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Industrial effluents caused environmental pollution and its potential ecological and human health impacts in Ethiopia: A review

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ABSTRACT

As a result of discharge of untreated or inadequately treated industrial effluents into receiving environments, in Ethiopia, environmental pollution with persistent inorganic and organic residues are potential threat to human health and the environment. This review explores the potential impacts of industrial effluents to the environment and human health in Ethiopia. Various search engines were employed to collect relevant reports on physico-chemical parameters and concentration levels of heavy metals reported in industrial effluents sampled from different industries located in Addis Ababa, and several regional states (Oromia, Amhara, and Sidama), Ethiopia. The results of this review study showed that large concentration levels of Electrical Conductivity, Total Dissolved Solids, Biological Oxygen Demand, Chemical Oxygen Demand, Total Suspended Solids, Total Nitrogen, and Total Phosphorus were found in all effluent samples of the studied industries which exceeds the permissible discharge limits established by the country, Ethiopia. In addition to the excessive release of these effluents into nearby receiving streams and rivers, the lack of adequate wastewater treatment facility was also observed. The review indicates that most water bodies receiving industrial effluents (e.g., rivers) in in the study areas are heavily contaminated with various physical and chemical pollutants, causing environmental and health problems for the communities relying on these water bodies.

Introduction

There is a growing need to use all available forms of water, nutrients, and energy efficiently, including their recovery from all types of waste channels (Damania et al., 2017). A paradigm shift is presently underway from a station that considers wastewater streamlets as a waste to be treated and disposed-off to a visionary interest in recovering water, nutrients, and energy from these watercourses in support of circular husbandry (Rao et al., 2017). Currently, the discharge of untreated wastewater remains a global issue. Wastewater product globally is anticipated to increase by 24 and 51 at the end of 2030 and 2050, respectively over the current station. Among the global regions, Asia is the largest wastewater patron, with current periodic estimates of 159 billion m3, representing 42 % of communal wastewater generated widely. By the end of the United Nation-Sustainable Development Goal (UN-SDG) period in 2030, Asia will be producing about 44 % of the world's wastewater. Other regions producing large volumes of wastewater include North America (67 billion m3 of wastewater) and Europe (68 billion m3). In distinction, sub-Saharan Africa produces the lowest periodic amounts of wastewater per capita (46 m3). The small amounts of wastewater product per capita across sub-Saharan Africa are primarily due to a limited force of water and deficiently managed wastewater collection systems in utmost communal settings (Qadir et al., 2020).

Human societies have always had an impact on natural ecosystems due to population expansion, agricultural intensification and industrial development. Literatures indicated that about 70 % of industrial wastewater enters into the nearby receiving waterways without any treatment in developing countries (Wang et al., 2013; Ilmos *et al.*, 2020; Omohwovo, 2024). In Ethiopia, regularly wastewater dumps directly into fresh water systems (Gezahegn et al., 2025; Naser et al., 2014). Tariq et al. (2020) stated that about 90 to 96 % of Ethiopian companies release their wastewater directly into adjacent water bodies and into open areas without any kind of treatment. Additionally, Gemeda et al., 2020 also mentioned that, only 13 % of the wastewater released by industries is uncontaminated by chemicals. As few studies reviewed in this

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paper indicated that, in Ethiopia the problem of untreated wastewater dumping from various businesses, urban trash, and agrochemical wastes in low land areas into open water bodies has become severe and is also becoming worse from time to time (Janna et al., 2019).

In numerous urban areas of Ethiopia, a huge volume of untreated wastewater is discharged into water bodies that are utilized for water systems or rural purposes and has negative impacts on human well-being and the environment (Weldesilassie et al., 2011). Moreover, there is no satisfactory country-wide information base of the surface water effect and well-being suggestions of industrial effluents in Ethiopia. Customary, wastewater treatment strategies may not remarkably compelling in removing these contaminants from wastewater effluents. Hence, the utilization of progressed strategies to expel them is completely fundamental. Choosing the fitting treatment strategy in expansion to specialized, financial, and natural issues requires full information of the wastewater properties delivered in these units (Balkema et al., 2002).

Since industrial wastewater discharge is known to have low pH, high temperature, high levels of various trace heavy metal(loid)s, and a significant volume of suspended materials, it can harm the nearby receiving water ecosystems. The recent assessment by Getachew, 2021 emphasized that agricultural practices, rapid industrial expansion without proper solid waste management and unavailability of wastewater treatment infrastructure, and urbanization related human activities led to water contamination in the Akaki River catchment of the Upper Awash River basin, Ethiopia. Given the detrimental consequences that pollutants can have on the environment and human health, the topic has consequently gained more public attention (Maschal & Truye, 2018; Lemessa et al., 2023).

The direct discharge of wastewater leads to the pollution of water bodies and groundwater, which can result in eutrophication (Qadir et al. 2020) and endanger the health of plants and animals (Ahmed et al., 2021). Anthropogenic activities draw an impact on surface water quality, causing environmental harm and health issues. Factors such as precipitation, climate, soil type, vegetation, geology, and flow conditions significantly affect surface water quality (Chaudhry & Malik, 2017). In dense urban areas, anthropogenic pollution is the biggest factor affecting water quality (Fawell & Nieuwenhuijsen, 2003). Untreated water can lead to water borne diseases including cholera and diarrhea (Ashbolt & Kirk, 2006). According to Firdissa and Soromessa, (2016), many of the contaminants in industrial wastewater effluents are teratogenic, carcinogenic, and allergenic to humans and have been demonstrated to hinder the growth of many bacteria, plants, and animals. For instance, the consumption of heavy metals directly might result from heavy metals caused pollution of water, which may cause several ecological and health impacts.

In addition to its environmental significance, surface water quality checking is a key to defend the well-being of human creatures from hurtful chemicals, and pathogens. As common in other African nations, in Ethiopia, untreated surface water sources are generally utilized for residential purposes, whereas they are ordinarily not tried for water quality. Concurring to the WHO‘s Rules for Secure Drinking Water (WHO, 2017), access to safe water is essential for all household purposes. With this in mind, the goals of this review paper were to: 1) summarize reported concentration levels of physico-chemical parameters and heavy metals in industrial effluents reported from areas including Addis Ababa City, and three Regional States (Oromia, Amhara and Sidama) in Ethiopia, 2) assesses environmental pollution as a result of the industrial effluents inconsideration of parameters such as physico-chemical, organic and heavy metals, 3) assess the potential impacts of environmental pollution to the health of humans and the environment and, 4) examine the existing different wastewater treatment approaches and challenges in Ethiopia.

This review paper significantly contributes in summarizing reported concentration levels of physical and chemicals pollutants reported in literatures for effluents released from industries in selected areas of Ethiopia, and evaluating the environmental and health impacts of those effluents sources contaminants. It also gives insight for researchers, government and other stakeholders the alarming effect of wastewater pollution in the country, which might alert environmental managers and policy makers for the possible intervention. However, this review is limited to highlight the impacts of industrial effluents which caused environmental pollution and ecological and human health impact in specific parts of Ethiopia. Detailed work will be needed in the future where all industries found in Ethiopia are included and probabilistic human and ecological risk assessments will also be discussed.

Methodology

This review study was conducted using systematic literature review method (Grant and Booth, 2009) in which qualitative content analysis was employed. This review presents an explicit recent record of industrial wastewater discharge and its possible consequences on the environment. The sources of information, search strategy, and criteria for inclusion/exclusion were manipulated as follows.

Sources of information, search strategy and inclusion criteria

All search alternatives were utilized in recognizing all significant writing. The scope of the review study was framed on the articles reported from 2002 to 2022. Relevant articles were searched using electronic databases and search engines including Google Scholar, Pub Med, Scopus, and Web of Science. In addition to journal articles, proclamation, gray reports and non-governmental records were included in this review study. The searching activity for important documents was performed utilizing keywords such as Human Health, Industrial effluents, Surface water hydrology, Industrial impact and etc. The search procedure from database was carried out after: (1) $_=$ Industrial Effluents ‘OR $_=$ Effluents from Industry‘/OR$_=$ Human health ‘OR$_=$ health’. OR$_=$ Surface water hydrology‘OR $_=$ risk/impact ‘OR $_=$ risk‘. OR $_=$ wastewater ‘OR $_=$ industrial sewage‘.

In total ninety-eight (98) documents including published articles, conference papers, editorial papers, and non-governmental reports were identified from various sources as aforementioned. Following the initial screening and inclusion criteria, 44 studies were included in the systematic review (Fig. 1). Below are the inclusion/exclusion criteria sued to select the appropriate documents for the reviewing purpose.

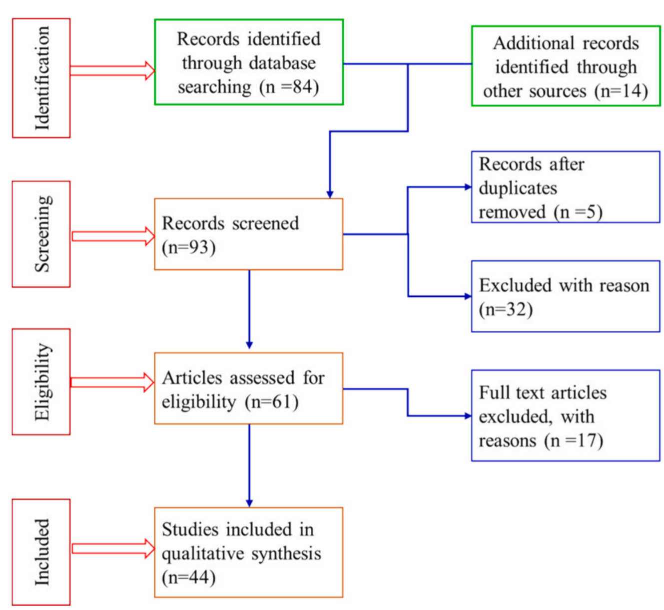

Fig. 1. Prisma chart indicating selected articles.

