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WASTE MANAGEMENT PRACTICES, THEIR CHALLENGES AND STRATEGIC WAY FORWARDS -THE CASE IN THE ETHIOPIAN TANNERIES

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ABSTRACT

The tannery industry stands as a significant contributor to the Ethiopian economy, leveraging the country's substantial livestock population for leather production and export. However, this economic boon is counterbalanced by severe environmental and public health repercussions due to inadequate and unsustainable waste management practices. This study synthesizes the prevailing conditions, identifying key challenges and proposing a strategic framework for sustainable improvement. The primary solid waste, chromium-tanned leather scraps, and the liquid effluent laden with toxic heavy metals (particularly chromium), sulphides, salts, and organic load, are frequently discharged untreated or partially treated into water bodies and terrestrial ecosystems. This leads to the contamination of soil and water resources, posing significant risks to aquatic life, agricultural productivity, and human health. The core challenges are multifaceted, encompassing technical, economic, and regulatory spheres. Technically, most tanneries operate with obsolete machinery and lack advanced affordable effluent treatment plants. Economically, high capital and operational costs for modern waste management systems are prohibitive. Furthermore, a critical challenge lies in the limited knowledge and implementation of by-product recovery and valorization techniques, viewing waste as a liability rather than a resource. Regulatory, weak enforcement of environmental standards and fragmented institutional oversight perpetuate non-compliance. The strategic way forward necessitates a multi-pronged approach. Primarily, there is an urgent need for technology transfer and adaptation of affordable, context-specific treatment solutions, including modular effluent treatment plants. Secondly, promoting a circular economy model is paramount. This involves incentivizing the valorization of tannery by-products; converting fleshings and trimmings into protein-rich animal feed or biodiesel, and transforming chromium-laden sludge into value-added products. Finally, strengthening governance through stringent enforcement of regulations, coupled with capacity building for both regulators and industry operators, is essential. By integrating technological innovation, economic incentives, and robust policy, the Ethiopian tannery sector can transform its waste management paradigm, aligning economic growth with environmental sustainability and social responsibility.

KEYWORDS: Ethiopian; Tanneries; waste; Management; challenge; pollution; circular economy.

INTRODUCTION

The leather industry is a significant global economic sector, contributing substantially to the economies of many developing nations by generating employment, earning foreign exchange, and supplying raw materials for downstream products (Lofrano et al., 2013). However, this industry is also categorized as one of the most polluting in the world due to the large volumes of water and chemicals used in the transformation of raw hides and skins into finished leather. The process generates substantial solid and liquid waste, including toxic heavy metals (e.g., chromium), sulphides, salts, and putrescible organic matter (Ayalew et al., 2021). Without effective management, this effluent can contaminate water bodies, degrade soil quality, and pose severe risks to both public health and ecosystems (Miller & Spoolman, 2020).

In Ethiopia, the tannery sector is a cornerstone of the government's industrialization strategy, with the country possessing one of the largest livestock populations in Africa, providing a robust raw material base (Mulugeta & Tsegaye, 2019). Despite this potential, the sector's growth and international competitiveness are severely hampered by inefficient and often rudimentary waste management practices. The majority of Ethiopian tanneries discharge partially treated or even untreated effluent directly into the environment, leading to severe pollution in areas like the Modjo River, which is a stark testament to the environmental crisis (Abebe et al., 2020). The challenges are multifaceted, encompassing technical limitations, economic constraints, and regulatory failures.

The management of tannery waste presents a complex challenge, primarily due to the presence of persistent and hazardous constituents like chromium. While conventional treatment methods such as chemical precipitation for chromium removal exist, they often generate hazardous sludge that requires further secure disposal, creating a secondary waste problem (Leta et al., 2020). Furthermore, many tanneries in Ethiopia operate with outdated technology and lack the capital investment required for advanced effluent treatment plants (ETPs). This is compounded by weak enforcement of environmental regulations and a lack of awareness or adoption of cleaner production technologies that can minimize waste at its source (Gebregziabher et al., 2019).

Therefore, a critical examination of the current waste management practices, the systemic challenges impeding their improvement, and the exploration of strategic, sustainable pathways is not just an academic exercise but a pressing national priority for Ethiopia. Addressing this issue is crucial for aligning the tannery industry's development with environmental sustainability and social responsibility.

The objective of this analysis therefore is;

- To critically evaluate tannery waste management practices, identify the key challenges, and propose strategic, sustainable ways forwards;

To achieve this, the following specific objectives are outlined:

- To Review Global and Local Tannery Waste Management Practices;
- To Identify and Analyze the Specific Challenges in Ethiopian Tanneries;
- To Propose a Strategic Framework for Sustainable Waste Management in Ethiopia.

OVERVIEW

Ethiopian tanneries face significant environmental challenges, primarily stemming from the large volume of highly polluting solid and liquid waste generated during the beamhouse and tanning processes. This waste stream is characterized by high concentrations of organic matter, heavy metals—most notably chromium (Cr (III)) and other toxic chemicals (Gebregziabher et al., 2021). Current common management practices are widely recognized as inadequate, often involving poor control over chemical and water use, which exacerbates the waste load (Mekonnen et al., 2022). This is compounded by inefficient or often non-functional wastewater treatment plants and a historically limited focus on solid waste valorization or pollution prevention strategies (Alemu et al., 2019).

