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# Impacts of Surface Water Quality in the Awash River Basin, Ethiopia: A Systematic Review

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Water quality impairment, due to anthropogenic activities and limited enforcement capacity, is a rapidly growing threat to water security as well as public health in developing countries. Cumulative effects of deteriorating water quality undoubtedly put pressure on public health and socio-economic developments. For example, most industries in Ethiopia discharge their effluent directly into freshwater systems without any treatment process. The problem is severe for rivers such as the Awash that pass through major cities. Although there were a few studies that looked into the issue, there is a lack of comprehensive water quality impact assessment on agriculture, health, and socio-economics. This article systematically summarizes current research on water quality issues in the Awash River Basin to generate comprehensive information that captures the water quality status of the river and impacts of water contamination, and identify information and management gaps. Results showed that water quality degradation along the river course and in selected tributaries exceeds water quality standards by the WHO and national guidelines. For example, E-coli bacteria concentration in two tributaries, Tinishu and Tiliku Akaki, reach up to 6.68 and 6.61 billion CFU 100 ml/L. Virological profile of creeks receiving wastewater from hospitals in the City of Addis Ababa contains coliphages levels reaching as high as $5.2 \times 10^3$ pfu/100 ml for urban rivers and up to $4.92 \times 10^3$ pfu/100 ml. Heavy metals that far exceed the tolerable levels for humans were also detected in vegetables produced using impaired water. Heavy metals such as Cd, Cr, Cu, Hg, Ni, and Zn were detected in potato, Zn and Hg in Cabbage, and Cr in onion and red beet. Lettuce irrigated with Akaki river water found to contain 0.263 (Cd), 420 (Fe), 13.44 (Zn), 7.87 (Cr), 7.49 (Cu), and 6.55 (Pb) in mg/kg both in excess of WHO guideline. In addition, a high concentration of Cr has been also found in fish tissues. There has never been a systematic evaluation of the impact of contaminated water in the Awash Basin. Comprehensive impact of water quality investigation that takes into account the different pollutants dynamic needs to be made to protect the well being of downstream beneficiaries including the aquatic ecosystem. In conclusion the systematic review has shown that for a river that cross-through emerging mega-city like Addis Ababa, the human and ecosystem health impact of aquatic ecosystems pollution should not afterthought action

**Keywords: impact, water quality, pollution, toxicity, Awash Basin, Ethiopia, Awash River**



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## INTRODUCTION

The role of clean water in social development, economic growth, and sustaining a healthy economic system has been well established (Katko and Hukka, 2015). The global community has been mainstreaming water supply and sanction as one of its core activities. Ensuring the availability and sustainable management of water and sanitation for all (SDG 6) is among the 17 sustainable development goals the global community is grabbling to achieve by 2030 (Kroll et al., 2019). Moreover, due to its cross-sectoral nature, improved water security has a catalyst role in the achievement of other SDGs targets.

Despite this, water security particularly in developing countries tends to be at a cross road (Yomo et al., 2019). Growing population, expansion of cities, rapid urbanization, the expansion of industrial activities, the difference in inter-sectoral priorities, and the low enforcement capacity are threatening the rivers, and lakes (McGrane, 2016; Berg et al., 2019). Environmental law enforcement in South Africa, as in other developing nations, has suffered significant setbacks due to a lack of technical expertise, insufficient finances, corruption, and penalties with low deterrent effects (Edokpayi et al., 2017).

Anthropogenic activities are responsible for the majority of water quality degradation in several rivers, where indiscriminate dumping of domestic and industrial wastes, as well as waste from other sources such as agriculture and health facilities, is common (Igwe et al., 2017; Amoatey and Baawain, 2019) and justified in Ethiopia (Tadesse et al., 2018), Bangladesh (Hasan et al., 2019; Islam et al., 2020, 2021), India (Pareek et al., 2020; Rakhecha, 2020), Rakiraki town in Fiji (Kumar et al., 2021), Kenya (Chebet et al., 2020) and South Africa (Edokpayi et al., 2017). Land and water quality degradation in Ethiopia, in general, was not impacted much by anthropogenic activities for the past decades due to the low population density that practice slash and burn agriculture with minimum fertilizer use (Ligdi et al., 2010). However, in the recent past, a wide range of pollutants including organic matter, salts, nutrients, sediments, heavy metals, etc. due to natural processes and anthropogenic sources are posing a serious threat to the land and water qualities of many of the basins in Ethiopia (Moges et al., 2017). The problem is aggravated further due to climate change, rapid population growth, urbanization, and agricultural practices that put intense pressure on natural resources including the availability and quality of freshwater resources (Berg et al., 2019).