Criteria: 1) Study area: the articles should report research investigation conducted in Ethiopia, 2) Study plan: any inquiry about the plan employed by investigators, 3) Language: the articles should be published in English language, 4) Population: the target of the investigation results reported in the articles should be for industrial effluents and 5) Publication issue: Original articles published in peer-reviewed journals from 2002 to 2022 were included.

The data were extracted from the included articles utilizing a foreordained information extraction frame. The information with respect to the creator, time of distribution, considered region, considered plan, test measure, and result were summarized from the included articles. The extracted information was displayed in the form of a table and content along with the key findings related to impact of effluent, well-being, surface water hydrology, and study area.

Results and discussion

Overview of industrial wastes in Ethiopia

Ethiopia has abundant water resources and contains the head-stream of multitudinous transboundary rivers, including the Nile River. Water stress is most apparent at the sub-national level and seasonally in some locales. According to the study from Berhanu et al. (2014) and FAO (2016), the water supply in the country is concentrated in western Ethiopia (Abay Basin), and water stress is highest in the eastern part of the country (especially Awash Basin) due to low supply and high demand. Majorities of industries in Ethiopia have discharged their waste in the form of liquid, dust patches, and banks without treatment (EEPA, 2003). The wastewater discharged from the industries contains suspended solids, both degradable and non-biodegradable organics, oils and greases, heavy metal ions, dissolved inorganics, acids, bases, and coloring composites, which have the capability to contaminate nearby rivers (Kanu and Achi, 2011). According to several studies, severe situations of artificial pollution and high level of biological oxygen demand (BOD) have been attributed to wastewaters from tanneries and textile industries around Addis Ababa, Ethiopia. Artisanal gold mining activities have also degraded watersheds throughout Ethiopia (CCA, 1999; Firdissa et al., 2016).

The primary threat to surface water quality in Ethiopia is pollution that arises from residential and industrial activities (Gebre et al., 2016). The majority of industries in the country discharge wastewater into nearby water bodies with little or no treatment (EPA, 2003). In many parts of Ethiopia, industrial effluents are discharged into surface waterways, and nonfunctional treatment plants are used to treat their effluents (Mersha, 2012). For instance, Yohannes and Elias (2017a) reported that 90 % of industries in Addis Ababa release their trash (effluent) without sufficient treatment. With the ever-increasing demand for irrigation water, farmers are regularly forced to use poor-quality water for irrigation purposes. According to Alayu and Yirgu (2018), industrial wastewater discharge has led to increased pollution due to harmful chemicals and nutrients. The disposal of direct industrial waste into water bodies has several repercussions (Fig. 2). Effluents with concentrations above the legally permissible limits are likely to degrade and destroy local environments directly and indirectly by affecting the physical and biological environment, such as land, water, and living organisms and human beings (Dadi et al. (2017). Utilizing polluted river water by downstream residents for agriculture and other activities can causes different social problems (Abrha and Chen, 2017).

Characteristics of the included studies

A total of 98 articles were conducted reported in Ethiopia and aimed to determine the potential impact of industrial effluents on surface water and human health. Of the reported literatures only 44 articles (45 %) were included in this review. From the 44 articles reviewed in this study, 6 studies (23 %) were conducted in the Oromia Regional State, 5 studies (19 %) in the Amhara Regional State, 14 studies (54 %) in Addis Ababa City, and 1 study (4 %) in the Sidama Regional State, Ethiopia (Table 1). Effluents collected from industries including brewery (30 %), tannery (34 %), paint (4 %), industrial park (4 %), soap and detergent (8 %), textile (4 %), meat processing (4 %), soft and beverage (4 %) industries and others (8 %) were addressed in the literatures reviewed in this study.

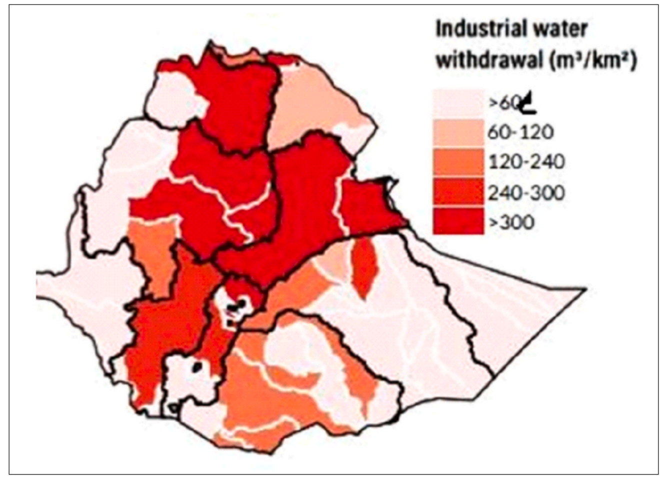

Fig. 2. Industrial water discharge from some towns of Ethiopia (Adane et al., 2020).

Physico-chemical parameters

The mean concentrations of physio-chemical parameters reported for the effluents discharged from different industries in Ethiopia were summarized in Table 2. The value of each parameter among factories with recommended standards were compared and discussed.

Electrical conductivity, total dissolved solids: Electrical conductivity (EC) is the measure of dissolved solids or mineral ions in the water. The more ions are in the wastewater, the higher the EC. The EC and total dissolved solid (TDS) concentrations among the studied industrial effluents in Ethiopia ranged from 523 μS/cm to 16,930 μS/cm, and 287 mg/l to 15410 mg/l, respectively. Among all industries in Ethiopia, the highest EC and TDS values were recorded for effluents discharged from industries in Addis Ababa and Oromia, especially those from AA, AE, BA, Ab, Di and NWT (Table 2). The minimum concentration of EC (523 μS/cm) and TDS (287 mg/l) values were recorded from effluents released from BLIP and RSD (Lamessa *et al.*, 2022). From breweries, the mean concentration EC and TDS was higher in BB (3330 $\pm$ 3.27 μS/cm; 1674 $\pm$ 1.42 mg/l) and MSD (3840 $\pm$ 3.98 μS/cm, and; 1912 $\pm$ 1.73 mg/l). From Tanneries, a high mean concentration of EC and TDS was registered in DiT, which accounted for 16930 $\pm$ 27.2 μS/cm and 8435 $\pm$ 3.1 mg/l, respectively (Table 2).

For many industries, the EC and TDS values recorded were beyond

Table 1
Types and regional distribution of industries for which their effluent were reported and included in the review.

Types of Industries	Region/City				Total
	Addis Ababa	Oromia	Amhara	Sidama	
Brewery	5	2	1	–	8
Tanning/Leather	5	2	2	–	9
Paint	1	–	–	–	1
Industrial park	1	–	–	–	1
Soap& detergent	2	–	–	–	2
Textile	–	–	1	–	1
Meat processing	–	–	1	–	1
Soft Drink	–	–	–	1	1
Other than the above	–	2	–	–	2

Table 2
Concentration levels of physical, biological and chemical parameters of effluent discharged from selected industries.

Industry type	Concentration levels for the reported physical, biological and chemical parameters										References
	EC(µS/cm)	TDS(mg/l)	pH	Temp. (C)	TA (mg/l)	TH(mg/l)	BOD (mg/l)	DO (mg/l)	COD (mg/l)	Turbidity (NTU)	
NAL	2120 ± 2.89	1064 ± 1.25	8.35 ± 0.39	26.4 ± 0.39	1080 ± 1.20	180 ± 0.36	ND	ND	ND	ND	a
BA	828.1 ± 5.46	414 ± 2.37	6.91 ± 0.07	27 ± 0.74	410 ± 0.72	420 ± 2.57	ND	ND	ND	ND	a
HB	3840 ± 4.78	1922 ± 2.39	8.49 ± 0.07	28.7 ± 0.8	4080 ± 13.98	510 ± 2.75	ND	ND	ND	ND	a
BB	3330 ± 3.27	1674 ± 1.42	8.43 ± 0.01	33.4 ± 0.44	3510 ± 2.22	1904 ± 1.53	ND	ND	ND	ND	a
MSD	3840 ± 3.98	1912 ± 1.73	8.39 ± 0.04	24.1 ± 0.54	530 ± 2.7	210 ± 0.86	ND	ND	ND	ND	a
EAB	2250 ± 4.67	1128 ± 2.03	8.05 ± 0.03	28.3 ± 0.64	2940 ± 3.18	1500 ± 2.19	ND	ND	ND	ND	a
AA	11860 ± 6.54	5940 ± 4.35	8.19 ± 0.08	17.2 ± 0.89	1620 ± 4.46	2400 ± 6.08	ND	ND	ND	ND	a
Bt	8890 ± 15.55	4481 ± 2.78	7.86 ± 0.09	22.8 ± 0.93	1215 ± 1.32	720 ± 3.19	ND	ND	ND	ND	a
AE	8750 ± 5.97	4372 ± 2.985	8.35 ± 0.09	22.9 ± 0.93	1260 ± 4.70	870 ± 3.22	ND	ND	ND	ND	a
Ab	5680 ± 5.11	2831 ± 2.22	8.22 ± 0.06	22.9 ± 0.69	1620 ± 3.47	900 ± 2.39	ND	ND	ND	ND	a
DiT	16,930 ± 27.2	8435 ± 3.13	8.24 ± 0.09	20.5 ± 0.98	3150 ± 4.91	1425 ± 3.39	ND	ND	ND	ND	a
NWAT	9220 ± 9.33	4615 ± 3.17	8.24 ± 0.05	30.3 ± 1.05	1395 ± 5.23	810 ± 3.64	ND	ND	ND	ND	a
KP	591 ± 4.88	296 ± 2.44	8.43 ± 0.07	16.7 ± 0.76	930 ± 3.81	165 ± 0.63	ND	ND	ND	ND	a
BLIP	1079 ± 3.35	538 ± 1.45	9.81 ± 0.04	19.6 ± 0.46	370 ± 1.27	210 ± 0.57	ND	ND	ND	ND	a
RSD	574.7 ± 3.19	287 ± 1.38	7.88 ± 0.04	29.6 ± 0.43	285 ± 1.17	140 ± 0.50	ND	ND	ND	ND	a
GBF	30,800 ± 26.5	15,4 1 ± 7.19	12.6 ± 0.02	18.9 ± 1.44	2970 ± 7.19	480 ± 4.96	ND	ND	ND	ND	a
AKWW	1021 ± 3.24	511 ± 1.62	7.89 ± 0.05	20.4 ± 0.54	600 ± 2.7	120 ± 0.86	ND	ND	ND	ND	a

