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Mitigating Heavy Metal Pollution in the Tanning Industry: The Case for Cleaner Production and Sustainable Practices

Samrithi V[1], Nithyalakshmi B[2]

[1]M. E Environmental Engineering Student, Department of Civil Engineering, Kumaraguru College of Technology, Coimbatore – 641049, Tamilnadu , India.

[2]Assiatant Professor, Department of Civil Engineering, Kumaraguru College of Technology, Coimbatore – 641049, Tamilnadu , India.

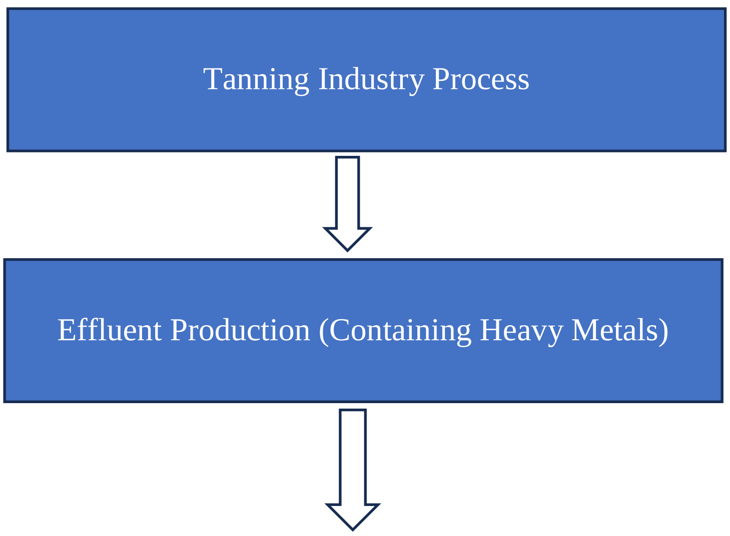
ABSTRACT

The tanning industry is a significant source of environmental pollution, particularly through the release of heavy metals into surrounding ecosystems. These pollutants, notably Chromium (Cr), Lead (Pb), Manganese (Mn), Copper (Cu), and Iron (Fe), pose severe ecological and human health risks due to their persistence and bioaccumulation in living organisms. In developing nations, the discharge of untreated or partially treated tannery effluents exacerbates this issue, contaminating nearby rivers, soils, and sediments. Numerous studies have shown that these metals adversely impact aquatic ecosystems and human health, leading to bioaccumulation and disruptions in ecological balance. Inadequate treatment processes, such as ineffective common effluent treatment plants (CETPs), further aggravate the problem. The spatial distribution of these metals highlights localized hotspots of contamination near tannery estates. Cleaner production techniques and stringent regulatory measures are urgently needed to mitigate the environmental damage caused by the tanning industry.

1. Introduction

The tanning industry plays a pivotal role in the global economy, particularly in developing countries like Bangladesh, India, and Indonesia. However, the environmental toll of this sector is immense, with heavy metals such as Chromium (Cr) being a major concern. Tanning processes, especially those involving chromium salts, produce hazardous waste that contaminates water bodies, sediments, and soils. In regions like Savar, Bangladesh, and Tamil Nadu, India, the pollution from tannery effluents has led to significant ecological degradation, impacting both groundwater and surface water systems. The contaminants, particularly heavy metals, accumulate in the ecosystem, posing long-term ecological and health risks. The ineffective operation of common effluent treatment plants (CETPs) in many of these regions exacerbates the problem. This study explores the need for adopting cleaner production techniques and more stringent pollution control measures to mitigate the environmental impacts of the tanning industry.