The environmental impact on local rivers increases as a city gets bigger, especially if the city cannot properly handle solid waste and wastewater. Untreated wastewater from industries and households may be discharged into rivers, where solid waste may accumulate along the course of the river (Dagnachew et al., 2019; Chebet et al., 2020), especially in developing countries where wastewater treatment facilities are not well developed. The discharge of untreated municipal and industrial wastes into water bodies, which resulted in increased heavy metal concentrations in river water, is linked to severe water quality degradation (Islam et al., 2020). Most cities of developing countries generate on the average of 30–70 $mm^3$ of wastewater per person per year (Edokpayi et al., 2017). Urban development interferes with water resources by altering the biophysical processes and fluxes of water, sediment, chemicals, microorganisms, and heat (McGrane, 2016). As cities develop in population, so does the total amount of water required for adequate municipal service. This rise in total municipal water demand is due to a combination of factors, including an increase in urban population and a trend toward economic development (McDonald et al., 2014). The rapid economic development of China has come at a cost to the environment, increasing volumes of untreated wastewater from households, and industrial and agricultural runoff all contributing to severe pollution of the aquatic environment (Ma et al., 2020). Water quality is becoming a serious problem in some basins in Ethiopia. For example, the Rift Valley Lakes and their contributing rivers are used for irrigation, soda abstraction, fish farming, and recreation (Ayenew and Legesse, 2007).

The pollution of surface water with trace elements has gotten a lot of attention around the world (Islam et al., 2020). Because of their extreme toxicity, abundance, and ease of accumulation by different organisms, heavy metals are regarded one of the most dangerous environmental pollutants (Islam et al., 2021). Industries in developing countries generate volumetric wastes which are discharged without treatment into nearby water bodies. For example, most industries in Uganda use outdated manufacturing technologies and do not have functional effluent treatment plants (Srinivasan and Reddy, 2009) and in Bangladesh and Ethiopia often discharge their wastewater into the freshwater system without any treatment (Naser et al., 2014; Girma, 2016). Therefore, raw and harmful wastes are discharged into the surrounding water bodies. Textile industries are huge industrial consumers of water and producers of wastewaters, with growing demand for textile products leading to an increase in textile wastewater output, making the textile sector one of the most serious sources of pollution globally (Mehari et al., 2015). Dadi et al. (2017) investigated the environmental and health impacts of effluents from four different textile and garment plants in Gelan and Dukem areas around Addis Ababa and found that the bacteriological pollutants in the effluent are higher than the permissible limit given by the Federal Environmental Protection Authority (FEPA) (Dadi et al., 2017). Such practices lead to water quality deterioration of many freshwater systems making them unsuitable for irrigation, domestic or industrial purposes (Keraga et al., 2017b).

Point and non-point source pollutions from towns and cities contribute nutrient-rich effluents that are conducive for eutrophication where an upsurge of algae growth in the lakes will happen, and thereby depletes the oxygen needed by fish and other ecosystems (Girma, 2016). Addis Ababa, which is part of the Akaki catchment, has a rapidly growing population, unregulated urbanization and industrialization, poor sanitation, and uncontrolled waste disposal, all of which contribute to a substantial deterioration in surface water quality (Kassegne et al., 2018). Rapid loss of ecosystems and land-use change, in part due to agricultural intensification, have been among the major drivers for recent increases in water in sedimentation and water quality issues in Ethiopia (Moges et al., 2017).

The river basin is convenient for irrigated agriculture and industrial development due to its proximity to major cities such as Addis Ababa, Nazert, Debre Zeit, Dessie, and Dire Dawa. It has been impaired by pollutants from large-scale irrigation scheme (Alemayehu, 2001; Keraga et al., 2017b). On top of these, most of the industrial plants and cities do not have wastewater treatment plants (Rooijen and Taddesse, 2009) releasing their effluents directly to the river basin. Therefore, the discharges of these domestic, industrial, and agricultural wastes have been polluting freshwater systems jeopardizing socio-economic and ecological assets in the river basin (Mengistie et al., 2017).