Industry type	Concentration levels for the reported physical, biological and chemical parameters										References
	EC(µS/cm)	TDS(mg/l)	pH(—)	Temp. (C)	TA (mg/l)	TH (mg/l	BOD(mg/l)	DO (mg/l)	COD(mg/l)	Turbidity (NTU)	
BLIP	523.3±47.7	325.07 ±20.93	8.41 ±0.22	15.62 ±3.57	ND	ND	1716 ±14.54	ND	126.4±12.3	ND	b
KIP-S	9200±8.55	ND	5.8±0.9	ND	ND	ND	ND	ND	ND	ND	c
KIP-T	860±58.3	ND	9.25 ±0.25	ND	ND	ND	ND	ND	ND	ND	c
KIP-T	3700± 13.1	ND	7.6±0.2	ND	ND	ND	ND	ND	ND	ND	c
KIP-M	1060 ±96.01	ND	7.7±0.25	ND	ND	ND	ND	ND	ND	ND	c
KIP-B	1950 ±48.09	ND	10.15 ±0.9	ND	ND	ND	ND	ND	ND	ND	c
HSD	1653 ±438.9	ND	8.5±0.54	27.36 ±1.17	ND	ND	ND	ND	4115.3 ±268.9	197.9±20.4	d
GShR	1001.1 ±375.8	ND	7.45 ±0.23	22.52 ±0.69	ND	ND	99.2 ±18.58	4.04 ±0.47	650±277.15	63.5±23.5	e
BDT	3953.2 ±150.5	2003.2 ±74.5	7.15 ±0.09	25.5±2.2	228 ±75.8	ND	342±52.5	ND	850.75 ±92.6	ND	f
EEPA	1500	250–500	6—9		–	–	30	4—6	150	–	g
USEPA	1500	250–500	6—9	40	–	–	150	4—6	150	–	h
WHO	1500	500	6.5–8.5	40	–	–	300	4—6	150	–	i

Industry type	Concentration levels of physical, biological and chemical parameters											References
	E. coli (CFU/100ml)	TSS (mg/l)	TS (mg/l)	TN(mg/l)	TP (mg/l)	NH_3 (mg/l)	NH_4^- (mg/l)	Nitrite (mg/l)	SO_4^{2-} (mg/l)	Cl-(mg/l)	S^{2-} (mg/l)	
BLIP	ND	50.7 ±35.7	ND	19.42 ±3.36	4.37 ±0.36	ND	ND	ND	ND	ND	ND	a
HSD	ND	60.8 ±18.9	1089 ±277	ND	ND	ND	ND	ND	ND	ND	ND	b
GShR	164±32	ND	ND	2.4±0.91	1.14 ±1.12	ND	ND	ND	ND	ND	ND	c
BDT	ND	399 ±68.6	ND	462.5 ±130.8	11.5±4.8	228 ±75.8	ND	ND	ND	1408. ±405.3	16.05 ±3.04	d
AA	ND	ND	ND	6.12 ±0.306	10.9 ±1.453	2.97 ±0.189	3.15 ±0.276	1.53±0.20	1360± 33.3	25±1.245	1.44 ±0.02	e
Ba	ND	ND	ND	0.61 ±0.015	0.9 ±0.001	1.62 ±0.009	1.71 ±0.001	0.40±0.01	165±9.2	40±1.623	0.02 ±0.001	e
AE	ND	ND	ND	13.34 ±1.153	1.26 ±0.010	0.05 ±0.009	0.05 ±0.001	0.48±0.01	185±11.2	44±2.622	0.09 ±0.001	e
Ab	ND	ND	ND	10.21 ±1.260	1.53 ±0.012	0.35 ±0.161	0.40 ±0.172	4.28±0.17	155±12.9	36±4.584	0.16 ±0.021	e
Di	ND	ND	ND	9.36 ±0.723	15.3 ±3.561	4.95 ±0.076	5.31 ±0.088	3.38±0.08	1140 ±21.3	14±4.98	1.08 ±0.010	e
NWAT	ND	ND	ND	0.7 ±0.031	1.26 ±0.011	0.50 ±0.018	0.50± 0.0	0.97±0.02	175±10.3	38±1.245	0.11 ±0.002	e
NAL	ND	ND	ND	1.4 ±0.015	1.05 ±0.06	0.58 ±0.009	0.62 ±0.02	0.23±0.01	34±1.17	9.8±0.52	0.17 ±0.001	e
BA	ND	ND	ND	0.91 ±0.161	6.21 ±1.333	0.94 ±0.094	1.00± 0.09	0.97±0.10	58±2.682	8.8 ±0.226	0.21 ±0.012	e

(continued on next page)

Table 2 (*continued*)

Industry type	Concentration levels of physical, biological and chemical parameters										References
	E. coli (CFU/ 100ml)	TSS (mg/l)	TS (mg/l)	TN(mg/l)	TP (mg/ l)	NH_3 (mg/l)	NH_4^+ (mg/l)	Nitrite (mg/l)	SO_4^{2-} (mg/ l)	Cl-(mg/l)	S^{2-} (mg/ l)	
HB	ND	ND	ND	32.54 ±2.046	112 ±13.22	0.40 ±0.028	0.40± 0.03	1.03±0.03	34±4.504	22±1.868	0.17 ±0.004	e
BB	ND	ND	ND	2.47 ±0.076	26.1 ±2.130	0.56 ±0.047	0.59 ±0.056	0.74±0.05	138 ±6.841	11±3.113	0.65 ±0.006	e
MS	ND	ND	ND	11.94 ±1.061	25.6 ±6.176	0.05 ±0.038	0.05± 0.05	0.06±0.04	185 ±8.673	34±2.490	0.06 ±0.005	e
EAB	ND	ND	ND	1.73 ±0.015	2.79 ±0.007	0.50 ±0.009	0.53 ±0.010	0.33±0.01	56±2.168	12±0.522	0.22 ±0.001	e
KP	ND	ND	ND	11.88 ±1.015	1.5 ±0.002	ND	ND	0.03±0.01	3±0.168	19±0.623	0.07 ±0.001	e
BLIP	ND	ND	ND	Trace	11.7 ±0.410	0.54 ±0.010	0.58 ±0.013	0.14±0.01	155 ±10.168	42±3.623	0.06 ±0.001	e
RSD	ND	ND	ND	2.16 ±0.015	0.56±0. 15	0.58 ±0.011	0.62± 0.02	0.27±0.01	11±0.169	9.0 ±0.643	0.09 ±0.001	e
AKWW	ND	ND	ND	10.07 ±0.077	36 ±2.001	0.01 ±0.047	0.01± 0.05	1.24±0.05	21±0.84	24±3.113	0.07 ±0.006	e
GBF	ND	ND	ND	7.65 ±0.138	5.13 ±0.505	1.44 ±0.085	1.53 ±0.089	1.40±0.09	155 ±19.513	30±1.603	0.04 ±0.011	e

Remark: National Alcohol & liqour NAL, Balezaf Alcohol – BA; Heiniken Brewery- HB; BIG Brewery – BB; Moha Soft Drink– MSD; East Africa Bottling – EAB; Addis Ababa- AA; Batu Tannery – Bt; Awash ELICO – AE; Abssiniya Tannery – AbT; Dire Tannery – DiT; New wing Addis Tanneries – NWAT; Kadisco paint – KP; Bole lemi IP – BLIP; Repi soap & Detregent – RSD; Ghion Berekina factories – GBF; Akakikalit Wastewater – AKWW. a – Dessie et al., 2022.
Remark: Bole Lemi IP – BLIP; Komb IP (Steel) – KIP-S; Komb IP (Textile) – KIP-T; Kom.IP (Tannery) – KIP-T; Kom. IP (Meat Processing) – KIP-M; Kom. IP Brewer – KIP-B; Hawasa Soft Drink – HSD; Gondor Shinita River – GShR; Bahirdar Tannery – BDT. b – Lemessa et al., 2022; c – Zinabu et al., 2017; d – Abebe, 2017; e – Getinet,2020; f – Aseffa & Ayalew, 2014; g – EEPA, 2003; h – USEPA, 2010; i – WHO, 2008.
Remark: Bole Lemi IP – BLIP; Hawasa Soft Drink – HSD; Gonder Shinta River – GShR; Bahirdar Tannery – BDT; Addis Ababa – AA; Batu – Ba; Awash ELICO – AE; Abssiniya Tannery – AbT; Dire Di; New wing Addis Tanneries – NWAT; National Alcohol &liqour – NAL; Balezaf Alcohol – BA; Heiniken Brewery – HB; BIG Brewery – BB; Moha soft – MS; East Africa Bottling – EAB; Kadisco paint – KP; Bole lemi IP – BLIP; Repi soap & Detergent – RSD; Akaki kalit WW – AKWW; Ghion Berekina factories – GBF. a – Lemessa et al., 2023; b – Abebe, 2017; c – Getinet, 2020; d – Aseffa & Ayalew, 2014; e – Dessie et al., 2022.

the recommended standard value for EC (1500 μS/cm) and TDS (250 – 500 mg/l) of the Ethiopian and international ecological quality guideline value (EPA, 2003; WHO, 2008; USEPA, 2010). Organic matter contents within the wastewater being discharged from industries might be linked to the increased amount of TDS and BOD. Total suspended solids (TSS) of all the wastewater samples exceeded the admissible limits (150 mg/l) for discharged effluents from Bahirdar Tannery (BDT; 399 mg/l). The minimal TSS values were recorded from effluents discharged from BLIP (50.7 mg/l) and HSD (60.8 mg/l), independently.

