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Sustainable Concept of Zero-Liquid Discharge and Its Impact on Climate Change: Detail Case Studies

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Abstract: In the developed world's metropolitan areas, proper wastewater treatment and recycling are of the utmost importance. Releasing wastewater into aquatic systems is the biggest environmental risk and the biggest barrier to wastewater regeneration and reuse. The origin of the wastewater also has an impact on its potential for reuse. There are three separate processes at work in the universe: the physical, the chemical, and the biological. The study examines the challenges associated with wastewater consumption, as well as wastewater treatment, reuse, and repurposing. One of the most compelling arguments for exploring the possibility of zero liquid discharge is the possibility of energy recovery from wastewater. Manufacturing operations that aim for Zero Liquid Discharge (ZLD) may recycle or reuse the solid waste they produce. ZLD system design is becoming more popular. To be sure, current ZLD systems have their drawbacks, the most notable of which are the high plant costs and high energy intensity of their crystallizers. Because of the growing public and media awareness of the consequences of wastewater pollution, stricter environmental restrictions are expected to push more polluting businesses onto ZLD. Moreover, climate plays such a significant role in the wastewater treatment plant; climate change may have far-reaching implications on the drainage system.

Keywords: Adsorption process; Social acceptance; Wastewater disposal; Wastewater reuse.

Introduction

Nature has endowed us with vast oceans, countless rivers, breathtaking waterfalls, and a plethora of lakes. Unfortunately, all of these sources of water are being contaminated as a result of waste from huge manufacturing sectors and urbanisation. As a result, water contamination has wreaked havoc on the lives of ordinary people. In response to this environmental issue, the 'Zero Liquid Discharge (ZLD) concept' has been implemented, with the goal of reusing wastewater by converting it to pure water. Water shortages and contamination have drawn a lot of interest to zero-liquid discharge (An). While it may serve an immediate function in wastewater remediation, discharging treated effluents into water bodies or centralised effluent treatment plants does not prevent the long-term outcome of pollutant buildup. In order to recover, reuse, and reclaim wastewater, current wastewater treatment practises will need to be changed (Date et al., 2022). However, as wonderful as the notion may seem, its economics have been a key obstacle in its adoption in certain underdeveloped nations where rules are insufficiently stringent (Kumar and Chanda, 2021). Water, as a natural resource and super solvent, is the most natural blessing of the world to humanity, however, day by day it is becoming poisoned, largely because of human interventions. In the form wastewater, it must be treated properly by recycling and for reusing, thus, encouraging improved management of water resources.

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Washing water supplies from washing machines, kitchen sinks, etc. may be reused after the proper treatment. Some drainage contains toxic pollutants and contaminants, while others contain all sizes of particulate matter, sediments and suspended matter. Agriculture consumes between 69% and 90% of the world's use of freshwater (irrigation, water, and cleaning of livestock, aquaculture), with the bulk being replaced by soil, wetlands, or released by additional nutrients and pollutants. Zero Liquid Discharge, or ZLD, systems are a treatment method that can be used to recover vital resources after they have been used (Panagopoulos, 2022). Effluent treatment factories are the last option before pollutants get released from industrial effluents. A critical wastewater management approach for addressing freshwater scarcity is ZLD, which improves water retrieval while minimising ecological effects. However, due to the higher concentrations of salts and foul in wastewater, a significant hurdle for ZLD is the absence of a viable membrane created desalination techniques that allow straight wastewater retrieval without expensive pre-treatment processes (Plósz et al., 2009; Campos et al., 2016; Vanitha et al., 2018; Mohan et al., 2020; Rathoure, 2020; Fayez et al., 2020; James et al., 2021; Xie et al., 2021; Zhang et al., 2021).