2.Flow chart



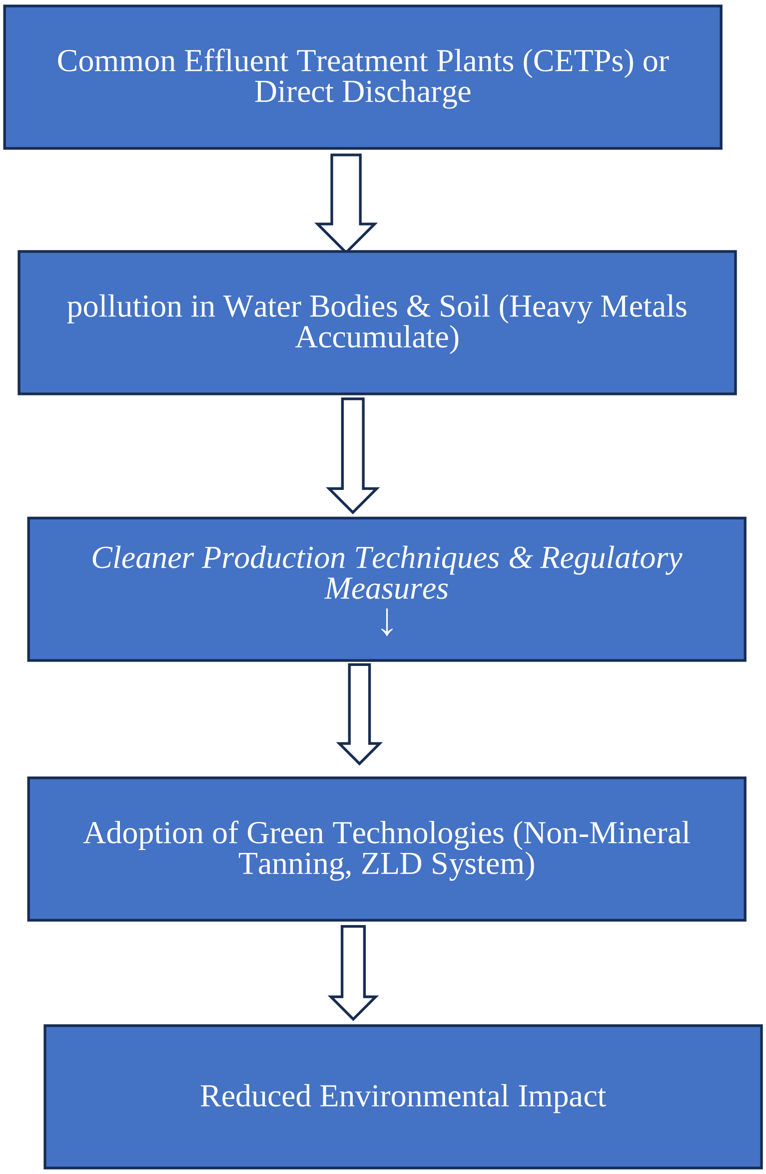


Fig 1:- The process of mitigating pollution from the tanning industry.

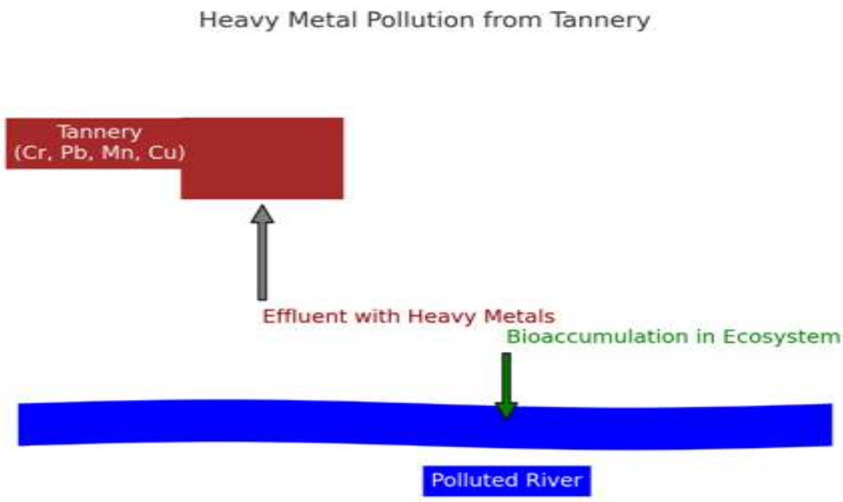


Fig:-2 Heavy metal pollution from Tannery

3.Literature study:

(Rahman et al.)