Temperature: Temperature is key water quality parameter affecting the values of DO, BOD, and COD of wastewater. Temperature values ranged from 15.6 – 33 °C, found within the standard limits (40 °C) of WHO (2008). The maximum temperature (33.4 °C) and the minimum (15.6 °C) were recorded from B4 BB and BLIP, respectively (Table 2).

pH: Water pH is one of the water quality determining parameter that indicates acidity or alkalinity of water. It affect various chemical and biological processes in water ecosystem The pH value from selected industries ranges from 5.8 to 12.6. The maximum value (12.6) was from effluents discharged from GBF (Table 2), and the minimum (5.8) was observed in effluent sample collected from BLIP (Table 2). The pH of the majority of the effluents from industries falls under the range of alkaline media and exceeded the permissible limits (6–9) established for freshwater ecological quality established by national and international institutions (EPA, 2003; WHO, 2008; USEPA, 2010).

Total Alkalinity and Total Hardness: As indicated in Table 2, the maximum values of total alkalinity (TA = 4080 mg/l)) and total hardness (TH = 2400 mg/l) were observed in effluents from HB and AA, respectively. The lowest mean concentration of TA (285 mg/l) and TH (120 mg/l) were reported for effluents from RSD and AKWW, respectively. The mean concentrations of total alkalinity (TA) in HB & BB were 4080 ± 13.9 mg/l and 3510 ± 2.2 mg/l, respectively.

Biological oxygen demand (BOD) and chemical oxygen demand (COD): The BOD measures the quantity of oxygen required by bacteria to biologically oxidize organic material under aerobic conditions. COD measures all organics: the biodegradable and the non-biodegradable substances. The maximum BOD and COD registered in the BLIP (Lemessa et al., 2022) and HSD (Abebe, 2017) were 1716 mg/l and 4115.1 mg/l, respectively, which are beyond the permissible value (500 mg/l for BOD and 150 mg/l for COD) of USEPA and WHO, 2008. However, the lowest BOD (99.2 mg/l) and COD (650 mg/l) were from the GShR (Getinet, 2020). The values of BOD and COD are critical in the wastewater analyses since they can show the amount of polluted organic materials in the water system. Usually there is a strong correlation between COD and BOD value. Its ratio can give the information whether the waste can be treated biologically or not.

Dissolved oxygen (DO): Dissolved oxygen is the most important and key parameter to measure water quality. The only DO value accounted in Table 2 was from the GShR (4.04 mg/l) (Getinet, 2020), which falls in the range of permissible limits of EEPA (2003), USEPA (2010), and WHO (2008) water quality standards (4–6 mg/l).

Furthermore, the study conducted on Bahir-Dar Textile Factory (BDTF) effluents revealed the presence of various impacts and worsening of water quality conditions near the head of the Blue Nile River in Bahirdar, Ethiopia (Mehari et al., 2015). Other studies suggest that the textile industry in Ethiopia may be the major source of water contamination because many textile firms operate without treatment systems and release their effluents directly into rivers (Sima and Restiani, 2017). Other studies confirmed that the Akaki River was significantly contaminated due to the discharge of partially treated or untreated industrial effluents into the water ecosystem (Amare, 2019).

The highest BOD (342 ± 52.5 mg/l), TDS (2008.25 ± 74.5 mg/l), EC (3953.25 ± 150.3 μS/cm), TSS (339 ± 68.6 mg/l), TDS (1089.7 ± 277.23 mg/l), total nitrogen (TN) (462.5 ± 130.8 mg/l) values were recorded in BDT. Similarly, the maximum COD (4115.3 ± 268.89 mg/l), EC (1653.4 ± 438.9 μS/cm), and turbidity (197.98 ± 20.39 NTU) were registered in HSD (Table 2.

Nutrients: The reported mean concentration (mg/l) of nutrients from the wastewater effluents of targeted factories in Addis Ababa were summarized in Table 2 and showed that the maximum nutrients such as nitrite (NO_2^-) in effluent from AbT (4.28 ± 0.17), HB (1.03 ± 0.05), in GBF (140 ± 0.09); nitrate (NO_3^-) in AE (13.34 ± 1.15), in HB (32.54 ± 2.04), in KP (11.88 ± 1.15); phosphate (PO_4^{3-}) in DiT (15.3 ± 3.56), in HB (112 ± 13.22), in AKWW (36 ± 2.001); ammonia (NH_3) in DiT (4.93 ± 0.076) and GBF (144 ± 0.005); ammonium ion (NH_4^+) in DiT (5.31 ± 0.088); chloride (Cl^-) in AE (44 ± 2.66), in EAB (34 ± 2.49), in BLIP (42 ± 3.6); and sulfide (S^{2-}) in AA (144 ± 0.025) were recorded. A high amount of ammonia can be responsible for eutrophication in the waterways or river. The productivity of algae and other water plants is initiated by the nitrogen contained in ammonia, which can serve as a nutrient that stimulates. Ammonia is also consuming oxygen from the water system during its oxidation to nitrite and nitrate, thus reducing the oxygen in the water, causing problems for fish and other animals in inhaling the oxygen.

Heavy metals

The concentration levels of various heavy metals found in wastewater samples discharged from different industrial areas of Ethiopia were summarized and depicted in Table 3.Table 4..

Iron (Fe): The concentrations of Fe from selected industries ranged from 221.4 mg/l – 17810.2 mg/l. The highest average concentration of Fe was observed in effluents discharged from AA (17810.2 mg/l), while the lowest iron concentration level was from the wastewater sample of the Awash River, which exhibited 221.5 mg/l. The maximum value encountered from selected industries of Addis Ababa (Dessie et al., 2022) was extremely exceeded the maximum limit (300 mg/l) established by USEPA and WHO (USEPA, 2010; WHO, 2008). The main reason for the high Fe values was possibly due to excessive discharge of effluent to receiving water bodies without/partial treatment. According to Abebe *et al.* (2023) describes that the wastewater discharged to the Awash River came from different municipal, commercial, and industrial discharges of upstream sites in which the iron concentration was below the permissible value (300 mg/l).

Manganese (Mn) and Chromium (Cr): The maximum concentration level of manganese (17920 mg/l) and chromium (3933.5 mg/l) were recorded in effluents collected from Sebeta soil(Terefe *et al.*, 2020) and from Kombolcha Tannery-KTa (Zinabu *et al.*, 2017), respectively. However, the lowest values of Mn (67 mg/l) and Cr (3.5 mg/l) were reported in effluents collected from Awash River and Bahirdar Tannery, respectively. The maximum values screened from both industrial areas (Awash River and Bahirdar Tannery) were above the permissible limits

Table 4

Heavy metal (loid)s	Potential Health Effects	References
Arsenic	Gastrointestinal, skin and nerve damage, cancer	[a;b]
Cadmium	Gastrointestinal, kidney and lung damage	[a;b]
Chromium	Lung and skin damage, cancer	[a;b]
Lead	Nervous and immune system and kidney damage embryo/feto toxic	[a;b]
Mercury	Brain and kidney damage, embryo/fetus toxic	[a;b]
Nickel	Lung, brain, kidney, liver, spleen and skin damage, cancer	[a;b]

Note: a – Kassa, 2012; b – Jomova et al., 2025.

Table 3
Heavy metal concentration from wastewater discharge of selected industries of Ethiopia.