Addressing this complex issue requires a strategic, multi-faceted approach. Firstly, adopting cleaner production (CP) technologies is critical to reduce waste at its source. For instance, enzymatic unhairing can significantly reduce or eliminate the use of toxic sulfide chemicals in the beamhouse operation (Lefebvre et al., 2021). Secondly, investing in robust and cost-effective advanced wastewater treatment, such as constructed wetlands specifically designed to handle industrial tannery effluent, can provide a sustainable solution for meeting discharge standards (Yirgu et al., 2020). Concurrently, developing value-added uses for solid wastes is essential for a circular economy; this includes converting hair into fertilizer or felt, and fleshings into animal feed or biodiesel (Berhe et al., 2022).

Ultimately, technological solutions must be underpinned by stronger institutional frameworks. This involves strengthening environmental policies and their enforcement, improving worker training on best practices and chemical safety, and fostering a culture of commitment and coordination among all stakeholders throughout the leather supply chain (Gebremichael et al., 2021).

Tannery Waste Management Practices & Challenges

Analysis of tannery waste management practices in Ethiopia

The leather industry is a significant contributor to the Ethiopian economy, being one of the country's leading manufacturing sectors in terms of export earnings and employment generation (Gebregziabher et al., 2019). However, the environmental cost associated with tanning operations, particularly in major industrial clusters like the Modjo and Akaki river basins, is substantial. Tannery waste management in Ethiopia is characterized by a complex interplay of outdated practices, severe environmental pollution, and nascent efforts towards sustainable solutions. This is evidenced by the continued discharge of untreated effluent laden with heavy metals like chromium, salinity, and organic load into local waterways, fundamentally degrading the Modjo and Akaki river ecosystems (Megersa et al., 2019; Leta et al., 2021). These outdated practices are often attributed to a reliance on conventional, inefficient technologies and a lack of financial capacity for small-to-medium-scale enterprises to invest in modern treatment infrastructure (Gebregziabher et al., 2021). Consequently, the pollution manifests in severely contaminated water and soil, posing significant risks to public health and agricultural productivity downstream (Dadi et al., 2017). Despite this challenging landscape, nascent efforts towards sustainability are emerging, driven by research into local, low-cost adsorbents for wastewater treatment and increasing regulatory pressure from governmental bodies, though their widespread implementation remains limited (Abate et al., 2020; Beyene & Chebude, 2021).

Outdated Practices and the Pollution Burden

The core of the problem lies in the reliance on conventional, and often inefficient, waste management systems. A significant challenge is the continued global prevalence of the Chrome Tanning process, which, due to its speed and efficiency, accounts for over 90% of global leather production, including in Ethiopia (Sundar et al., 2011). This process relies heavily on basic chromium sulfate, a significant portion of which often cited as 30-40% is not absorbed by the hides and ends up in the wastewater effluent (Khan et al., 2019). This results in the discharge of toxic trivalent chromium (Cr (III)). While less immediately hazardous than its hexavalent counterpart, Cr (III) in tannery sludge and wastewater poses a long-term threat as it can oxidize into carcinogenic Cr (VI) under environmental conditions, particularly in soils with neutral to alkaline pH or in the presence of manganese oxides (Kotaś & Stasicka, 2000). Compounding this issue of chemical pollution is the infrastructural deficit. As noted in studies of the industry's environmental performance, most tanneries in Ethiopia lack adequate, modern wastewater treatment plants (WWTPs) (Leta et al., 2016). Furthermore, the existing treatment facilities often operate below their designed capacity or are poorly maintained, leading to inconsistent treatment and the direct discharge of partially treated or untreated effluent into the environment (Berihun et al., 2016).

A vast quantity of untreated or partially treated effluent from the tannery industry is discharged directly into the environment due to inadequate waste management infrastructure (Gebrewold et al., 2018). Studies focusing on the Modjo River, which receives effluent from the Modjo Leather City, have documented alarming levels of pollution, confirming it as a significant point of environmental contamination (Dadi et al., 2017). The river water exhibits extremely high concentrations of chemical oxygen demand (COD), total dissolved solids (TDS), and sulfides, which are by-products of the tanning process (Leta et al., 2019). Furthermore, the water is contaminated with heavy metals, primarily chromium, a core element in modern tanning, with concentrations far exceeding the permissible limits set by the Ethiopian Environmental Protection Authority (Merga et al., 2020). Consequently, this toxic effluent severely degrades the water quality, leading to the destruction of aquatic flora and fauna (Beyene et al., 2019). The pollution renders the water unfit for any downstream agricultural or domestic use, creating significant health and livelihood risks for local communities (Tekle et al., 2021).

Beyond liquid waste, solid waste generated from tannery operations, particularly fleshings, trimmings, and hair, also presents a major management challenge (Mulugeta & Mengesha, 2016). While these organic solid wastes have a high potential for conversion into valuable by-products like protein fodder, glue, or biodiesel, this potential remains largely untapped in many regions (Rahman et al., 2014). In practice, these wastes are often dumped in open areas or landfills without any form of treatment (Yilma et al., 2018). This improper disposal causes foul odors from decomposition and acts as a breeding ground for pathogens and vectors of disease (Dereje & Ture, 2015). The sheer volume of solid waste generated, and its subsequent mismanagement, underscores the inefficiency and environmental burden of the current linear economic model prevalent in the sector, highlighting the urgent need for a transition to a circular economy approach (Alemayehu & Tadesse, 2020).