Zero Liquid Discharge

Zero Liquid Discharge (ZLD) is a water management engineering solution that recovers all water and reduces pollutants to solid waste. Although many water processes want to optimise freshwater recovery and reduce wastes, ZLD is the most challenging goal, as wastewater is more concentrated and the costs and complexities of recuperation increase. Treatment of waterusing reverse osmosis concentrate (ROC) is currently one of the most promising techniques for its disposal. This is due to the fact that it produces freshwater with high recovery as well as valuable materials such as salts, and it also reduces waste volume as well as environmental pollution. Water-polluting businesses have been driven toward zero-liquid discharge as a result of increased public attention to the severe repercussions of water pollution as well as rigorous environmental rules on wastewater discharge (ZLD). Scaling and fouling difficulties, however, increase energy consumption and limit permeate flux at high salt concentrations. This is mostly caused by calcium, magnesium, and silica precipitation, which ultimately leads to a reduction in ZLD performance. In addition, developing technologies are capable of effectively removing scale-forming ions, albeit at the expense of large capital and operating expenditures. Despite the fact that ZLD efficiency has increased because of novel adaptations of conventional reverse osmosis technology, scale and fouling continue to be a challenge (Yaqub et al., 2022). The concentration of salinity, scaling compounds and organics increases, adding costs for handling these increases. ZLD is accomplished by the combination of wastewater treatment technology to treat the concentration of toxins. A zero liquid discharge facility (ZLD) is an industrial factory that does not discharge wastewater. There has been a rise in interest in the development of ZLD (zero-liquid-discharge) system designs (Chen et al., 2021). A typical ZLD has been shown in Figure 1, such technologies involve industrial wastewater pre-treatment and evaporation till the dissolved solids form crystals. These crystals are dewatered and removed. The vapour obtained through evaporation is condensed and re-engineered. Certain methods may recover useful materials, such as ammonium sulfate or sodium chloride salt. The expertise of the Verkh-Isetsky steel plant in Sverdlovsk is valuable for the design of ZLD industrial wastewater treatment systems of the metallurgical, machinery and metalworking industries, especially in connection to industrial wastewater treatment and sludge processing. The proposals for organizing ZLD industrial wastewater treatment systems in pickling facilities with the recurrent use of processed rinse water and processing the wasted pickling solutions and sludges are examined (Anastasios et al., 2015; Zouboulis et al., 2015; Tolkou et al., 2016; Muhammad and Wontae, 2019; Aksenov et al., 2020; Anil et al., 2020; Qasim et al., 2021; Christian et al., 2021; Qian et al., 2021).

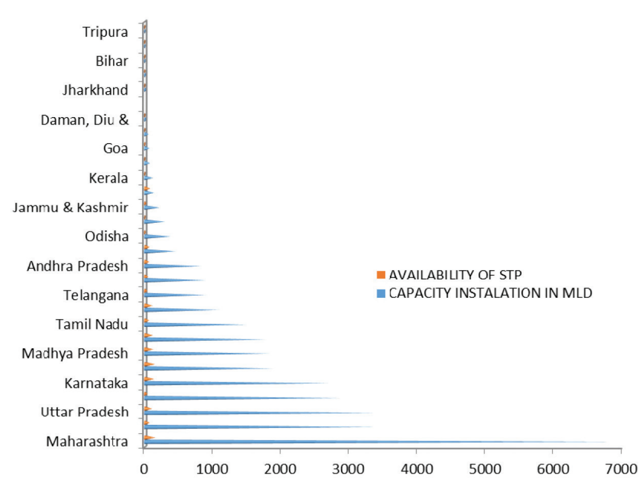

Figure 1: State zone capacity installation and availability in India.

Importance of Proper Liquid Waste Disposal

(a) Environmental safeguard: Improper disposal of liquid waste can cause severe damage to the environment. The equilibrium of underwater environments may be disrupted and marine animals killed. Or it can penetrate the ground, kill trees, damage natural environments and cause loss of biodiversity.

(b) Human health security: If waste fluids leak, pour out or drain over the ground, the groundwater and the source of surface water used for drinking can be contaminated. If pollutants are removed by treatment with plant filters, the person may ingest them, and depending on the waste composition, they may develop stomach diseases, heavy metal toxicity or other serious conditions.

(c) Aesthetic concerns: Improper liquid waste disposal can give an unpleasant smell to the disposal environment. Even if it does not actively harm residents, its everyday practices will make it more disagreeable and lead to complaints. Right disposal of wastes will be helpful to maintain good ties with neighbours, who will be happy to contribute to the quality of the air they enjoy (Reznik et al., 2020; Dickin et al., 2020).

Case Study on Wastewater Discharge Policies and Guidelines

(a) The European Union: European regulation would protect a wide variety of diverse environmental sensitivities in different geographic regions. The first goal was the collection and treatment of wastewater, with a focus on wastewater from more than 2,000 "agglomerations," equivalent population (PE). PE is used as a metric since it permits the use of traditional European combining sewage systems in the handling of surface rinse, household, commercial and industrial mixtures. In 1991, the Directive on Urban Wastewater Treatment laid out this regulatory framework (UWWTD). The UWWTD forbids decentralised networks from being used inside population centres (>2000 PE). However, the Directive contains the following advisory: "If establishing a collection scheme is either not justified because it does not yield an environmental advantage or because it would require over cost, it is necessary to employ individual systems or other relevant systems that achieve the same degree of environmental security."