Industry type/name	Concentration levels of heavy metals (mg/l)							References
	Fe	Mn	Cr	Ni	Cu	Zn	Pb	
AA	17810.2 ± 4.36	6279.1 ± 4.49	2007 ± 8.32	38.07 ± 0.09	2132.0 ± 0.51	5130.3 ± 0.78	6.32 ± 0.74	a
Ba	2431.0 ± 1.36	8235.0 ± 35.33	1347.2 ± 2.11	17.26 ± 0.11	30.50 ± 0.12	177.60 ± 0.31	13.44 ± 2.3	a
AE	13.44 ± 2.3	807.8 ± 4.79	634.0 ± 3.6	18.82 ± 0.18	49.63 ± 0.39	293.9 ± 1.13	16.69 ± 0.654	a
Ab	5414.0 ± 27.90	246. ± 3.40	1332.0 ± 7.32	27.12 ± 0.146	170.90 ± 1.80	771.10 ± 3.75	6.74 ± 1.73	a
Di	2051 ± 3.25	7069.2 ± 2.60	2010.0 ± 6.52	30.09 ± 0.04	2215.0 ± 0.77	5170.7 ± 0.91	4.15 ± 0.79	a
NWAT	2959.1 ± 4.36	579.2 ± 3.59	2015.0 ± 7.62	31.08 ± 0.08	112.0 ± 0.49	497.6 ± 0.90	5.12 ± 0.84	a
NAL	1285.0 ± 16.82	55.65 ± 0.196	36.01 ± 0.345	17.05 ± 0.127	28.52 ± 0.11	160.7 ± 0.39	5.45 ± 0.68	a
BA	9749.0 ± 7.05	541.70 ± 4.06	34.84 ± 0.17	18.23 ± 0.04	30.70 ± 0.12	1960.3 ± 0.29	20.97 ± 0.46	a
HB	9875.0 ± 38.65	88.20 ± 0.52	87.42 ± 9.70	16.74 ± 0.126	47.57 ± 0.08	220.1 ± 0.77	11.50 ± 0.60	a
BB	10,410 ± 25.58	5187.7 ± 2.46	120.8 ± 0.58	45.39 ± 0.134	2059.2 ± 1.43	1866.0 ± 18.17	40.41 ± 1.11	a
MSD	1100.0 ± 8.46	54.25 ± 0.15	31.10 ± 0.12	19.98 ± 0.17	57.95 ± 0.11	357.9 ± 0.69	29.49 ± 0.285	a
EAB	9530.0 ± 16.35	257.60 ± 0.23	180.20 ± 9.12	31.87 ± 0.03	352.60 ± 2.45	2040.0 ± 15.16	0.01	a
RSD	500.0 ± 2.32	44.23 ± 0.24	42.7 ± 1.19	16.10 ± 0.07	40.65 ± 0.21	457.9 ± 0.70	26.07 ± 0.55	a
BLIP	508.5 ± 2.08	207.9 ± 0.85	45.13 ± 0.154	19.19 ± 0.237	62.40 ± 0.17	420.50 ± 2.64	39.94 ± 0.57	a
AKWW	899.6 ± 3.74	354.8 ± 1.18	68.03 ± 3.89	18.11 ± 0.11	27.64 ± 0.27	298.3 ± 0.92	17.32 ± 0.45	a
KP	272.1 ± 0.55	66.98 ± 0.86	33.67 ± 1.49	11.95 ± 0.19	22.05 ± 0.13	134.70 ± 1.10	17.32 ± 0.50	a
GBF	570.5 ± 3.44	55.32 ± 0.29	2054.0 ± 1.20	24.10 ± 0.17	851.56 ± 0.31	477.9 ± 0.85	25.28 ± 0.65	a
Industry type/name	**Concentration levels of heavy metals (mg/l)**							**References**
	Fe	**Mn**	**Cr**	**Ni**	**Cu**	**Zn**	**Pb**	
SeSo	ND	17919.8±5973.3	ND	474.93±158.3	0.48254±0.16	0.051737±0.01	37.79±12.59	b
SeVe	ND	63561±2118	ND	913.7±304.57	34649±11549	0.0370±0.012	40.718±13.5	b
KS	ND	ND	91±35.5	ND	131±49.3	171300±68955	19±7.6	c
KTex	ND	ND	24.55± 18.35	ND	35.5± 20	215±80.5	2.9±0.7	c
KTa	ND	ND	39933.5±27.7	ND	73.5±25.5	685±443.5	66.5±0.75	c
KMP	ND	ND	136.05±17	ND	18.9±1.5	155±84	265±116	c
KB	ND	ND	448±95.2	ND	77±25	215±54.5	3.5±0.45	c
BT	ND	ND	3.535±0.55	ND	ND	ND	ND	d
MT	ND	ND	196.4±19.73	0.746±0.0567	0.233±0.0133	2.336±0.11	ND	e
USEPA	300	500	100	20	1300	500	15	f
WHO	300	400	50	70	2000	3000	10	g

Remark: Addis Ababa – AA; Batu – Ba; Awash ELICO – AE; Abssiniya – Ab; Dire – Di; New wing Addis Tanneries – NWAT; National Alcohol & Liqour – NAL; Balezaf Alcohol – BA; Heiniken Brewery – HB; BIG Brewery – BB; Moha Soft Drink – MSD; East Africa Bottling – EAB; Repi Soap & Detergent – RSD; Bole lemi IP – BLIP; Akaki kalit WW – AKWW; Kadisco Paint – KP; Ghion Berekina factories – GBF. a – Dessie et al., 2022.

Remark: Sebeta (Soil) – SeSo; Sebe (Veg) – SeVe; Kom Steel – KS; Kom. Tex – KTex; Kombolcha Tannery – KTa; Kom Meat Proc. – KMP; Kom. Brewery – KB; Bahirdar Tannery – BT; Modjo Tannery – MT. b –Terefe et al., 2020; c – Zinabu et al., 2017; d – Aseffa & Ayalew, 2014; e – Amanial, 2015; f – USEPA, 2010; g – WHO, 2008.

of USEPA (Mn = 500, Cr = 100) and WHO (Mn = 400, Cr = 50) (WHO, 2008; USEPA, 2010).

Nickel (Ni) and Copper (Cu): The value of Ni ranges from 0.746 − 913 mg/l and for Cu from 0.233 − 34649 mg/l. The lowest and highest values were reported in effluents from SeVe and MT for Ni and from SeSo and SeVe for copper, respectively (Table 3). The maximum values reported for Ni and Cu were exceeded by several magnitudes as compared to the guideline limits established by WHO (Ni = 70 mg/l & Cu = 2000 mg/L) and USEPA (Ni = 20 mg/l & Cu = 1300 mg/L) as indicated in Table 3.

Zinc (Zn) and Lead (Pb): The average values of Zn and Pb from selected industries were in the ranges of 0.037—–171300 mg/l and 2.9—–265 mg/l, respectively. The lowest and highest values were reported for effluents from Sebeta vegetable and Kombolcha Steel effluents for Zn, & from Kombolcha textile industry, and Kombolcha meat processing factory effluents for Pb, respectively (Table 3). The highest concentrations of Zn (171300 mg/l) and Pb (265 mg/l) from both Kombolcha Steel & Meat processing were above the admissible limits for USEPA (Zn = 500 mg/l and Pb = 15 mg/l) and WHO (Zn = 300 mg/l & Pb = 10 mg/l) (USEPA, 2010 WHO, 2008).

Potential impacts of industrial effluents

Industrial effluents are liquid wastes generated during industrial processes. The improper disposal of industrial wastewater effluents has long been a major issue, causing worry among both the government and the industrial ecology. Effluent disposal often fails to meet pretreatment requirements and toxic-pollutant- effluent constraints, despite being technically and economically feasible for specific criteria. These anomalies cause significant environmental pollution, which poses major health risks. Untreated wastes from urban and industries hve discharged into inland water bodies, causing smell, discoloration, and oiliness (Akaninwor et al., 2007). Discharges of untreated or partially treated wastes including algal nutrients, non-biodegradable organics, heavy metals, and other toxicants accelerate the deterioration of recipient water bodies. Thus, effluents discharged in to the environment has enormous impact on the surface and ground water, health of human and animals, soil and edible plants, socio-economy of the local society.

Impact on surface water

Surface water is one of the most affected ecosystems on earth, and its pollution have led to severe ecological degradation including decline in water quality and accessibility, intense flooding, loss of species, and changes in the distribution and structure of the submarine biota thus, making surface water courses not sustainable in providing ecosystem goods and services. Decline in water quality can lead to increased treatment costs of drinkable and industrial process water (Rainwater-Harvest-co.za., 2010).

The use of water with poor quality for agrarian conditioning can affect crop yield and create food instability. The presence, transport, and fate of heavy metals and organic composites (which are poisonous and persistent) in water bodies are a cause for serious concern globally (CSIR, 2010).

Surface water is increasingly under overdue stress due to population growth and increased industrialization. Wastewater can contains contaminants including microorganisms, heavy metals, nutrients, radionuclides, pharmaceuticals, and particular care products, which can pose an immense impact on aquatic life inhabits in surface water, and to the health of human. The health of the aquatic ecosystem can be negatively affected by the presence of poisonous substances. This is further aggravated with high discharges of industrial wastes. According to the report by CSIR (2010), the release of domestic and industrial wastewater has led to the increase in freshwater pollution and reduction of clean water resources. From developing countries, huge amounts of wastewater generated do not undergo any form of treatment. In many urban centers, various forms of wastewater treatment facilities (WWTFs) exist, but most of them are producing ill-treated effluents, which are disposed of onto freshwater courses (UN-Water, 2023; UN-Water, 2024).

Effluents from industries can pose acute impacts on the receiving water bodies that are due to high degrees of ammonia and chlorine, and high loads of oxygen-demanding materials, or poisonous concentrations of heavy metals and organic pollutants (Morin-Crini et al., 2022; Jahan & Singh, 2023). The organic load of wastewater discharged effluents from wastewater treatment facilities, usually contributes to the oxygen demand level of the receiving water. There's increased depletion of dissolved oxygen (DO) in surface water that receives ill-treated wastewater. The presence of degradable organics in wastewater, which leads to low levels of DO, is responsible for the detrimental effect when compared to surface water sources. Low DO values can lead to the malfunctioning of some fish species and can ultimately lead to the death of fish (Igbinosa and Okoh, 2009; Morin-Crini et al., 2022). Surface water is anticipated to have low BOD/COD values to sustain aqutic life. High levels of BOD and COD can cause harm to aquatic organisms, especially fish. Low levels of BOD and COD in river systems indicate poor water quality, while high levels indicate polluted water.