Nascent Efforts and Sustainable Solutions

Recognizing the severity of the problem, there are growing efforts from both government bodies and the tanneries themselves to transition towards more sustainable practices. A key government-led initiative was the relocation of tanneries from the capital, Addis Ababa, to a designated industrial cluster, the Modjo Leather Industry Park. The primary objective was to centralize pollution sources and facilitate the establishment of a centralized effluent treatment plant (CETP) (Gebregziabher et al., 2021). The concept of the Circular Economy is gaining traction as a potential pathway for sustainable tannery waste management. Research is increasingly focused on waste valorization converting waste into valuable resources. For instance, studies have demonstrated the feasibility of converting chrome-tanned shavings (a major solid waste) into leather boards or composite materials, thereby reducing the burden on landfills and creating economic value (Murali et al., 2021). Similarly, there is active exploration into the use of tannery fleshings for the production of biogas through anaerobic digestion, which can provide a renewable energy source for the tanneries (Kolomaznik et al., 2021).

Furthermore, there is a push for the adoption of cleaner production technologies. This includes improved process control to reduce chemical consumption and the exploration of alternative, more eco-friendly tanning agents, such as vegetable tannins or other metal-free syntans, though their widespread adoption is limited by cost and performance factors (Sathish et al., 2022).

1. The Nature and Magnitude of Tannery Waste

Tannery operations generate vast amounts of solid and liquid waste, categorized into three main streams.

(1) Solid Waste: This includes raw trimmings, fleshings, hair, and chrome-tanned shavings and off-cuts. It is estimated that for every ton of hide processed, over 600 kg of solid waste is generated (Gebregziabher et al., 2021). Of the total solid waste generated, a

significant portion, especially hair and fleshings, is often dumped indiscriminately or left to decompose in open areas, causing severe odor and public health issues (Rahman & Hossain, 2020, p. 112).

(2) Liquid Effluent: The most polluting aspect is the wastewater, which is a complex mixture of toxic chemicals, including sulfides from the dehairing process, chromium from the tanning stage, and high levels of dissolved salts, organic matter, and heavy metals (Alemu et al., 2019). Effluent from this source is typically characterized by high concentrations of Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Dissolved Solids (TDS) (Smith et al., 2020).

(3) Chromium Pollution: The use of chromium (III) salts in the tanning process is a primary environmental concern. While Cr (III) is less toxic than Cr (VI), it can oxidize under environmental conditions. Inadequate management leads to the discharge of chromium-laden sludge and effluent, contaminating water bodies and agricultural soils, posing carcinogenic risks to ecosystems and human health (Mulugeta & Mengesha, 2020).

2. Predominant Waste Management Practices

The current practices can be broadly classified into end-of-pipe treatment and limited valorization efforts.

A. Common Effluent Treatment Plants (CETPs)

The concept of Common Effluent Treatment Plants (CETPs) was developed as a strategic response to the challenges faced by small and medium-scale industries, such as tanneries, in managing their wastewater independently. As noted by scholars, "CETPs are considered as a viable treatment solution for cluster of small scale industries, owing to their low capital and operating cost, and minimal requirement of land and skilled manpower" (Khan et al., 2021, p. 145). In an attempt to centralize waste management, tanneries in clusters like the Modjo Leather City are connected to a Common Effluent Treatment Plant (CETP). The conventional treatment process for such industrial effluents, particularly from tanneries, typically involves a sequence of physical and chemical operations. This sequence generally includes: Screening for the removal of large solid particles; Equalization to homogenize the effluent flow and characteristics; Chemical Coagulation and Flocculation, often using lime and alum to precipitate dissolved pollutants; and finally Sedimentation to separate the generated sludge from the treated water (Tadesse & Guya, 2017).

However, the performance of these CETPs is often sub-optimal. Studies have shown that the final effluent frequently fails to meet the national Environmental Protection Authority (EPA) discharge standards, particularly for parameters like chromium, sulfide, and TDS (Tadesse & Guya, 2017). A review of the literature reveals consistent barriers to effective water purification. Scholars have identified that these systems frequently suffer from inadequate design (Chen, 2021), operational inefficiencies (Global Water Institute, 2022), and the prohibitive cost of treatment chemicals (Olsson et al., 2020).

B. Solid Waste Management: Limited Valorization

The management of solid waste is a mixed picture, with some valorization and much disposal.

Hides and Skins Trimmings: The market for hides and skins trimmings is frequently characterized by poor organization (FAO, 2022). This is partly because these by-products are only inconsistently sold to local artisans, who use them for the production of glues and animal feed (FAO, 2022). Fleshings and Hair: A large quantity of these wastes is often dumped in open landfills or burned, causing air and soil pollution (Gebremichael et al., 2021). Chrome Shavings: These are the most problematic solid wastes due to their high chromium content. While some tanneries store them, and a few pilot projects have explored their use for producing leather boards or extracting chromium, widespread, industrial-scale recycling is not yet a reality in Ethiopia (Bereka & Assefa, 2018).

3. Major Challenges and Drivers of Pollution

Several interconnected factors contribute to the poor state of tannery waste management in Ethiopia.

Technological and Infrastructural Deficits: Many tanneries use outdated and inefficient processing technologies that generate more waste and consume more water and chemicals compared to modern, cleaner technologies (Alemu et al., 2019). Weak Enforcement of Regulations: Although Ethiopia has environmental laws and standards, enforcement is often lax. The high cost of compliance and insufficient monitoring capacity allow polluting practices to continue with relative impunity (Tadesse & Guya, 2017). Economic constraints: present a formidable barrier. The implementation of advanced waste treatment and recycling technologies requires substantial capital investment, which is often prohibitive for many tanneries that operate on thin profit margins (Joseph & Nithya, 2009). This financial burden discourages investment in cleaner technologies, even when the long-term benefits are recognized, locking smaller operators into polluting practices. Lack of awareness and technical expertise: perpetuates the cycle of pollution. There is a well-documented gap in the technical know-how regarding cleaner production methods and a limited understanding of the economic potential inherent in waste valorization among industry operators (Kanagaraj et al., 2015). This knowledge deficit means that tanneries may not only be unaware of cleaner alternatives but also fail to perceive their waste as a valuable resource, thus missing opportunities for both environmental and economic improvement.