(b) Germany: Among other things, the Ordinance on Requirements for Wastewater Discharge to Waters (AbwV), the Federal Water Act (WHG), and other binding EU legislation are the most relevant national wastewater management rules in Germany. Based on the wastewater 5-day demand for biochemical oxygen (BOD_5), AbwV defines consistency requirements for 5 types of WWTPs. The German legislation allows for the establishment, not only on the WWTP power but also on the form and properties of the waste recipient, of various national administrative regulations regarding wastewater quality.

(c) Ireland: In rural households (related to one-third of Ireland's population), more than 80% handle and discharge wastewater from an area that does not come under the control of the municipal sewage system with an estimated 500,000 treatment systems. Wastewater treatment plants must comply with the specifications laid down in UWWTD and must follow tighter, site specification guidelines that allow water systems to comply with the criteria set out in the water framework directive. Water treatment plants must be handling loads between 500 and 10,000 PE.

(d) Sweden: The phosphorus removal from urban wastewater in Sweden started in the 1970s to avoid the eutrophication of wetlands. Today, all water sources in Sweden are defined as eutrophication-sensitive and this results in an unparalleled tightening of the waste WWTP quality regulations. The WWTPs in Sweden are phosphorus eliminated primarily by the commonly used biological treatment process exacerbated by additional chemical precipitation in Scandinavian countries.

(e) France: For smaller plants, France has laid down guidelines. As for France, unlike Ireland, requirements are graded as below 1.2 kg of BOD_5 a day and over 1.2 kg of BOD_5, but under 120 kg a day and are directed at BOD, COD and SS. France was one of the first European Nations in 1991 to issue guidelines for wastewater reuse.

(f) Denmark: One of the most conservative of all EU countries is the Danish legislation on the disposal of wastewater. The discharge tax for BOD_5, TN, and TP was introduced in Denmark. This tax has thoroughly modified and made the "Polluter Pays Principle" mandatory for operators of WWTPs. The tax rates on excess wastewater released into receiving waters are set at the Euro to Danish Krone exchange rate of 7.47 for three parameters: BOD_5 (2.47 euro/kg), TN (4.44 euros/kg) and TP (24.46 euros/kg).

(g) Jordan: In its approach to wastewater application and protection, Jordan is considered one of the most advanced countries. A total of 90% of the treated wastewater is used for irrigation primarily in agriculture because of extreme water shortages. A pragmatic security strategy focussing on water quality at the point of use as illustrated by the WHO was created. Farmers are mindful of the level of nutrients in wastewater, which enables the use of fertilisers to be reduced by as much as 60%, thereby providing economic benefits and reducing water pollution. Despite the strong urbanisation rate of 83.91 per cent and high reuse, Jordan shows one of the lowest levels globally.

(h) Switzerland: Switzerland has three tiers of water management: state, cantonal and regional. As a non-EU country, Switzerland has its national water and wastewater management regulations which primarily conform to EU water policies. For basic parameters such as BOD_5, COD and TSS, three key nutrients, ammonium, nitrites and orthophosphates are developed in Switzerland for municipal wastewater discharge.

(i) Dubai: Dubai Municipality's Environment Department released a new circular, which was complemented by all industrial wastewater generation plants, such as laundry facilities and gas stations, and the approved waste transporters in the Dubai Emirate. Both the generator and the waste transporters are responsible for meeting the prescribed requirements and for preventing any illegal waste combination. The management, disposal and storage of wastewater are the responsibility of local governments in the UAE. In Abu Dhabi, the collection and treatment of wastewater collected and dissolved from both residential and industrial users is done by the Abu Dhabi Sewerage Services Company (ADSSC). To minimise environmental impacts and discourage chemical waste from accumulating, the proposed law seeks to lay down new ground laws for businesses and tankers that extract liquid waste from different locations.

(j) China: After the execution of 'The Action Plan for the Prevention and Treatment of Water Pollution,' Zero liquid wastewater discharge (ZLD) has become a trend for environmental governance, and its complicated composition and heavy materials have given more attention to desulphurisation wastewater (Shuangchen et al., 2019).