The impacts of nutrients, such as nitrite, nitrate, and phosphorus, into water bodies can induce eutrophication. Eutrophication can result when nutrient-rich wastewater effluents are discharged onto watercourses (Dorgham, 2014; Jwaideh et al., 2022). This can lead to algae blooms and growth of plants in the water ecosystem. When this happens, the turbidity of the water increases, plant and animal biomass increases, sedimentation rate increases, species diversity decreases, and anoxic conditions may develop, and this could give rise to a change in the dominant species of the aquatic biota (Edokpayi, 2016; Jwaideh et al., 2022). To animals including humans, surface water impurity by trace metals poses a major health threat, such as cardiovascular, neurological, and renal issues. Chemical pollution in water is substantially caused by nitrates, fluorides, arsenic, cadmium, lead, and other dangerous metals (CGWB, 2013; Li & Wu, 2019).

Human health impacts of industrial discharge

Human health is negatively impacted by excessive anthropogenic activities such as the release of hazardous waste, agricultural waste, and industrial effluents into surface waters. Through dermal contact and oral ingestion of metals contaminated water, typhoid, cholera, encephalitis, hepatitis, skin infection, hair loss, liver cirrhosis, renal failure, and neurological dysfunction spread (Li & Wu, 2019; Islam et al., 2021). Industrial hazardous waste can cause death and morbidity. Symptoms may include respiratory infections, skin reactions, allergies, eyesight loss, corneal opacity, abortion, pregnancy malformation, stunted growth, neurological disorders, mental depression, psychiatric changes, altered immune response, and chromosomal abnormalities (Kilivelu & Yatimah, 2008). Unhealthy workers may be less productive, miss work with greater frequency, and make potentially costly blunders. The wastewater from factories frequently contains odorous waste. Strong odors can degrade the quality of life near the site and weaken or eliminate community support for future production or development. Controlling odors through garbage treatment and recycling can enhance community relations and lower costs (USAID, 2009).

McGrane (2016) elicited that, in urban environments, where a range of contaminants have an impact on water quality, novel contaminants continue to present new issues for monitoring and treatment regimens. For instance, Addis Ababa's water resources are severely polluted as a result of rapid population increase, unchecked urbanization, industrialization, and inadequate waste management methods, endangering both human health and ecosystem function as a whole (Yohannes and Elias, 2017). Since downstream Addis River water is being used for various purposes such as drinking water supply and irrigation, public health risks are high (Rooijen and Taddesse, 2009). Drinking or swimming in contaminated water can lead to health issues such as gastroenteritis, stomach flu, and skin illnesses (Turbow et al., 2003). According to Landrigan et al. (2018), unsafe drinking water caused 1.3

million fatalities worldwide in 2015.Not only does drinking or swimming pose health risks, but so does the ingestion of HMs accumulated in fish and crops (Khan et al., 2008). Bioaccumulation of heavy metals in fish and vegetables is supported by evidence from several scholars (Kawser Ahmed et al. (2016) and Rashid et al., 2017). Toxic elements can cause endocrine disruption, cancer, renal damage, and immune system diseases.

Drinking water contamination has been linked to severe sickness and mortality on a global scale. It is used to transmit contagious diseases such as guinea worm infection, cholera, dysentery, diarrhea, and typhoid (Wolde et al., 2020). For example, those who rely on the Akaki River's water will eventually be impacted by elevated levels of many toxins and irrigation products (vegetables) and, consequently, have negative impacts on human health and ecosystems (Zinabu and Desta 2002). According to a Bedada et al. (2019) evaluation of nine sub-cities of thirteen rivers and four hospitals, wastewaters of Addis Ababa would continue to represent a major health risk and will result in an increase in the number of deaths and also will affect the aquatic life and drinking water.

River water is used for home and agricultural reasons by those living downstream. People who depend on the river for their livelihood now face serious health hazards as a result of these behaviors. One of the most prevalent ways that dangerous substances enter the body of humans is through the consumption of food crops that have been exposed to heavy metals; yet, some symptoms don't manifest for several years after exposure (Srinivasan and Reddy, 2009). The World Health Organization (WHO) estimates that 80 % of infections are spread by water, making surface water a significant source of infection for both humans and marine organisms (Islam et al., 2021). According to several research projects conducted near Addis Ababa, crop cultivation utilizing dirty water threatens human health and life (EFDR, 2000). Thus, the river water ultimately threatens human health and the ecosystem as a result of the elevated level of several pollutants and irrigation products such as vegetables (Zinabu and Desta, 2002).

According to Quansah *et al.* (2018), in most African countries, like Ethiopia, wastewater and sewage water are disposed of indiscriminately, and this might be responsible for the high environmental pollution and degradation being experienced. Among all, cholera, the waterborne disease, has been reported to have substantial impacts on communities confronted with conflicts, absence of infrastructure, inadequate health care systems, and famine (Legros, 2018). In Ethiopia, concerted efforts are required by all stakeholders to curb water-related issues.

Effluent sourced pollutants can directly impact human health and biodiversity. Direct evidence includes case studies linking specific pollutants to diseases like kidney disease, and epidemiological data demonstrating increased rates of certain diseases in areas with higher pollution levels. Some examples of Health Impacts:

1. Kidney Disease: Exposure to pollutants like heavy metals, pesticides, and certain chemicals can lead to kidney damage and disease, including Chronic Kidney Disease of Unknown Etiology (CKDu), which is linked to areas with high levels of contamination. CKD is also a global health problem (Hill et al., 2016; Atlani et al., 2024).
2. Cancer: Some pollutants, like PFAS and certain microplastics, have been linked to increased cancer risk, particularly breast cancer, due to their endocrine-disrupting effects. The results could also help us better understand how environmental factors affect the emergence of cancer in a population (Marino *et al.*, 2023).

Case studies and epidemiological data consistently demonstrate that effluent pollutants can have direct and significant impacts on human health, ranging from kidney disease and respiratory problems to the spread of waterborne diseases.

Impact on soil and edible plants

Common causes of anthropogenic metal pollution in soils include urban and industrial wastes. Heavy metal deposition in soil is a major issue in agricultural production due to the negative effects on food quality, crop growth, and soil environmental health (Naser et al., 2014). The use of low-quality water for agricultural purposes can reduce crop output and result in food insecurity. According to several researchers, greater amounts of heavy metals have been found in various parts of the nation (Edokpayi et al., 2017). Compared to grain or fruit crops, leafy vegetables' edible sections can acquire heavy metals more quickly (Mapanda et al., 2005). Heavy metals are acquired in edible vegetables and inedible parts, which is enough to cause both clinical problems in animals and people.

The cultivation of vegetables in soils irrigated with wastewater containing high concentrations of toxic metals usually takes up such metals and accumulates the edible and non-edible parts of the vegetables in quantities large enough to cause potential health risks both to animals and humans consuming these metal-rich plants (Naser et al., 2014). As Ahmad and Goni (2009) manifested, heavy metals have special features that make them toxic even at very low concentrations. They are non– biodegradable and persistent in various environmental media and can accumulate in plants and animals. Heavy metals enter into the human body through the oral route and have been identified as the major pathway. Consumption of food crops from farm lands irrigated with wastewater and ill- treated wastewater effluents could put people who feed on the mat risk of several diseases, some of which only become evident after many years of exposure (Igbinosa and Okoh, 2009).

Heavy metals emitted by industries can diffuse in the environment and eventually be deposited in soil. Plants growing in such locations may absorb heavy metals into their bodies. Heavy metals such as iron, molybdenum, manganese, zinc, copper, magnesium, selenium, and nickel play an important part in plant growth and development, but they can be poisonous at high levels. Industrial effluents, such as textile effluent, include both nutrients that support crop growth and harmful chemicals. Plant physiological functions such as photosynthesis, water relations, and mineral feeding are all affected by repeated metal exposure. Toxic effects included chlorosis, yellowing, early leaf fall, poor growth, and decreased flower, fruit, and green yields. As a result, it is critical that the consequences of the use of industrial effluents in crop fields and their effect on soil properties are examined before they are recommended for use in irrigation (EEPA, 2003/4).

It has been proposed that agricultural soil is the most significant sink for heavy metals because of its high potential to retain metals. There is evidence to imply that agricultural soil contains elevated levels of heavy metals due to increased anthropogenic activity. The chemical composition of irrigation water may have an indirect impact on plant growth by changing the availability of plant nutrients or directly by being poisonous or insufficient. It has been hypothesized that agricultural soil is the most significant sink for heavy metals due to its high metal retention capacity.

Socio-economic impacts

Rapid urbanization in emerging countries has affected both the landscape and the lives of millions. Ethiopia, like other developing countries, is suffering multifaceted socioeconomic and environmental difficulties associated with industry, notably in its urban centers, which are regions of industrial expansion. The industrial sector is responsible for significant environmental and social repercussions. Many developing-country governments place a high focus on industrial development. Industrial growth can significantly boost a country's economy (Paul et al., 2012). The report from EEPA, textile industries have an important role in creating job opportunities, generating economic benefit through the export market, and creating local market opportunities (EPA, 2000/01). The greatest jobs, accounting for over 27 % of overall manufacturing employment, were generated from textile industries. Ethiopian industrial manufacturing accounts for approximately 7 % of national GDP significantly lower than agriculture and 12 % of total industry (EPA, 2000). Industrial development creates employment and economic benefit for the surrounding communities by adding value to resources and generating foreign exchange for the country.

