The use of technologically advanced equipment will reduce the cost of operation in ZLD. Consent to operate (CTO) must be given to industries on environmental grounds rather than net production of textiles. Although ZLD is a capital-intensive prospect, but its implementation will give beneficial results in longer run and the spillover effect on the environment will be nil. By using ZLD, there will be no impact on surrounding soil salinity, no groundwater pollution. Also, compliance with stringent legislative and environmental regulations can be achieved. The conservation of water resources through recovery and reuse of treated effluent and salt are the aim of ZLD. In a nutshell, the industrial water cycle is optimized, and a consistency of water supply and quality can be achieved.

References

1. MOEF&CC Notification (2016) Part II, Section 3, Sub-section (i), Environmental Protection (Protection) Fifth Amendment Rules. Ministry of Environment, Forest and Climate Change (MOEF&CC)
2. Mishra P, Soni R (2016) Analysis of dyeing and printing wastewater of Balotara textile industries. Int J Chem Sci 14(4):1929–1938
3. Singh AP (2018) Status report on CETPs, STPs and industrial pollution in Jojari River (Jodhpur to Balotra, Rajasthan). National Green Tribunal (NGT), New Delhi order dated 16.03.2018
4. CPCB (2015) Guidelines on techno—economic feasibility of implementation of zero liquid discharge (ZLD) for water polluting industries, central pollution control board (CPCB). MOEF, Govt. of India, New Delhi
5. CPCB (2014–15) Report on assessment of pollution from textile dyeing units in Tirupur, Tamil Nadu and measures taken to achieve zero liquid discharge. MOEF, Bengaluru
6. Ahirrao S (2014) Zero liquid discharge solutions. In: Industrial wastewater treatment, recycling and reuse, 489–520
7. Sustainabilityoutlook (2015) Market outlook zero liquid discharge in indian industry, article in Sustainability Outlook magazine. Retrieved from https://www.sustainabilityoutlook.in/content/market-outlook-zero-liquid-discharge-zld-indian-industry-755285 on 07.08.2019