(k) India: The Zero Liquid Discharge (ZLD) technologies were adopted by the owners of Dyeing Units in Ludhiana, India to avoid untreated waste from dumping into MC sewer lines. Companies in India offer link colouring plants with traditional effluent therapy plants to profit from this pattern (CETP). As a result, the Punjab Pollution Control Board (PPCB) has instructed dyeing device operators, before 31 December 2020, to follow a zero liquid discharge strategy or attach their devices to CETPs to prevent enforcement. In Ludhiana, people have been plagued by unnecessary waste disposal by dyeing in sewage pipes. Therefore, producers in India have capitalised on this problem to deliver their unit owners' facilities. The null liquid discharge market explains why it is expected that the demand will hit 211 million dollars by 2026. For manufacturers in the Indian zero liquid discharge market, the textile industry has become a primary revenue driver. Dollar Industries Ltd. — one of India's leading brands, focuses on eco-friendly production and pioneering as a brand following the Null Liquid Discharge Guidelines. As reusable water in India is extremely scarce, textile industries are increasingly conscious of ZLD wastewater-free water purchasing technologies. The manufacture of huge amounts of wastewater in the industry such as pesticides, petrochemicals, minerals, pharmacology and industrial waste. This wastewater is mostly aimed at drainage tanks, surface water sources or deep wells in some situations. But it leads to contamination of the atmosphere. Consequently, the Indian Government has enforced drainage dumping rules. Several environmental and governmental bodies have enacted rules to curb water waste and encourage water recycling. The ZLD market is concentrated in a few states, including Tamil Nadu, Gujarat, Orissa, Maharashtra, and Andhra Pradesh. The strict enforcement of water discharge legislation, as well as the corporate world's ethical obligation for environmental clearance, will be the primary drivers of this industry. Low-cost technologies will dominate the ZLD market since it is now too expensive for mass adoption, both in terms of fixed and running costs. This will shortly lead to the demand for zero liquid dumpings in India. Zero liquid leakage is one of the leading systems for wastewater disposal, with recovery from effluents of about 90 to 95% vapour. In the last few years, the installation of this process has gained momentum. There are also new possibilities in the presence of government mandates and a high rate of recovery of zero liquid dumpings (Schellenberg et al., 2020; Preisner et al., 2020). The installation capacity, sewage production, and proposed STP sites of India have been well explained in Figure 1 and Tables 2-4, respectively.

Impact on Climate Change

ZLD is a significant method for managing wastewater that is now being applied all over the world, despite the fact that high operational costs and energy consumption continue to be limiting constraints for ZLD technology. The negative effects that pollution has had on the ecosystem have led to a decrease in the amount of available freshwater, shifts in the climate on a global scale, and the poisoning of groundwater. All of this has resulted in regulatory agencies being obliged to urge various companies to adopt ZLD. This strategy may become more practical and sustainable in the near future as a result of developments in technology and the exploration of fresh methods for overcoming all of the restrictions posed by ZLD technologies. Comparing the performance of various industrial wastewater treatment facilities, such as the ZLD system, may benefit from the use of a recently developed performance evaluation method called carbon footprint analysis. Wastewater treatment facilities provide a beneficial contribution to reducing the environmental effect; however, the energy consumption of these plants must also be taken into account in order to have a comprehensive understanding of the environmental impact. Recent advancements in the idea of zero liquid discharge facilities (also known as ZLD facilities) are significant for the resource recovery method (Mohan et al., 2021). Because of the high amount of energy it uses, the management system in ZLD facilities requires a technique that has been carefully established in order to accurately measure the environmental effect of the wastewater treatment plants. When industrial effluent is discharged into natural receiving bodies, wastewater treatment issues become one of the most pressing concerns. The fact that methane emissions caused by treated effluent discharge contribute the second-highest proportion of GHG emissions in the case of a conventional treatment facility highlights the significance of water recycling via the establishment of a ZLD treatment plant. Therefore, it is essential to develop methods that would reduce the carbon footprint of the planned ZLD wastewater treatment facilities for industrial effluents or drainage systems, which would, in turn, reduce the total negative effect on the environment and contribute to greener and cleaner earth.