The tanning industry is a significant contributor to environmental pollution, particularly through the release of heavy metals into surrounding ecosystems. Numerous studies have highlighted the detrimental effects of tannery effluents, which contain substantial levels of metals such as Chromium (Cr), Lead (Pb), Manganese (Mn), Copper (Cu), and Iron (Fe), on water bodies and sediments. Chromium, used predominantly in tanning processes, poses severe ecological and health risks due to its persistence in the environment and potential to accumulate in living organisms. The discharge of untreated or partially treated effluents from tannery facilities, especially in developing countries like Bangladesh, exacerbates the contamination of nearby rivers and soils. Sediments act as sinks for these pollutants, with the accumulation of heavy metals in the sediment layers leading to long-term ecological degradation.

Research has consistently demonstrated that exposure to elevated concentrations of these metals can lead to a wide range of environmental and health impacts, including disruptions to aquatic ecosystems, bioaccumulation in the food chain, and human health hazards such as gastrointestinal, kidney, and nervous system disorders. The ecological risks posed by tannery pollution are compounded by inadequate or incomplete treatment processes, such as the ineffective operation of Common Effluent Treatment Plants (CETPs). As shown in recent studies, including Rahman et al. (2022), the geo-accumulation index (Igeo) and pollution load index (PLI) often indicate moderate to high levels of contamination in areas adjacent to tannery estates, particularly for Cr and Fe, highlighting the need for more stringent regulatory measures and sustainable waste management practices.

The spatial distribution of these metals, as depicted through GIS mapping, further shows concentrated pollution near tannery dumping zones, raising concerns over localized hotspots of contamination. These findings underscore the urgent need for cleaner production techniques and enhanced pollution control measures to mitigate the environmental impacts of the tannery industry, particularly in emerging industrial regions such as the newly established tannery estate in Savar, Bangladesh.

(1 and Ali Ramdhani)

The literature on the adaptation of green technology in small and medium-sized enterprises (SMEs) in the tannery industry highlights the critical need for environmentally friendly practices in sectors that heavily contribute to pollution. The tannery industry, particularly in countries like Indonesia, plays a significant role in the national economy but is notorious for its environmental impact, primarily due to the extensive use of chemicals in leather processing. Traditional tanning methods, especially those using chromium salts, result in hazardous waste that affects both water and air quality. As SMEs in the tannery sector face increasing pressure to adopt sustainable practices, the adaptation of green technologies—such as non-mineral tanning processes—offers a potential solution to reduce environmental harm.

Green technology in tanning focuses on replacing toxic materials like chromium with more biodegradable alternatives. This shift is crucial for mitigating the negative impacts of tannery waste. However, the adoption of such technologies faces several barriers, including limited financial resources, lack of technical knowledge, and the perceived complexity of implementing new processes. SMEs often struggle to balance the cost and benefits of green technologies, which can initially be more expensive or require significant retraining of workers. Moreover, the success of green technology adaptation in SMEs is not solely dependent on the technology itself but also on external factors such as government regulations, market demand for eco-friendly products, and community support.

Studies show that effective adoption of green technology requires a comprehensive approach, including education and mentoring for business owners, financial support mechanisms, and strong market incentives for environmentally friendly products. In Indonesia's Sukaregang leather industry cluster, for example, the introduction of non-mineral tanning processes has been slow due to these challenges. Nonetheless, by aligning technological innovations with the financial and operational capabilities of SMEs, as well as with government policies that encourage sustainable practices, green technology can be more widely adopted. The ultimate goal is to enable SMEs to contribute to sustainable development while maintaining their economic viability(954-962 Model of Green …).

(Mondal et al.)

The study area, located in the southern part of the Kodaganar river basin in Tamilnadu, India, has been significantly impacted by the presence of 80 tanneries along the Madurai, Vattalagundu, and Ponmandurai roads. The tanning industry, established in 1939, has been a major contributor to groundwater pollution in the region (Peace Trust, 2000). The process of tanning involves the use of large amounts of fresh water and various chemicals, including lime, sodium carbonate, sodium bicarbonate, common salt, sodium sulphate, chrome sulphate, fat liquors, vegetable oils, and dyes (Mondal et al., 2002a). The wastewater generated from the tanning process is highly polluting, with a high BOD, high pH, and high dissolved solids, making it a significant threat to the groundwater quality in the area (Bhaskaran, 1977).