4. Emerging Sustainable Practices and Future Directions

Recognizing the severity of the problem, there is a growing push towards more sustainable practices, driven by both regulatory pressure and research.

Cleaner Production (CP): Research is promoting CP techniques, such as water recycling, chemical recovery, and improved process control, to minimize waste at the source. For instance, hair-saving unhairing methods can reduce sulfide pollution and recover hair as a valuable protein (Gebregziabher et al., 2021). Waste-to-Resource Initiatives: There is significant research focus on valorizing tannery waste. This includes: Production of Biodiesel and Animal Feed: Poultry feed and biodiesel have been successfully produced from fleshing waste in laboratory settings (Gebremichael et al., 2021). Compost and Biogas: Co-composting tannery sludge with other organic waste is being explored to produce organic fertilizer, though the chromium content remains a critical concern that requires pre-treatment (Mulugeta & Mengesha, 2020). Chromium Recovery: Methods for extracting and reusing chromium from spent tanning liquor and chrome shavings are seen as a key solution for closing the loop and reducing toxicity (Bereka & Assefa, 2018).

Tannery Waste Management Challenges in Ethiopia

Waste Generation

The transformation of raw hides into leather is an inherently wasteful process, characterized by the generation of substantial quantities of high-polluting solid and liquid waste. A significant portion of the raw hide weight, often cited as 30-40%, is converted into solid waste during the beamhouse operations (pre-tanning), resulting in by-products such as hair and fleshings (Ahmad et al., 2019). The subsequent tanning process, particularly chromium tanning which accounts for approximately 90% of global leather production, introduces further pollution challenges. This includes the generation of chromium-laden sludge from the treatment of wastewater (Sathish et al., 2020). The liquid effluents from tanneries are a major environmental concern, as they are complex mixtures containing residual toxic chemicals from processing, high levels of suspended solids, and dangerous concentrations of heavy metals like chromium, nickel, and zinc (Kanagaraj et al., 2015; Lofrano et al., 2013). The presence of chromium, especially in its hexavalent form (Cr-VI), is a critical issue due to its high toxicity, mutagenicity, and carcinogenicity, posing severe risks to aquatic ecosystems and human health (Ludvik, 2000).

Inadequate Waste Control: As Critical Environmental Challenge

The tannery industry is a cornerstone of Ethiopia's manufacturing sector, contributing significantly to export earnings and employment. However, this economic contribution is severely offset by the sector's profound environmental footprint, primarily stemming from inadequate waste control. This inadequacy manifests in two critical areas: insufficient regulation of chemical and water inputs and the persistently poor efficiency of wastewater treatment plants.

A primary concern is the lack of sufficient control over chemical and water consumption. Ethiopian tannery operations are characterized by inefficient processes leading to excessive use of water and chemicals like sodium sulfide, chromium salts, and sulfides. This inefficiency is not merely a technical failure but is rooted in the widespread use of outdated and "low-cost technologies" that are inherently resource-intensive (Leta et al., 2004). The problem is compounded by poor chemical management practices, where excess, unspent chemicals are routinely washed off and discharged directly into effluent streams, representing both a significant economic loss and a severe pollutant load (Alemu et al., 2019). This uncontrolled consumption directly leads to the generation of highly concentrated, toxic wastewater, overwhelming the subsequent treatment systems.

The second and most consequential failure lies in the operation of wastewater treatment plants (WWTPs) with poor efficiency. Even in tanneries where treatment facilities exist, their performance is often grossly inadequate. A seminal study on the Modjo tannery effluent, one of Ethiopia's largest leather industrial zones, found that the treated wastewater consistently failed to meet the national regulatory standards for key parameters such as Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and total suspended solids (TSS) (Leta et al., 2004). This inefficiency is systemic. Research indicates that the design of many treatment plants is flawed from the outset, often failing to account for the specific characteristics and high variability of tannery effluent, leading to frequent system shocks and failures (Bekele, 2014).

The core of the treatment problem often resides in the ineffective handling of chromium, a heavy metal of significant toxicological concern. Studies have shown that conventional treatment methods employed in Ethiopia are insufficient for removing chromium to safe levels. For instance, Alemayehu et al. (2021) demonstrated that effluent from tanneries in the Awash River basin contained chromium concentrations far exceeding permissible limits, posing a direct threat to aquatic ecosystems and public health. The poor removal efficiency is frequently attributed to inadequate process control in the primary coagulation and sedimentation stages, which are critical for heavy metal removal (Berihun, 2018).

Environmental Impact of the waste

The discharge of untreated wastewater into rivers represents a profound environmental and public health crisis, with impacts that cascade through aquatic ecosystems and human communities. The primary consequence is the severe degradation of water quality, driven by two key processes: deoxygenation and eutrophication.

The introduction of large quantities of organic pollutants, measured as biochemical oxygen demand (BOD), initiates a destructive cycle. As heterotrophic bacteria proliferate to decompose this organic matter, they consume dissolved oxygen (DO) from the water column. This consumption can rapidly deplete oxygen levels to a point where a river becomes hypoxic (DO < 2 mg/L) or even anoxic (DO ~ 0 mg/L), a state incapable of supporting most aquatic life (Chapman, 1996). This leads to widespread fish kills and a catastrophic loss of biodiversity, as sensitive species like salmonids and mayflies are eliminated, leaving only pollution-tolerant organisms such as sludge worms and certain chironomid larvae.