Conclusion Remarks

The negative effects that wastewater has on the environment are discussed in depth in this article. Roughly half of the world's population resides in urban areas, and a considerable amount of human activity is concentrated in cities, both of which contribute to the warming of the planet. The challenges and roadblocks encountered while putting ZLD systems into action have been dissected and broken down in detail in this analysis. Waste water services are very important to society, but they also leave us susceptible to the effects of climate change and put the health and sanitation of the population in jeopardy. In some treatment systems, temperature plays an important role, particularly in the operations that are carried out normally and without the use of any machinery. Temperatures that are high both boost the efficacy of the removal process and make it possible to apply certain treatment methods. Dangerous to both humans and the environment, liquid waste may refer to a variety of different types of liquid waste. In

Table 2: Relative data on the Inventory for 2014 & 2020

Sl. No	*Sewage treatment plants condition*	*2014*		*2020*	
		No. of sewage treatment plants	*Capacity in million litres per day*	*No. of sewage treatment plants*	*Capacity in million litres per day*
1	Working order	522.00	18, 883.00	1,093.00	26,869.00
2	Actual Application	-	-	1,093.00	20,235.00
3	Compliance	-	-	578.00	12,197.00
4	Non-functional	79.00	1,237.00	102.00	1,406.00
5	In progress (Construction)	145.00	2,528.00	274.00	3,566.00

Table 3: State-wise sewage generation, installed treatment capacity and actual used

S. No.	*State*	*Complete sewage production in million litres per day*	*Installation capacity*		*Actual amount treated or capacity used*		
			In million litres per day	*Percentage of sewage generation*	*In million litres per day*	*Total percentage of sewage generation*	*Percentage of installation capacity*
1	*Andaman & Nicobar Islands*	23.00	0.00	0.00	0.00	0.00	0.00
2	*Andhra Pradesh*	2,882.00	833.00	29.00	309.00	11.00	37.00
3	*ArunachalPradesh*	62.00	0.00	0.00	0.00	0.00	0.00
4	*Assam*	809.00	0.00	0.00	0.00	0.00	0.00
5	*Bihar*	2,276.00	10.00	0.00	0.00	0.00	0.00
6	*Chandigarh*	188.00	293.00	156.00	235.00	125.00	80.00
7	*Chhattisgarh*	1,203.00	73.00	6.00	6.00	0.00	8.00
8	*Daman Diu*	67.00	24.00	36.00	7.00	10.00	29.00
9	*Goa*	176.00	66.00	38.00	25.00	14.00	38.00
10	*Gujarat*	5,013.00	3,378.00	67.00	2,687.00	54.00	80.00
11	*Haryana*	1,816.00	1,880.00	104.00	1,284.00	71.00	68.00
12	*Himachal Pradesh*	116.00	136.00	117.00	51.00	44.00	38.00
13	*Jammu & Kashmir*	665.00	218.00	33.00	49.00	7.00	22.00
14	*Jharkhand*	1,510.00	22.00	1.00	15.00	1.00	68.00
15	*Karnataka*	4,458.00	2,712.00	61.00	1,786.00	40.00	66.00
16	*Kerala*	4,256.00	120.00	3.00	47.00	1.00	39.00
17	*Lakshadweep*	13.00	0.00	0.00	0.00	0.00	0.00
18	*Madhya Pradesh*	3,646.00	1,839.00	50.00	536.00	15.00	29.00
19	*Maharashtra*	9,107.00	6,890.00	76.00	4,242.00	47.00	62.00
20	*Manipur*	168.00	0.00	0.00	0.00	0.00	0.00
21	*Meghalaya*	112.00	0.00	0.00	0.00	0.00	0.00
22	*Mizoram*	103.00	10.00	10.00	0.00	0.00	0.00
23	*Nagaland*	135.00	0.00	0.00	0.00	0.00	0.00
24	*NCT Delhi*	3,330.00	2,896.00	87.00	2,412.00	72.00	83.00
25	*Odisha*	1,282.00	378.00	29.00	50.00	4.00	13.00
26	*Puducherry*	161.00	56.00	35.00	30.00	19.00	54.00
27	*Punjab*	1,889.00	1,781.00	94.00	1,360.00	72.00	76.00
28	*Rajasthan*	3,185.00	1,086.00	34.00	478.00	15.00	44.00
29	*Sikkim*	52.00	20.00	38.00	14.00	27.00	70.00
30	*Tamil Nadu*	6,421.00	1,492.00	23.00	995.00	15.00	67.00
31	*Telangana*	2,660.00	901.00	34.00	706.00	27.00	78.00
32	*Tripura*	237.00	8.00	3.00	1.5.00	1.00	19.00
33	*Uttar Pradesh*	8,263.00	3,374.00	41.00	2,510.00	30.00	74.00
34	*Uttarakhand*	627.00	448.00	71.00	187.00	30.00	42.00
35	*West Bengal*	5,457.00	897.00	16.00	213.00	4.00	24.00
	Total	72,368.00	31,841	44.00	20,236.00	28.00	64.00