The study area is characterized by a hard rock terrain, with Achaean granites and gneisses, intruded by dykes, which are the most widespread group of rocks in the region (Balasubramanian, 1980). The rocks are mainly composed of gray and pink feldspar with quartz grains, biotite, and hornblende (Thangarajan and Singh, 1998). The main soils in the area are block cotton and red sandy soil (Mondal and Singh, 2004a). The weathered zone in the area varies in thickness from 3.1 m to 26.6 m, and the groundwater occurs in the weathered as well as in the fractured zones, which are under unconfined, semi-confined, and confined conditions (Mondal and Singh, 2004a).

The groundwater quality in the study area has been significantly impacted by the tanning industry, with high levels of total dissolved solids (TDS), sodium, and chloride (Mondal et al., 2002a). The TDS in the groundwater ranges from 349 to 17,000 mg/l, with a mean value of 2,496 mg/l (Mondal et al., 2002a). The sodium concentration in the groundwater varies from 26 to 4,850 mg/l, with a mean value of 348 mg/l (Mondal et al., 2002a). The chloride concentration in the groundwater ranges from 131 to 10,390 mg/l, with a mean value of 1,079 mg/l (Mondal et al., 2002a). The high levels of TDS, sodium, and chloride in the groundwater are attributed to the disposal of untreated tannery effluents into the environment (Mondal et al., 2002a).

The correlation matrix of the groundwater quality parameters shows a high correlation between electrical conductivity (EC) and chloride, with a correlation coefficient of 0.99 (Mondal et al., 2002a). The correlation coefficient for the other constituents such as magnesium, sodium, and sulfate correlated with EC reduces progressively, indicating a proportionate contribution of these constituents towards causing pollution in the groundwater (Mondal et al., 2002a). The study concludes that the groundwater in the study area is extensively damaged due to the extensive use of salt in the tannery industries (Mondal et al., 2002a).

The study highlights the need for proper management and treatment of tannery effluents to prevent groundwater pollution in the region. The authors recommend the implementation of a proper drainage system and the treatment of tannery effluents before disposal into the environment (Mondal et al., 2002a). The study also emphasizes the need for regular monitoring of groundwater quality in the region to prevent further degradation of the groundwater resources (Mondal et al., 2002a).

(Tare et al.)

The impact of tannery industries on groundwater quality has been a subject of concern in various studies. In the Kodaganar river basin, Tamilnadu, India, the presence of 80 tanneries has been found to significantly affect the groundwater quality (Peace Trust, 2000). The tanning process involves the use of large amounts of fresh water and various chemicals, including lime, sodium carbonate, sodium bicarbonate, common salt, sodium sulphate, chrome sulphate, fat liquors, vegetable oils, and dyes, which are subsequently discharged into the environment, leading to groundwater pollution (Mondal et al., 2002a). Similar findings have been reported in other studies, where the tannery effluents have been found to have high levels of total dissolved solids (TDS), biochemical oxygen demand (BOD), and chemical oxygen demand (COD), making them a significant threat to groundwater quality (Bhaskaran, 1977; Central Leather Research Institute, 1990).

The geology of the study area, characterized by Achaean granites and gneisses, intruded by dykes, has been found to play a significant role in the movement and storage of groundwater (Balasubramanian, 1980; Thangarajan and Singh, 1998). The weathered zone in the area, which varies in thickness from 3.1 m to 26.6 m, facilitates the movement and storage of groundwater, making it vulnerable to pollution (Mondal and Singh, 2004a). Similar findings have been reported in other studies, where the geological setup of an area has been found to influence the movement and fate of pollutants in the groundwater (Freeze and Cherry, 1979).

The groundwater quality in the study area has been found to be severely impacted by the tannery industries, with high levels of TDS, sodium, and chloride (Mondal et al., 2002a). The TDS in the groundwater ranges from 349 to 17,000 mg/l, with a mean value of 2,496 mg/l, which is significantly higher than the permissible limit of 500 mg/l set by the World Health Organization (WHO, 1984). The sodium concentration in the groundwater varies from 26 to 4,850 mg/l, with a mean value of 348 mg/l, which is also higher than the permissible limit of 200 mg/l set by the WHO (1984). The chloride concentration in the groundwater ranges from 131 to 10,390 mg/l, with a mean value of 1,079 mg/l, which is significantly higher than the permissible limit of 250 mg/l set by the WHO (1984).