Concurrently, wastewater rich in nutrients particularly nitrogen (N) and phosphorus (P) acts as a potent fertilizer for aquatic plants and algae. This triggers cultural eutrophication, characterized by massive algal blooms that blanket the water's surface. These blooms block sunlight, causing the death of submerged aquatic vegetation. Furthermore, when the algal biomass dies and decomposes, the bacterial respiration further exacerbates oxygen depletion, creating or intensifying "dead zones" in the river and downstream estuaries (Smith & Schindler, 2009).

The risks to community well-being are direct and severe. Contaminated rivers serve as reservoirs for pathogens, including bacteria (e.g., E. coli, Salmonella), viruses (e.g., hepatitis, rotavirus), and parasites (e.g., Giardia, Cryptosporidium). These pathogens pose a significant threat to populations using the river for drinking water (even after rudimentary treatment), bathing, or irrigation of crops. The World Health Organization (WHO, 2022) estimates that unsafe water, sanitation, and hygiene are responsible for hundreds of thousands of deaths annually from diarrheal diseases alone, with the majority being children in developing regions.

Beyond biological agents, untreated wastewater often contains a cocktail of chemical pollutants, including heavy metals (e.g., lead, mercury, cadmium), industrial solvents, and persistent organic pollutants (POPs). These toxic substances can accumulate in the sediments and be biomagnified up the aquatic food chain, ultimately posing long-term carcinogenic, mutagenic, or teratogenic risks to humans who consume fish or other aquatic organisms (UN-Water, 2021). The contamination of soil and groundwater through the irrigation of crops with polluted river water further extends the pathway of exposure, compromising food safety and long-term agricultural sustainability.

Solid Waste Management practices

The proper management of solid waste is a critical environmental and public health challenge for Ethiopia, a nation experiencing rapid urbanization and population growth. This challenge is significantly exacerbated by a scarcity of suitable landfill sites and insufficient mechanisms for solid waste valorization (Alemu, Megersa & Leta, 2018). The existing system is largely characterized by inadequate service coverage, inefficient collection, and a heavy reliance on uncontrolled dumping, posing severe risks to both urban ecosystems and human health.

The Scale and Composition of the Problem

Urban centers in Ethiopia, particularly the capital Addis Ababa, generate substantial and growing volumes of municipal solid waste (MSW). Estimates suggest that Addis Ababa alone generates over 0.4 kg/capita/day, resulting in more than 3,500 tons of waste daily, with collection rates lagging significantly behind (Moges, 2020). The composition of this waste stream is predominantly organic, with biodegradable materials primarily food scraps and agricultural residues comprising 60-85% of the total MSW (Tadesse, 2018). This high organic fraction is a key characteristic that, while presenting a major challenge for disposal, also represents a significant opportunity for valorization that remains largely untapped.

Key Challenges in the waste Management System

1. Inadequate Collection and Service Coverage

A primary bottleneck in the management chain is the inefficient collection of waste. Service coverage is often limited to city centers, with peri-urban and informal settlements frequently neglected. As a result, a substantial portion of generated waste is either dumped indiscriminately in open spaces, water bodies, and ravines or burned informally, leading to soil, water, and air pollution (Getahun et al., 2012). The existing collection infrastructure is often outdated and insufficient, with a lack of proper transfer stations and a fleet of vehicles that is inadequate for the task.

2. Scarcity of Sanitary Landfill Sites

The scarcity of engineered landfill sites is a critical exacerbating factor. Most cities rely on open dumpsites, such as the now-closed "Koshe" dump in Addis Ababa, which was infamous for its environmental hazards and the tragic landslide in 2017 that claimed over 100 lives (BBC, 2017). The development of new sanitary landfills, like the Repi landfill designed to replace Koshe, faces immense challenges, including high capital costs, difficult terrain, and significant community opposition (NIMBY - "Not In My Backyard") due to the associated nuisances and perceived health risks (Alemu, Megersa & Leta, 2018). This scarcity forces municipalities to rely on unsustainable and dangerous disposal methods.

3. Insufficient Mechanisms for Valorization

Despite the high organic content of the waste stream, mechanisms for valorization—the process of converting waste into valuable resources like energy, compost, or materials—are severely underdeveloped. While composting has been promoted as a logical solution, numerous initiatives have failed due to technical problems, lack of market for the final product, and poor integration with the formal waste management system (Moges, 2020). For instance, the composting plant at the Kaliti site in Addis Ababa has historically operated far below its capacity due to operational and marketing challenges (Tadesse, 2018). Other valorization pathways, such as waste-to-energy or plastic recycling, remain in their infancy, operating mostly through the informal sector without formal recognition or support.

4. Institutional and Financial Constraints

Solid waste management in Ethiopia is hampered by weak institutional capacity, fragmented responsibilities between different levels of government, and chronic underfunding (World Bank, 2018). Municipal budgets are often insufficient to cover the high operational costs of a modern waste management system. Furthermore, cost recovery through user fees is low and inefficient, making the system financially unsustainable in the long term.

5. Regulatory & Enforcement Gaps

The chasm between the ambitious environmental policies on paper and the reality on the ground in Ethiopia is a critical issue, primarily driven by significant regulatory and enforcement gaps, compounded by profound institutional inadequacies (Ayele, 2019; Gebremichael, 2021).