Social impacts arise in tandem with environmental impacts following the implementation and operation of new projects as well as the operations of existing factories in the manufacturing sector. These activities cause changes to the environment that may affect human health or safety, cultural heritage—or, in general—alter environmental, social, economic, and/or cultural conditions. Managing and improving the social performance of the manufacturing sector contributes to sector competitiveness as much as improving quality and the environment. The major overall impacts observed in the manufacturing sector in Ethiopia (Amare, 2019; EEPA, 2003/04) included:

Unclean work environments affecting the health and safety of workers and communities in the neighborhoods of manufacturing plants, which may include:

1. Workers exposed to occupational disease,
2. Accidents and injuries lead to the disability of workers,
3. Health problems, including respiratory system disease, such as asbestosis or byssinosis (occupational lung disease that primarily affects workers in cotton processing) or silicosis (lung disease caused by breathing in tiny bits of silica, a mineral that is a mixture of sand, rock, and mineral ores such as quartz), result in the loss of productivity of workers.
4. Contamination of vegetables and agricultural products irrigated with water polluted with chemicals and heavy metals discharged from manufacturing plants into rivers, which result in the health impacts of humans,
5. Groundwater contamination through sewer line-leakage of polluted waters and Workers are underpaid by the companies hiring them because of no legally binding minimum wage for labor applicable throughout the country of Ethiopia, which is, in turn, a misuse of out sourcing practices. The out sourcing companies charge the receiving companies double or triple the monthly wage per worker, which is not allowed in eco-industrial parks. This manifest economic and social counteract on the country.

Industrial wastewater treatment techniques in Ethiopia

Although the number of industries in Ethiopia is few, their impact in terms of pollution is enormous. This is due to the majority of industries lacking treatment plants and discharging their waste in the form of liquid, dust particles, and smoke (Fenta, 2014). Several studies on wastewater treatment techniques (WWT) approaches have emerged over the past few decades, and new and inventive technologies (Fig. 3) are being created (Chi et al., 2020; Goh et al., 2020; Nisar *et al.*, 2020). For instance, wastewater treatment trends in Addis Ababa, Ethiopia, illustrate that an estimated annual volume of 49 million cubic meter total wastewater, from which about 4 industrial wastewaters (Van Rooijen et al., 2009) is, is treated in secondary sewage treatment sites of the Kality treatment plant and Kotebe sludge treatment. The treatment involves circulating sewer in various ponds for about 30 days in order to make the level of BOD fall below 5 mg/L (Mohammed, 2007).

Several techniques are used in Ethiopia to treat wastewater discharged from industries. For example, Dessie et al. (2022) displayed the use of aluminum electrodes in the electrocoagulation process of effluents from textile industries in the Amhara region, typically Bahirdar, Kombolcha, and Debirebirhan. The electrocoagulation process was essential to remove metals and organic and inorganic pollutants. Since the chemicals are directly discharged into the environment without treatment, the study convinced the use of electrocoagulation to remove physico-chemical pollutants rather than the biological pollutants, which is the limitation of the method, unable to remove the biological contaminates. The majority of the industries in the IPDC used advanced conventional wastewater treatment technologies (IPDC report, 2020). The main target of a wastewater treatment plant is to permit industrial effluents to be disposed of without danger to human health or unacceptable damage to the natural environment. However, many industries in Ethiopia lack skillful professionals for operation and maintenance, lack cooperation and collaboration among regulatory bodies, lack effective treatment technologies, lack willingness to build WWTPs, and lack operating conditions. Along these challenges, wastewater treatment plants are not fully meeting standard discharge limits of the Ethiopian Environmental Protection Authority (EEPA, 2003) and have no effective response to control the process of the plant. Therefore, to make the plant more effective in control response and meet standard discharge limits.

According to Bora and Dutta (2014), the process by which pollutants or polluting loads are removed from the aqueous phase utilizing a variety of techniques. Physical, biological, chemical, and sludge treatment procedures are common ways employed in wastewater treatment (Musa and Idrus, 2021). According to Bhargava (2016), the physical treatment

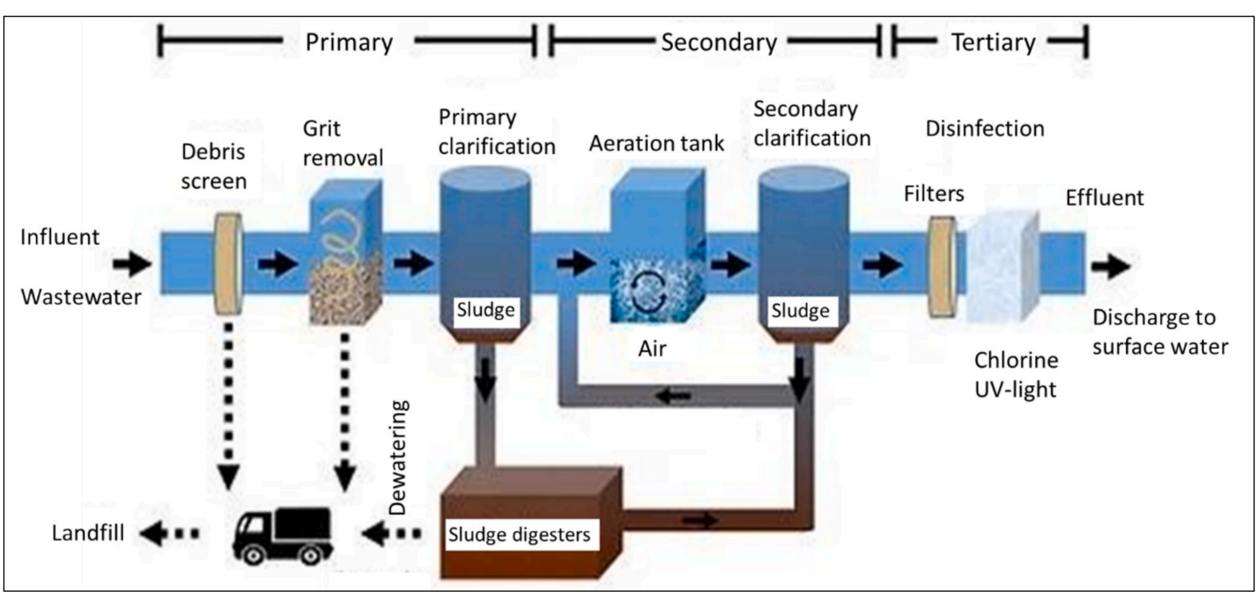

Fig. 3. Wastewater Treatment System ().
Source: **www.yasa.ltd**

method involves screening, sedimentation, skimming, filtration, and aeration. Microorganisms are used in the biological approach to decompose the organic compounds in wastewater. Aerobic, anaerobic, and composting processes are all used in the procedure (Baszak et al., 2011; Gupta et al., 2018). To eliminate the germs contained in WW, the chemical treatment uses oxidizing agents like chlorine and ozone. Additionally, it entails pH stabilization, which involves adding an acid or base to the water to bring the pH level to a neutral range (Bhargava, 2016; Crini and Lichtfouse, 2019). Ji *et al.* (2020) described that small solid sediments are anticipated in the liquid phase after centrifuging the segregated liquid phase, and minimum residual moisture is anticipated in the solid portion of the sludge treatment. Although expensive, activated carbon has a favorable advantage of having a high capacity for adsorption of various contaminants (Islam *et al.*, 2019).

In the creation of nanomaterial's, nanotechnology has opened a new frontier with the five essential sequential steps of the wastewater treatment technique being the preliminary, primary, secondary, and tertiary treatments, as well as the treatment of any generated sludge (Crini and Lichtfouse, 2019). The features of the wastewater and desired treatment determine the method or combination of procedures to be used for wastewater treatment (Saidan et al., 2020; Steyn *et al.*, 2021). The benefits and drawbacks of selected WW treatment systems from various sources are shown in Table 5. New approaches are being attempted to supplement the traditional methods of WWT due to the complexity of WW in terms of new pollutants and the required greater efficiency of treatment (Edokpayi et al., 2017; Tetteh et al., 2019). Built-in wetlands, anaerobic systems, oxidation ditches, traditional (activated sludge), aerated lagoons, stabilization ponds, rotating bio-contactors, etc., are the common WWT approaches applied to both sewage and industrial WW (Kilingo et al., 2021). In most African countries, like Ethiopia, stabilization ponds (physical and biological) WWT systems are widely used (Chukwueloka, 2020).

Similar advanced technologies were developed in countries like Turkye on wastewater treatment of paint and meat. Three treatment scenarios that contain electrocoagulation, Fenton process, and membrane distillation have been developed and introduced for wastewater treatment facility of a paint industry in Turkey. Due to its versatility and environmental compatibility, the electrocoagulation process has gained significant attention for the treatment of wastewater from the meat, pulp and paper, metal cutting, textile, olive, and chemical mechanical polishing industries (Akyol, 2012; Horváth et al., 2024). This is because, electrocoagulation technology doesn't produce any pollutants or corrosion, it is environmentally benign. When compared to conventional techniques, this technology offers a few benefits, such as easy management, shorter retention times, a reduction or elimination of the need for chemical substances, rapid sedimentation of the electro generated flocs, bare installation, and a reduction in sludge production (Akyol, 2012; Holt et al., 2005; Kobya et al., 2006). This method applies electric flow using sacrificial metal electrodes dipped in tainted solution (Daneshvar et al., 2004).