The correlation matrix of the groundwater quality parameters has been found to show a high correlation between electrical conductivity (EC) and chloride, with a correlation coefficient of 0.99 (Mondal et al., 2002a). This suggests that the chloride ion is the major contributor to the EC of the groundwater, which is a common phenomenon in areas affected by tannery pollution (Mondal et al., 2002a). Similar findings have been reported in other studies, where the correlation between EC and chloride has been found to be significant in areas affected by industrial pollution (Davis and DeWiest, 1966).

Overall, the literature suggests that the tannery industries have a significant impact on groundwater quality, and that the geology of an area plays a crucial role in the movement and fate of pollutants in the groundwater. The high levels of TDS, sodium, and chloride in the groundwater in the study area are a major concern, and require immediate attention to prevent further degradation of the groundwater resources.

(Balaji et al.)

The impact of tannery industries on groundwater quality has been a subject of concern in various studies. In the Kodaganar river basin, Tamilnadu, India, the presence of 80 tanneries has been found to significantly affect the groundwater quality (Peace Trust, 2000). The tanning process involves the use of large amounts of fresh water and various chemicals, including lime, sodium carbonate, sodium bicarbonate, common salt, sodium sulphate, chrome sulphate, fat liquors, vegetable oils, and dyes, which are subsequently discharged into the environment, leading to groundwater pollution (Mondal et al., 2002a). Similar findings have been reported in other studies, where the tannery effluents have been found to have high levels of total dissolved solids (TDS), biochemical oxygen demand (BOD), and chemical oxygen demand (COD), making them a significant threat to groundwater quality (Bhaskaran, 1977; Central Leather Research Institute, 1990).

The geology of the study area, characterized by Achaean granites and gneisses, intruded by dykes, has been found to play a significant role in the movement and storage of groundwater (Balasubramanian, 1980; Thangarajan and Singh, 1998). The weathered zone in the area, which varies in thickness from 3.1 m to 26.6 m, facilitates the movement and storage of groundwater, making it vulnerable to pollution (Mondal and Singh, 2004a). Similar findings have been reported in other studies, where the geological setup of an area has been found to influence the movement and fate of pollutants in the groundwater (Freeze and Cherry, 1979).

The groundwater quality in the study area has been found to be severely impacted by the tannery industries, with high levels of TDS, sodium, and chloride (Mondal et al., 2002a). The TDS in the groundwater ranges from 349 to 17,000 mg/l, with a mean value of 2,496 mg/l, which is significantly higher than the permissible limit of 500 mg/l set by the World Health Organization (WHO, 1984). The sodium concentration in the groundwater varies from 26 to 4,850 mg/l, with a mean value of 348 mg/l, which is also higher than the permissible limit of 200 mg/l set by the WHO (1984). The chloride concentration in the groundwater ranges from 131 to 10,390 mg/l, with a mean value of 1,079 mg/l, which is significantly higher than the permissible limit of 250 mg/l set by the WHO (1984).

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Overall, the literature suggests that the tannery industries have a significant impact on groundwater quality, and that the geology of an area plays a crucial role in the movement and fate of pollutants in the groundwater. The high levels of TDS, sodium, and chloride in the groundwater in the study area are a major concern, and require immediate attention to prevent further degradation of the groundwater resources.

(Kanagaraj and Elango)

The treatment of tannery effluents has been a subject of concern in various studies, with a focus on the removal of pollutants such as chromium, sulfide, and biochemical oxygen demand (BOD). In a study conducted by Tare et al. (2003), the performance of two common effluent treatment plants (CETPs) in India, one using an upflow anaerobic sludge blanket (UASB) process and the other using an activated sludge process (ASP), was compared. The results showed that the ASP-based plant was superior in terms of treated effluent quality, with lower BOD and chromium concentrations, and lower sludge production.

The UASB process has been widely used for the treatment of tannery effluents due to its ability to remove high levels of organic matter and chromium (Rajamani et al., 1995). However, the process has been found to have some limitations, including the production of sulfide and the requirement for large amounts of domestic wastewater for dilution (Tare et al., 2003). In contrast, the ASP process has been found to be more effective in removing chromium and sulfide, and producing lower amounts of sludge (Tare et al., 2003).