A primary manifestation of the regulatory gap is the disconnect between federal proclamations and local implementation. While Ethiopia has a robust framework, including the seminal Environmental Policy of Ethiopia (1997) and subsequent proclamations like The Environmental Impact Assessment Proclamation No. 299/2002 and its successor No. 299/2021, their application is consistently inconsistent. As noted by Ayele (2019), "the translation of these federal environmental mandates into regional and woreda (district) level practices is fraught with ambiguity and a lack of contextualized guidelines," creating a legal vacuum at the point of enforcement (p. 45).

This regulatory weakness is inextricably linked to a severe enforcement gap within the mandated institutions. The responsible bodies, primarily the Environmental Protection Authority (EPA) at the federal level and its regional counterparts, are critically under-resourced. They suffer from a chronic lack of technical capacity, funding, and political leverage to hold powerful actors, particularly state-owned enterprises and large-scale agricultural investors, accountable. A study on the floriculture industry around Lake Ziway, a major foreign exchange earner, found that "while most farms had conducted an EIA, compliance with mitigation measures was rarely monitored, and violations went unpunished due to the institutional weakness of the regional environmental bureau" (Meseret, 2020, p. 112; Mekonnen & Woldeamanuel, 2021). This demonstrates that the existence of a regulation is meaningless without a credible threat of enforcement.

The institutional inadequacy is further deepened by fragmentation and a lack of coordination. Environmental management is split across multiple ministries (Water and Energy, Agriculture, etc.), with the EPA often unable to effectively coordinate or impose its will. This "silo effect" leads to contradictory policies, such as the promotion of large-scale sugar plantations in the Omo River Basin driven by agricultural development goals undermining the EPA's mandate to protect ecosystems and the livelihoods of indigenous communities. As Gebremichael (2021) argues, "the institutional architecture for environmental governance is subordinated to developmentalist state agendas, rendering regulatory bodies peripheral and ineffective" (p. 78).

Strategic Way Forwards to improve Ethiopian Tanneries waste management practices

The Ethiopian leather industry holds significant economic potential, but its growth is hampered by severe environmental and social challenges, particularly from tannery operations (Gebregergis et al., 2019). A strategic, multi-faceted approach is essential to transition towards a sustainable and competitive sector (Mulugeta, 2017). The following framework outlines the key strategic pillars for this transformation, integrating the need for economic viability with stringent environmental and social accountability (Ayele et al., 2022; UNIDO, 2018).

1. Environmental Compliance and Cleaner Production

The most immediate challenge is the pollution from tanneries, which often discharge untreated effluent containing heavy metals, salts, and organic waste into water bodies. A shift from end-of-pipe treatment to Cleaner Production (CP) is critical. This involves adopting in-process modifications to reduce waste at its source. For instance, hair-saving unhairing methods and chrome recovery and reuse systems can drastically reduce chemical consumption and toxic sludge (Mekonnen et al., 2022). As Gebregziabher et al. (2021) argue, investing in centralized effluent treatment plants (CETPs), particularly in industrial clusters like the Modjo Leather City, is not only an environmental imperative but also an economic one, as it reduces the compliance burden on individual SMEs(Small and Medium Enterprises.

2. Invest in Advanced Treatment Technologies

Even with CP, end-of-pipe treatment remains crucial. Conventional treatment systems often struggle with the complex cocktail of organics, salts, and heavy metals in tannery effluent. Investing in advanced technologies is imperative. Constructed wetlands, for instance, offer a nature-based, cost-effective solution for polishing effluent and removing heavy metals through phytoremediation, demonstrating "significant removal efficiencies for Cr(III), BOD, and TSS" (Yirga et al., 2020, p. 112). For higher purity standards, membrane bioreactors (MBRs) combine biological treatment with membrane filtration, producing an effluent suitable for reuse, thereby addressing water scarcity and reducing discharge (Lofrano et al., 2013).

3. Valorize Solid Wastes

A paradigm shift from viewing solid wastes as a disposal problem to recognizing them as valuable resources is critical. Tannery solid wastes including hair, fleshings, and chromium-tanned shavings are rich in protein and other compounds. Innovative valorization methods can transform this waste stream. For example, hair and fleshings can be hydrolyzed to produce high-value protein hydrolysates for the feed and fertilizer industries (Chojnacka et al., 2021). Similarly, chromium-containing shavings can undergo pyrolysis to produce biochar, which can be used for wastewater treatment or as a soil amendment, creating a circular economy model (Kebede et al., 2021).

4. Strengthen Environmental Governance

Robust environmental governance is the backbone of effective pollution control. This requires strengthening both planning and enforcement mechanisms. The mandatory and rigorous application of Environmental Impact Assessments (EIAs) for new and expanding tanneries is essential to foresee and mitigate negative impacts (MoEFCC, 2002). Furthermore, the existing regulatory framework must be enriched with clear, enforceable discharge standards for key pollutants like chromium and sulfide, coupled with a credible enforcement regime that includes meaningful penalties for non-compliance, as weak enforcement is often cited as a primary failure point (Gebregziabher et al., 2021).

5. Improve Worker Safety and Health

The hazardous environment within tanneries poses direct risks to worker health. Adherence to international Occupational Health and Safety (OSH) standards is non-negotiable. This goes beyond the provision of Personal Protective Equipment (PPE) to encompass a systemic approach. Comprehensive worker training on chemical handling, particularly for sodium sulfide and chromium compounds, is vital (Mekonnen et al., 2020). Furthermore, implementing robust hazard identification systems, such as regular chemical exposure monitoring and clear signage, can proactively prevent accidents and chronic health issues (ILO, 2018).