Table 4: State zone sewage production and treatment capacity (non rural area of India)

States/UTs	*Sewage production in million litres per day*	*Installation capacity in million litres per day*	*Projected capacity in million litres per day*	*Overall capacity in million litres per day*	*Working capacity in million litres per day*
Andaman & Nicobar Islands	23.00	0.00	0.00	0.00	0.00
Andhra Pradesh	2,882.00	833.00	20.00	853.00	443.00
Arunachal Pradesh	62.00	0.00	0.00	0.00	0.00
Assam	809.00	0.00	0.00	0.00	0.00
Bihar	2,276.00	10.00	621.00	631.00	0.00
Chandigarh	188.00	293.00	0.00	293.00	271.00
Chhattisgarh	1,203.00	73.00	0.00	73.00	73.00
Dadra & Nagar Haveli	67.00	24.00	0.00	24.00	24.00
Goa	176.00	66.00	38.00	104.00	44.00
Gujarat	5,013.00	3,378.00	0.00	3,378.00	3,358.00
Haryana	1,816.00	1,880.00	0.00	1,880.00	1,880.00
Himachal Pradesh	116.00	136.00	19.00	155.00	99.00
Jammu & Kashmir	665.00	218.00	4.00	222.00	93.00
Jharkhand	1,510.00	22.00	617.00	639.00	22.00
Karnataka	4,458.00	2,712.00	0.00	2,712.00	1,922.00
Kerala	4,256.00	120.00	0.00	120.00	114.00
Lakshadweep	13.00	0.00	0.00	0.00	0.00
Madhya Pradesh	3,646.00	1,839.00	85.00	1,924.00	684.00
Maharashtra	9,107.00	6,890.00	2,929.00	9,819.00	6,366.00
Manipur	168.00	0.00	0.00	0.00	0.00
Meghalaya	112.00	0.00	0.00	0.00	0.00
Mizoram	103.00	10.00	0.00	10.00	0.00
Nagaland	135.00	0.00	0.00	0.00	0.00
NCT of Delhi	3,330.00	2,896.00	0.00	2,896.00	2,715.00
Orissa	1,282.00	378.00	0.00	378.00	55.00
Pondicherry	161.00	56.00	3.00	59.00	56.00
Punjab	1,889.00	1,781.00	0.00	1,781.00	1,601.00
Rajasthan	3,185.00	1,086.00	109.00	1,195.00	783.00
Sikkim	52.00	20.00	10.00	30.00	18.00
Tamil Nadu	6,421.00	1,492.00	0.00	1,492.00	1,492.00
Telangana	2,660.00	901.00	0.00	901.00	842.00
Tripura	2,37.00	8.00	0.00	8.00	8.00
Uttar Pradesh	8,263.00	3374.00	0.00	3374.00	3,224.00
Uttarakhand	627.00	448.00	67.00	515.00	345.00
West Bengal	5,457.00	897.00	305.00	1,202.00	337.00
Total	**72,368.00**	**31,841.00**	**4,827.00**	**36,668.00**	**26,869.00**

Source: ENVIS Centre on Hygiene, New Delhi, India (Ministry of Environment, Forest & Climate Change, Government of India).

the case of laboratory waste, for instance, it may take the form of a mist, a sludge or even a liquid. In most cases, establishments such as restaurants, automobiles, homes, and other buildings with washing facilities, laboratories, and industrial structures that make use of tank removal operations are the sources of trash of this sort. When it comes to the implementation of ZLD, it has been shown that the industrial sector achieves the highest levels of productivity. Together with the installation of ZLD wastewater treatment plants, which may guarantee a lower carbon footprint by reducing carbon emissions, the use of renewable energy sources should be supported. This should take place in parallel with the development of ZLD wastewater treatment plants. It is possible to successfully utilise the carbon footprint of a particular ZLD treatment plant as a performance indicator in order to further cut down on the amount of energy that is used on-site.

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