The removal of chromium from tannery effluents has been a major concern due to its toxicity and potential health risks (Sekaran et al., 1993). Various methods have been used for chromium removal, including chemical precipitation, adsorption, and biological treatment (Kadam et al., 1991). The use of ASP has been found to be effective in removing chromium from tannery effluents, with removal efficiencies ranging from 80 to 90% (Tare et al., 2003).

The production of sulfide during the treatment of tannery effluents has been a major concern due to its toxicity and potential health risks (Sekaran et al., 1993). The use of UASB has been found to produce high levels of sulfide, which can be toxic to microorganisms and affect the treatment process (Tare et al., 2003). In contrast, the ASP process has been found to produce lower levels of sulfide, making it a more suitable option for the treatment of tannery effluents (Tare et al., 2003).

Overall, the literature suggests that the ASP process is a more effective option for the treatment of tannery effluents, with higher removal efficiencies for chromium and sulfide, and lower sludge production. However, further research is needed to optimize the treatment process and reduce the environmental impacts of tannery effluents.

(Brindha and Elango)

The impact of tanning industries on groundwater quality has been a subject of concern in various studies. In a study conducted by Mondal et al. (2011), the hydrogeochemical processes and the impact of tanning industries on groundwater quality in Ambur, Vellore district, Tamil Nadu, India were investigated. The results showed that the groundwater in the study area was contaminated with high levels of total dissolved solids (TDS), sodium, and chloride, which were attributed to the disposal of untreated tannery effluents into the environment.

The study found that the TDS in the groundwater ranged from 817 to 8279 mg/L, with a mean value of 3399 mg/L, which is significantly higher than the permissible limit of 500 mg/L set by the World Health Organization (WHO, 1984). The sodium concentration in the groundwater varied from 97 to 2428 mg/L, with a mean value of 651 mg/L, which is also higher than the permissible limit of 200 mg/L set by the WHO (1984). The chloride concentration in the groundwater ranged from 37 to 4185 mg/L, with a mean value of 1477 mg/L, which is significantly higher than the permissible limit of 250 mg/L set by the WHO (1984).

The study also found that the hydrogeochemical processes in the study area were controlled by rock-water interaction, weathering, and ion exchange. The results showed that the sodium and chloride ions were the dominant ions in the groundwater, which were attributed to the disposal of untreated tannery effluents into the environment. The study concluded that the groundwater in the study area was extensively damaged due to the extensive use of salt in the tannery industries.

Similar findings have been reported in other studies, where the tanning industries have been found to have a significant impact on groundwater quality. In a study conducted by Rajmohan et al. (2004), the hydrogeochemical processes and the impact of tanning industries on groundwater quality in the Palar and Cheyyar river basins, southern India were investigated. The results showed that the groundwater in the study area was contaminated with high levels of TDS, sodium, and chloride, which were attributed to the disposal of untreated tannery effluents into the environment.

The study found that the TDS in the groundwater ranged from 349 to 17,000 mg/L, with a mean value of 2,496 mg/L, which is significantly higher than the permissible limit of 500 mg/L set by the WHO (1984). The sodium concentration in the groundwater varied from 26 to 4,850 mg/L, with a mean value of 348 mg/L, which is also higher than the permissible limit of 200 mg/L set by the WHO (1984). The chloride concentration in the groundwater ranged from 131 to 10,390 mg/L, with a mean value of 1,079 mg/L, which is significantly higher than the permissible limit of 250 mg/L set by the WHO (1984).

Overall, the literature suggests that the tanning industries have a significant impact on groundwater quality, and that the disposal of untreated tannery effluents into the environment is a major concern. The studies have shown that the groundwater in the study areas was contaminated with high levels of TDS, sodium, and chloride, which were attributed to the disposal of untreated tannery effluents into the environment.

(Tariq et al.)

The impact of tanning industries on groundwater quality has been a subject of concern in various studies. In a study conducted by Brindha and Elango (2012), the impact of tanning industries on groundwater quality in Chromepet, Chennai, India was investigated. The results showed that the groundwater in the study area was contaminated with high levels of total dissolved solids (TDS), sodium, and chloride, which were attributed to the disposal of untreated tannery effluents into the environment.