6. Foster Stakeholder Collaboration

Addressing the complex challenges of the tannery sector cannot be achieved by a single entity. A coordinated, multi-stakeholder platform is necessary. This involves fostering collaborative efforts among tanneries (through associations like the Ethiopian Tanners Association), government bodies (e.g., MoI, EPA), academic institutions, and local communities. Such a platform can facilitate technology transfer, joint research initiatives, and collective action plans for shared infrastructure, such as centralized effluent treatment plants, which are often more feasible than individual solutions for small-scale tanneries (Beyene et al., 2022).

7. Public-Private Partnerships (PPPs)

Public-Private Partnerships (PPPs) have emerged as a prominent model for improving municipal solid waste management (SWM), particularly in developing countries where municipal authorities often struggle with financial constraints, technical limitations, and inadequate service coverage. The core rationale for PPPs is to leverage the efficiency, innovation, and capital of the private sector to complement public sector oversight and social welfare goals (World Bank, 2023). A critical, yet often overlooked, component of a successful and equitable SWM-PPP is the formal integration of the informal waste pickers who already perform a significant portion of recycling and collection services in many cities.

The inefficiencies of purely public SWM systems are well-documented. Municipalities frequently face budget shortfalls, leading to irregular waste collection, inadequate recycling, and environmental pollution. PPPs are designed to address these gaps by introducing performance-based contracts, managerial expertise, and technological advancements. As noted by the International Solid Waste Association (ISWA), "When properly structured, PPPs can lead to improved service quality, cost recovery, and environmental outcomes" (ISWA, 2021, p. 14). This model shifts the role of the public authority from a direct service provider to a regulator and contract monitor, ensuring that public interest standards are met.

However, the success of a PPP in the waste sector is deeply linked to its approach to the pre-existing informal recycling economy. An estimated 20 million people worldwide work as informal waste pickers, providing a valuable environmental service by diverting recyclables from landfills and reducing greenhouse gas emissions, often at no cost to the municipality (World Bank, 2023). A poorly designed PPP that ignores or marginalizes these informal workers can lead to social conflict, impoverishment, and the disruption of established, efficient recycling networks. As Scheinberg et al. (2010, p. 7) argue, "Informal sector integration is not an ‘add-on’ but a core element of modern solid waste management in middle- and low-income countries."

Formally integrating informal waste pickers into PPP frameworks moves beyond mere tolerance to active inclusion, yielding multiple benefits.

- **Improved Livelihoods and Social Justice:** Integration provides waste pickers with stable incomes, access to social security, safer working conditions, and greater social dignity. Wilson et al. (2006) highlight that recognizing the contribution of informal recyclers is a matter of social equity and a step towards poverty alleviation.
- **Enhanced System Efficiency:** Waste pickers possess unparalleled knowledge of local waste streams and collection routes. A PPP that incorporates them as contracted service providers or members of cooperatives can tap into this expertise, leading to

higher recycling rates and reduced costs for the formal system. A study of Pune, India, found that integrating the Kagad Kach Patra Kashtakari Panchayat (KKPKP) cooperative into the city's SWM system significantly improved door-to-collection coverage and recycling efficiency (Chikarmane, 2012).

- **Expanded Service Coverage:** By partnering with waste picker cooperatives, municipalities can extend formal waste collection services to low-income or peri-urban areas that are often neglected by both the public and private formal sectors. This model, successfully implemented in cities like Belo Horizonte, Brazil, demonstrates how PPPs can be structured to achieve universal service coverage while promoting social inclusion (Dias, 2016).

8. Intensifying Public Awareness

Effective solid waste management (SWM) is a cornerstone of sustainable urban development and environmental protection. However, the efficacy of even the most technologically advanced waste management systems is contingent upon active and informed public participation. Therefore, intensifying public education on waste reduction, source separation, and the proper use of waste services is not merely an auxiliary activity but a critical imperative, as public participation is the key to success in any solid waste management scheme (Moya & Jain, 2019). This approach must be multifaceted, leveraging targeted communication strategies and understanding the socio-psychological drivers of pro-environmental behavior.

The foundation of any waste management hierarchy is waste reduction, as preventing waste generation at the source yields the greatest environmental and economic benefits. Public awareness campaigns must move beyond generic messages to provide tangible strategies, such as promoting the purchase of products with minimal packaging, encouraging the use of reusable bags and containers, and fostering a culture of repair and reuse. As noted in a study on consumer behavior, "informing consumers about the environmental consequences of their waste generation and providing them with feasible alternatives can significantly influence their pre-purchase and post-purchase decisions" (Tonglet, Phillips, & Read, 2004, p. 31). Campaigns that frame waste reduction not as a sacrifice but as a smart, modern lifestyle choice can enhance their appeal and effectiveness.

Following reduction, source separation is the linchpin for successful recycling and composting programs. The commingling of waste streams at the point of generation contaminates recyclables and organic matter, rendering them unsuitable for processing and defeating the purpose of separate collection systems. Research has consistently shown that the convenience and clarity of recycling systems are paramount. For instance, a study found that "the provision of a kerbside recycling scheme, particularly one with a high level of convenience, was the most significant factor in explaining increased participation and recycling rates" (Timlett & Williams, 2008, p. 629). Intensified education must, therefore, provide crystal-clear, standardized, and easily accessible information on what materials belong in which bin, using a combination of textual, pictorial, and even digital guides (e.g., QR codes on bins) to minimize confusion.