Similarly, Fenton is effective in treatment of wastewater, particularly containing organic chemical pollutants. Of all the oxidants that are available, hydroxyl radicals (*OH) are the most remarkable. Fe^{2+} ions catalyze the homolytic cleavage of hydrogen peroxide, which produces these radicals and is known as Fenton's process (Kurt et al., 2006).

Membrane filtration is also an alternate technique for treating wastewater from paint is membrane technology. Depending on the pore size, particles, colloids, and macromolecules can be removed using the reverse osmosis (RO), nano-filtration (NF), ultrafiltration (UF), and microfiltration (MF) processes. Around the world, membrane separation is used to treat water and wastewater. Because of their inherent viability, quantifiable modular design, ease of maintenance, and superior rejection rate, membrane processes have grown in significance (Dasgupta et al., 2015).

In the same manner meat industry in Turkiye employ a variety of treatment techniques, including chemical, biological, and biochemical procedures. Wastewater from meat industry can be treated using a variety of techniques, the majority of which center on biological processes like aerobic reactors, stabilization ponds, and activated sludge (Davarnejad & Nasiri, 2017). Notwithstanding their effectiveness and affordability, these systems typically produce large amounts of sludge, have a large footprint, require a long retention period, and require a lot of energy for aeration (Daneshvar et al. 2007; Bayar et al. 2014; Davarnejad & Nasiri 2017). For wastewater treatment, physicochemical treatment is recommended in addition to biological methods. Dissolved air flotation (DAF), coagulation, and electrochemical methods are examples of various physicochemical treatment technologies (Lecompte, 2015). One common process is chemical coagulation. In addition to these traditional techniques, meat processing wastewater can be treated using advanced treatment techniques like the advanced oxidation process (AOP), membrane configurations, electrocoagulation, adsorption, microfiltration, reverse osmosis, ultrafiltration, and UV (ultraviolet light) and their combinations (Lecompte & Mehrvar, 2014). More importantly, the environmental impact must be taken into account before choosing the treatment method to use.

Industries may disregard treatment due to a complex web of interconnected factors, including low enforcement, high capital expenditures, a lack of technological expertise, and short-term profit-driven decision-making. Lax enforcement may be less costly, but it can have long-term consequences for the law, human health, and the environment. The high upfront costs of upgrades or new technologies may prevent adoption, especially for smaller businesses. Lack of readily available and affordable technologies, particularly in developing countries, may further hinder implementation. Furthermore, disregarding treatment may have more immediate financial benefits than long-term costs, prioritizing short-term financial gains over environmental or health concerns. Adoption may be hampered by upgrades, particularly for smaller companies. The absence of readily available and affordable

Table 5
Advantages and disadvantages of selected treatment systems of wastewater sources. ().

Treatment system	Nature of wastewater	Pollutants removed	Advantages	Disadvantages	References
Aerobic filter	Pretreated domestic and industrial wastewater of narrow COD/BOD ratio	BOD, TDS, TSS	Little land area required, simple and relatively durable, high treatment efficiency	The filter material can increase the cost of construction, risk of filter clogging	[a, b]
Stabilization Lagoos (Aerobic facultative maturation pond)	Domestic, industrial, and agricultural wastewater	BOD, SS, TN, TP	Low capital cost, low operational and maintenance cost, minimal expert required	Requires large area of land, may produce undesirable odors	[c, d]
Aerobic biological Treatment(Activated sludge)	Domestic and Industrial wastewater	BOD,SS,TN, TP	High efficiency, little land area, suitable for local-scale & regional-scale treatment, odor free	High cost, requires sludge disposal area requires operational and maintenance experts, inefficient in deep water and little bacterial loads remove	[e, f]

Remark: COD- chemical oxygen demand, BOD – Biological oxygen demand; TDS – Total dissolved solid; TSS – Total suspended solid; SS – suspended solid; TN – total nitrogen; TP – total phosphorus; a – Waqas et al., 2020; b – Singh et al., 2021; c – Wilas et al., 2016; d – WWDR, 2017; e – Gupta et al.,2016; f – Edokpayi et al., 2017.
Source: Onu et al., 2023

technologies can further hinder implementation, particularly in developing regions. Furthermore, the immediate financial benefits of neglecting treatment might outweigh the perceived long-term costs, leading to a prioritization of short-term gains over environmental or health concerns. A multifaceted approach is needed to combat these problem through Stronger Enforcement for monitoring environmental and health impact assessment; Technology Development and Access; Public Awareness and Education help to build pressure for change; collaboration and partnerships among industry, government and research institution to develop and adopt best practices.

Legal frameworks to control industrial pollution

The Regulation 159/2008 (Prevention of Industrial Pollution Regulation) was issued by the Federal Environmental Protection Authority of Ethiopia, aimed to avoid industrial pollution and promote compatibility of industrial development with environmental conservation. The proponent expected to avoid or reduce the generation and discharge of pollutants to a level not beyond the environmental standards. The regulation also obliges industrial operators to manage its apparatus, inputs and outputs in a way that avoids the destruction of the environment and human health as well. According to the Federal Democratic Republic of Ethiopia (FDRE) Water Resource Management Proclamation no.197/2000, Article. 2(10, 11 & 12), any person using water for industry or for any other purposes which may cause pollution shall have an obligation:

- To install and use waste treatment method,
- To discharge only the type and volume of treated waste permitted,
- To allow the supervising body to take the treated waste discharge sample at any time and
- To renew the treated waste discharge, permit every two years, not later than one month prior to its expiry.

Industrial effluents containing heavy metals, and their accumulation in sediments and biota, present a persistent threat to ecosystems health (Xu *et al.*, 2014; Kelderman, 2012). This holds true also for sub-Saharan African countries, where regular monitoring & auditing is limited (Ndimele *et al.*, 2017; Akele *et al.*, 2016). Thus, identifying effluent concentrations and discharge management are of increasing importance if environmental risks and hazards are to be addressed (Rudi *et al.*, 2012). Policies to promote economic gains can lead to a path of "pollute now; clean-up later" (Sikder *et al.*, 2013; Alcamo *et al.*, 2012; Rudi *et al.*, 2012). The seemingly existing paradox of crafting good environmental policies but low enforcement has a risk of making the industrial growth unsustainable.

The guiding principles provide a suitable basis for the effective management of water pollution are: Prevent pollution rather than treating symptoms of pollution, Use the precautionary principle, Apply the polluter-pays-principle, Apply realistic standards and regulations, Balance economic and regulatory instruments, Encourage participatory approach with involvement of all relevant stakeholders, Apply water pollution control at the lowest appropriate level, and Give open access to information on water pollution.

Conclusions and future outlooks

It is understandable that industrial expansion plays a key role in the process of economic development of countries worldwide. Similarly, manufacturing industries have been inevitably emerging in developing countries contributing for their observable rapid economic growth. However, effective waste management solutions should be used to protect the environment, animals, and humans from negative consequences. The majorities of the industries are lack wastewater treatment facilities and instead release toxic effluent in to neighboring rivers, lakes, and streams. Heavy metal concentrations in rivers, plants irrigated by river waters, and soil exceeded allowed limits. The levels of cationic/anionic pollutants, trace heavy metal (loid)s, and bacteria in most water sources of the basin exceed WHO and EPA legal standards, making them unfit for human use. To address the negative effects of toxic industrial wastes, an integrated and area-specific strategy to industrial waste management was necessary for effective and efficient industry waste management. The novelty of this SR is that it is the first to combine information from many recognized research works on the impact of contaminated water on humans, vegetables, and soil, as well as toxic and socioeconomic effects. Thus, the government must devise mitigation strategies such as heavy metal removal systems from contaminated river water and soil, recycling waste management strategies, centralized or decentralized treatment plants, the conversion of industrial residuals into biogas production, and societal awareness creation.

This review study can help provide background information for future research, as well as early policy guidance for water resource managers and policymakers. It is strongly advocated to have strong institutions capable of formulating new laws and enforcing the existing environmental legal framework. Furthermore, a sensitive ecosystem requires an institutional organization responsible for regular monitoring and evaluation in order to protect fragile riparian populations and ecosystems. To this purpose, the review results found that the environment and human health are at risk from the discharge of untreated wastewater from the industrial expansion activities in the country.

Recommendations

In developing countries like Ethiopia, the expansion of industries and industry-related problems on the environment and humans are obvious. In the near future, waste management practice with full responsibility through various waste treatment technologies should be applied in all industrial sectors. The government of Ethiopia (EEPA) shall give a due attention for the environmental sustainability through adopting immediate enforcement of environmental regulation. Industrial expansions have a profound economic importance, inversely raise environmental issues. All stake holders like government, industries, and communities tends to play their crucial role and responsibility to enhance the pollution reduction strategies by formulating and using different waste water treatment plant models. Typically, an exemplary effluent management practice has been done in Hawassa Industrial Park to model a solution which is more feasible and good practice need to be expanded in varies industrial sectors.

Environmental monitoring policies are revised in accordance with the current pollution problems and try to set up the check and balance auditing system. Unless all environmental problems are encountered, the life of humans and the socio-economic status of the country are posed. The government and the proponents are the key to alleviating environmental challenges faced today.

Consent for publication

The manuscript's submission has been approved and agreed to by the authors.

Author Contribution

The manuscript was written in complete form by **AG**, with by **SM and LM** made language edition,.revisions and reviews.

CRediT authorship contribution statement

Abiy Gezahegn: Writing – original draft, Investigation. **Lemessa B. Merga:** Writing – original draft, Methodology. **Siraj Mammo:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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