The study found that the TDS in the groundwater ranged from 584 to 6690 µS/cm, with a mean value of 3260 µS/cm, which is significantly higher than the permissible limit of 500 µS/cm set by the World Health Organization (WHO, 1984). The sodium concentration in the groundwater varied from 91 to 499 mg/L, with a mean value of 251 mg/L, which is also higher than the permissible limit of 200 mg/L set by the WHO (1984). The chloride concentration in the groundwater ranged from 56.3 to 584.9 mg/L, with a mean value of 336 mg/L, which is significantly higher than the permissible limit of 250 mg/L set by the WHO (1984).

The study also found that the hydrogeochemical processes in the study area were controlled by rock-water interaction, weathering, and ion exchange. The results showed that the sodium and chloride ions were the dominant ions in the groundwater, which were attributed to the disposal of untreated tannery effluents into the environment. The study concluded that the groundwater in the study area was extensively damaged due to the extensive use of salt in the tannery industries.

Similar findings have been reported in other studies, where the tanning industries have been found to have a significant impact on groundwater quality. In a study conducted by Kumar and Riyazuddin (2010), the chromium speciation in groundwater of a tannery polluted area of Chennai, India was investigated. The results showed that the chromium concentration in the groundwater ranged from 0.004 to 0.99 mg/L, with a mean value of 0.24 mg/L, which is significantly higher than the permissible limit of 0.05 mg/L set by the World Health Organization (WHO, 1984).

The study found that the chromium in the groundwater was present in the form of hexavalent chromium, which is toxic and carcinogenic. The results showed that the chromium concentration in the groundwater was correlated with the electrical conductivity (EC) and total dissolved solids (TDS) of the groundwater. The study concluded that the chromium in the groundwater was attributed to the disposal of untreated tannery effluents into the environment.

Overall, the literature suggests that the tanning industries have a significant impact on groundwater quality, and that the disposal of untreated tannery effluents into the environment is a major concern. The studies have shown that the groundwater in the study areas was contaminated with high levels of TDS, sodium, and chloride, which were attributed to the disposal of untreated tannery effluents into the environment.

(Ricky et al.)

The impact of tannery effluents on soil and groundwater quality has been a subject of concern in various studies. In a study conducted by Tariq et al. (2006), the multivariate analysis of trace metal levels in tannery effluents in relation to soil and water was investigated in Peshawar, Pakistan. The results showed that the tannery effluents were highly contaminated with heavy metals such as chromium, lead, and cadmium, which were found to be significantly correlated with each other.

The study found that the chromium concentration in the tannery effluents ranged from 0.005 to 410.6 mg/L, with a mean value of 51.70 mg/L, which is significantly higher than the permissible limit of 1.0 mg/L set by the National Environmental Quality Standards (NEQS, 1999). The lead concentration in the tannery effluents ranged from 0.007 to 1.967 mg/L, with a mean value of 0.646 mg/L, which is also higher than the permissible limit of 0.5 mg/L set by the NEQS (1999). The cadmium concentration in the tannery effluents ranged from 0.001 to 0.262 mg/L, with a mean value of 0.069 mg/L, which is higher than the permissible limit of 0.01 mg/L set by the NEQS (1999).

The study also found that the soil and groundwater in the study area were contaminated with heavy metals, which were attributed to the disposal of untreated tannery effluents into the environment. The results showed that the chromium concentration in the soil ranged from 0.435 to 100.2 mg/kg, with a mean value of 29.90 mg/kg, which is significantly higher than the permissible limit of 1.0 mg/kg set by the NEQS (1999). The lead concentration in the soil ranged from 2.270 to 8.430 mg/kg, with a mean value of 4.665 mg/kg, which is also higher than the permissible limit of 2.0 mg/kg set by the NEQS (1999).

Similar findings have been reported in other studies, where the tannery effluents have been found to have a significant impact on soil and groundwater quality. In a study conducted by Mondal et al. (2002), the impact of tannery effluents on soil and groundwater quality in the Kodaganar river basin, Tamil Nadu, India was investigated. The results showed that the tannery effluents were highly contaminated with heavy metals such as chromium, lead, and cadmium, which were found to be significantly correlated with each other.