Finally, public education must extend to the proper use of waste services. This includes informing citizens about collection schedules, procedures for disposing of bulky or hazardous waste, and the repercussions of improper practices like illegal dumping and littering. A key concept here is the "pay-as-you-throw" (PAYT) system, which creates a direct economic incentive for waste reduction. As Kinnaman (2006) explains in his review of PAYT programs, "by charging households for each unit of waste generated, these programs provide a continuous and direct financial incentive to recycle more and to generate less waste" (p. 16). Public awareness campaigns are essential for explaining how such systems work, ensuring public buy-in, and preventing unintended negative consequences like increased illegal dumping.

The methodology of these awareness campaigns is as important as their content. Relying on a single channel is insufficient. A successful strategy employs a diverse mix of tools, including traditional media (posters, radio, local newspapers), digital platforms (social media, municipal apps), and, most importantly, direct community engagement through workshops, school programs, and person-to-person outreach. Schultz (2002) emphasizes that strategies incorporating normative social influence and personalized communication are far more effective than broad, impersonal messages. Furthermore, feedback mechanisms, such as informing residents about the collective recycling achievements of their neighborhood, can reinforce positive behaviors and foster a sense of community efficacy.

9. Enhance Monitoring and Evaluation

To ensure the effectiveness of the aforementioned strategies, a robust Monitoring and Evaluation (M&E) system must be established. As articulated by the United Nations Development Programme (UNDP), a well-designed M&E framework is critical for tracking progress, demonstrating accountability, and informing strategic decision-making to achieve desired outcomes (UNDP, 2009). This system should systematically track key environmental performance indicators (EPIs), such as water consumption per unit of hide processed, chemical usage intensity, and pollutant load in effluent. The regular collection of this data facilitates environmental auditing, a process which allows tanneries and regulators to "identify areas for improvement, track progress over time, and ensure the effective implementation of waste management strategies" (Sarkar, 2012, p. 45). This practice aligns with the principles of adaptive management, where feedback from monitoring data is used to refine and improve operational practices (Holling, 1978). Furthermore, transparent reporting of this data, potentially through sustainability reports or public disclosures, is not merely a regulatory obligation but a strategic tool. It can build crucial trust with regulators and the public while creating an internal driver for continuous improvement, a concept central to the Plan-Do-Check-Act (PDCA) model for environmental management systems (ISO, 2015).

CONCLUSION

The overall conclusion is that waste management practices within the Ethiopian tannery industry are currently ineffective, unsustainable, and pose a significant risk to both the environment and public health. The sector is likely characterized by outdated and linear practices ("take-make-dispose") that fail to adequately handle the large volumes of solid and, more critically, liquid waste generated, particularly the toxic and heavily polluted wastewater from the tanning processes.

The core challenges are multifaceted and interlinked. They likely include: **T**echnical and Infrastructural Deficiencies: A lack of modern, efficient, and affordable waste treatment technologies, especially for Chromium-laden wastewater. Regulatory and Enforcement Gaps: The existence of environmental policies may not be matched by stringent enforcement, leading to non-compliance and a culture of impunity. Economic Constraints: Tanneries, often operating with thin profit margins, face high costs for installing and operating proper waste treatment plants. Lack of Awareness and Expertise: A potential gap in technical know-how regarding cleaner production methods and the economic potential of converting waste into valuable by-products.

Consequently, the current situation not only leads to severe environmental degradation contaminating water bodies and soil but also undermines the long-term economic sustainability and international reputation of one of Ethiopia's key export sectors.

RECOMMENDATIONS

To address these challenges, a multi-pronged and strategic approach is necessary, moving from a linear waste model to a circular economy framework. The following recommendations are proposed:

- Policy, Regulation, and Enforcement: Strengthen and Strictly Enforce Environmental Laws: Regulatory bodies must move beyond policy creation to consistent monitoring and enforcement of effluent standards, with clear penalties for non-compliance and incentives for good performance. Implement the "Polluter Pays" Principle: Firmly enforce this principle to hold tanneries financially responsible for the environmental damage they cause, creating a strong economic incentive for them to invest in pollution control.
- Technological and Infrastructural Solutions: Promote Cleaner Production (CP) Technologies: Encourage or mandate tanneries to adopt CP methods that reduce waste at the source, such as water-saving techniques, more efficient chemical use, and Chrome recovery systems. Invest in Centralized Effluent Treatment Plants (CETPs): Given the high cost for individual tanneries, a viable solution is for industrial zones to establish shared CETPs, making advanced treatment more economically feasible. Adopt and Adapt Affordable Treatment Methods: Research and promote the use of locally adaptable and lower-cost treatment technologies, such as constructed wetlands for secondary treatment.
- Economic and Circular Economy Initiatives: Develop a Waste-to-Wealth Strategy: Actively support research and businesses that can valorize tannery waste. Solid wastes like fleshings, trimmings, and sludge can be converted into: Fleshing Waste: Protein-rich animal feed, organic fertilizers, or biodiesel. Trimmings and Shavings: Gelatin, collagen for cosmetics, or biodegradable materials. Sludge: Bio-gas through anaerobic digestion. Provide Financial Incentives: The government and development banks should offer soft loans, tax breaks, or grants for tanneries investing in waste treatment and recycling technologies.
- Capacity Building and Stakeholder Engagement: Enhance Technical Training: Provide regular training for tannery managers and workers on modern waste management, environmental regulations, and the operational know-how of new technologies. Foster Multi-Stakeholder Collaboration: Create a formal platform for collaboration between government agencies, tannery associations, academic institutions (for R&D), and local communities to ensure transparency and shared responsibility.

By implementing these strategic recommendations, the Ethiopian tannery industry can transform its waste management from a liability into an opportunity, ensuring its future is not only profitable but also environmentally sustainable and socially responsible.

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