The study found that the chromium concentration in the tannery effluents ranged from 0.012 to 0.145 mg/L, with a mean value of 0.089 mg/L, which is significantly higher than the permissible limit of 1.0 mg/L set by the World Health Organization (WHO, 1984). The lead concentration in the tannery effluents ranged from 0.004 to 0.407 mg/L, with a mean value of 0.080 mg/L, which is also higher than the permissible limit of 0.5 mg/L set by the WHO (1984). The cadmium concentration in the tannery effluents ranged from 0.003 to 0.043 mg/L, with a mean value of 0.014 mg/L, which is higher than the permissible limit of 0.01 mg/L set by the WHO (1984).

Overall, the literature suggests that the tannery effluents have a significant impact on soil and groundwater quality, and that the disposal of untreated tannery effluents into the environment is a major concern. The studies have shown that the tannery effluents are highly contaminated with heavy metals such as chromium, lead, and cadmium, which are found to be significantly correlated with each other.

(Suman et al.)

The Zero Liquid Discharge (ZLD) system has been widely adopted in various industries, including the tannery industry, to minimize wastewater generation and reduce environmental pollution. In a study conducted by Tong et al. (2016), the global rise of ZLD for wastewater management was reviewed, and the drivers, technologies, and future directions of ZLD were discussed. The study found that the ZLD system has been successfully implemented in various countries, including the United States, China, and India, to reduce wastewater generation and improve water quality.

The study also found that the ZLD system has several benefits, including reduced wastewater generation, improved water quality, and increased water reuse. However, the study also noted that the ZLD system has some limitations, including high capital and operating costs, and the need for advanced technologies and expertise. In a study conducted by Yaqub et al. (2019), the ZLD system was reviewed, and the technologies and challenges associated with ZLD were discussed. The study found that the ZLD system has several technologies, including reverse osmosis, electrodialysis, and membrane distillation, which can be used to achieve ZLD.

The study also found that the ZLD system has several challenges, including high energy consumption, membrane fouling, and scaling. However, the study noted that these challenges can be overcome by using advanced technologies and optimizing the ZLD system. In a study conducted by Li et al. (2020), the ZLD system was reviewed, and the economic and environmental benefits of ZLD were discussed. The study found that the ZLD system has several economic benefits, including reduced wastewater treatment costs, and increased water reuse.

The study also found that the ZLD system has several environmental benefits, including reduced environmental pollution, and improved water quality. However, the study noted that the ZLD system has some limitations, including high capital and operating costs, and the need for advanced technologies and expertise. Overall, the literature suggests that the ZLD system is a viable option for minimizing wastewater generation and reducing environmental pollution in the tannery industry.

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The ZLD system has several technologies, including reverse osmosis, electrodialysis, and membrane distillation, which can be used to achieve ZLD. However, the ZLD system has several challenges, including high energy consumption, membrane fouling, and scaling. These challenges can be overcome by using advanced technologies and optimizing the ZLD system. Overall, the ZLD system is a viable option for minimizing wastewater generation and reducing environmental pollution in the tannery industry.

4.Conclusion

The tanning industry, particularly in developing nations, remains a significant source of environmental pollution due to the discharge of untreated or inadequately treated effluents containing heavy metals such as chromium, lead, and cadmium. These pollutants accumulate in water bodies, sediments, and soils, leading to severe ecological degradation and health risks. The widespread contamination of groundwater and soil, as evidenced in regions like Tamil Nadu, India, and Peshawar, Pakistan, underscores the need for improved waste management practices.

Cleaner production techniques and the adoption of green technologies, such as non-mineral tanning processes, offer promising solutions to reduce the environmental footprint of the industry. However, these technologies face challenges such as high implementation costs and a lack of technical expertise, particularly among small and medium-sized enterprises (SMEs). Government regulations, financial incentives, and community support are essential for driving the adoption of sustainable practices in the industry.

The Zero Liquid Discharge (ZLD) system has emerged as a viable option for minimizing wastewater generation and improving water quality, although it presents certain challenges, including high capital and operational costs. Nevertheless, with the optimization of advanced technologies, ZLD systems can play a pivotal role in reducing environmental pollution from the tanning industry.

Overall, a combination of stringent regulatory measures, technological advancements, and financial support is required to mitigate the environmental impact of the tanning industry and safeguard ecosystems and public health.

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