The costs of water scarcity, misallocation, and pollution can be difficult to measure, and they are not always visible (Mekonnen and Amsalu, 2018). Smallholder farmers grow a variety of vegetables in and around Addis Ababa. Without developed modern irrigation techniques, water scarcity is rampant and these farmers rely on the Akaki River as their primary source of water for irrigation. Due to a scarcity of freshwater, partially treated and untreated wastewater from a variety of industries, as well as gray water from the Addis Ababa city environment, are now used for irrigation (Mengesha et al., 2021). While water quality is a complex issue and involves multiple disciplines, this review focuses on water quality with respect cation, metals and heavy metals in surface water, and their impacts on vegetables, soil, biodiversity, human health, toxic and socioeconomic effects. The river collects untreated and unmanaged domestic, industrial, and agricultural pollutants from the catchment immediately along its course, which could lead to a change in quality of water. As a result, among the major rivers of Ethiopia, the Awash River is the most vulnerable to many types of serious pollution (Keraga et al., 2017b).

There has been little research on the impact of contaminated water on human and animal health, as well as the socio-economic implications on the riverine community, the downstream population, the basin, and the country as a whole. Although it is not complete and does not cover the entire basin and sub-basins, this systematic review provides valuable insight into the positive aspects of several studies that reveal the state of rivers pollution by heavy metals and their sources.

Although various initiatives have to investigate the state of pollution in Awash (Keraga et al., 2017a), basin-wide synthesis of the state of surface water pollution is lacking. Hence, the purpose of this article is to synthesize and generate information that captures the impact of contaminated water on human health, vegetables, and soil, as well as toxic, biological, and socio-economic effects that rely on river systems, as well as to identify knowledge gaps that are needed for the basin's long-term development and management. The following clear, logical, and well defined research question was formulated: what is the impact of contaminated water in Awash Bain and the knowledge gap that is needed for the sustainable development and management of the basin?

## METHODOLOGY

Systematic review (SR) is useful to synthesize trends and conceptualizing findings from large bodies of information (Özerol et al., 2018). The recent and innovative approach in undertaking SR is the PRISMA (Preferred Reporting Items for Systematic Review and Meta-analysis statement) (Moher et al., 2009). Synthesis of impact of water quality in the Awash Basin has been a valid explanatory topic for our review.

For this SR, we developed a search strategy to identify relevant literature. This search strategy was tailored to three databases: Web of sciences, Scopus, Google and Google scholar, and the search terms used were the following: water quality, Impact of water quality, water pollution, industrial pollutants, and heavy metals. All searches included journal articles, books and book chapters. The selection criteria were based on the PRISMA checklist. The search mainly focused on the mapping existing literature on the impact of water quality, water pollution, and heavy metals in the field of environmental sciences, and earth sciences. The search span was from the year 2000–2021 in English only. The search was mainly focused on Ethiopia. The search from any other country was considered accordingly. A total of 85 research articles were excluded at this stage. There were 105 records extracted at this stage.

All duplications were extensively examined to maintain the quality of the review. For the analysis and purification of the papers, the abstracts were checked deeply to ensure the quality and relevance of research papers included in the review process. We read the abstracts of 182 studies to see if they were relevant to the study topic and research questions. We got the full-text article for quality assessment after a total of 97 studies were deemed relevant. In a later stage, a careful examination of each study publication was carried out. We looked through the full-text publications to assess the quality and relevance of the studies. One article was not included in the study since it was written in a language other than English. In addition, 29 more publications were excluded from the study once the duplicate records were filtered out. After evaluating each article against the aforementioned inclusion and exclusion criteria, we chose 68 papers. The literature inclusion and removal at each level is depicted in **Figure 1**. Sixty eight papers were chosen for data extraction, and the following aspects were extracted: Articles must be published journal articles. Reports, dissertations, and unpublished documents were excluded. Through cited references, we discovered an additional 31 studies. In total, 99 studies were considered in this review.

We extracted information on the following subtopics from each study: (1) water quality status of rivers in the Awash Basin; (2) seasonal fluctuations of trace metals in lakes and reservoirs in the Awash Basin; (3) point source pollutants; and (4) health, vegetable, soil, biological, socioeconomic, and toxic effects of water pollution. All data extraction and coding were performed using Microsoft Excel and Mendeley Reference Manager.

## THE AWASH BASIN

The Awash River originates from the Ethiopian highland plateau around the Ginchi area and drains part of the northern rift valley system in Ethiopia (**Figure 2**). The river has no outlet to an ocean; rather it joins Lake Abe at the Ethio-Djibouti border. Most of the ∼113,304 km$^2$ catchment area of the basin is within

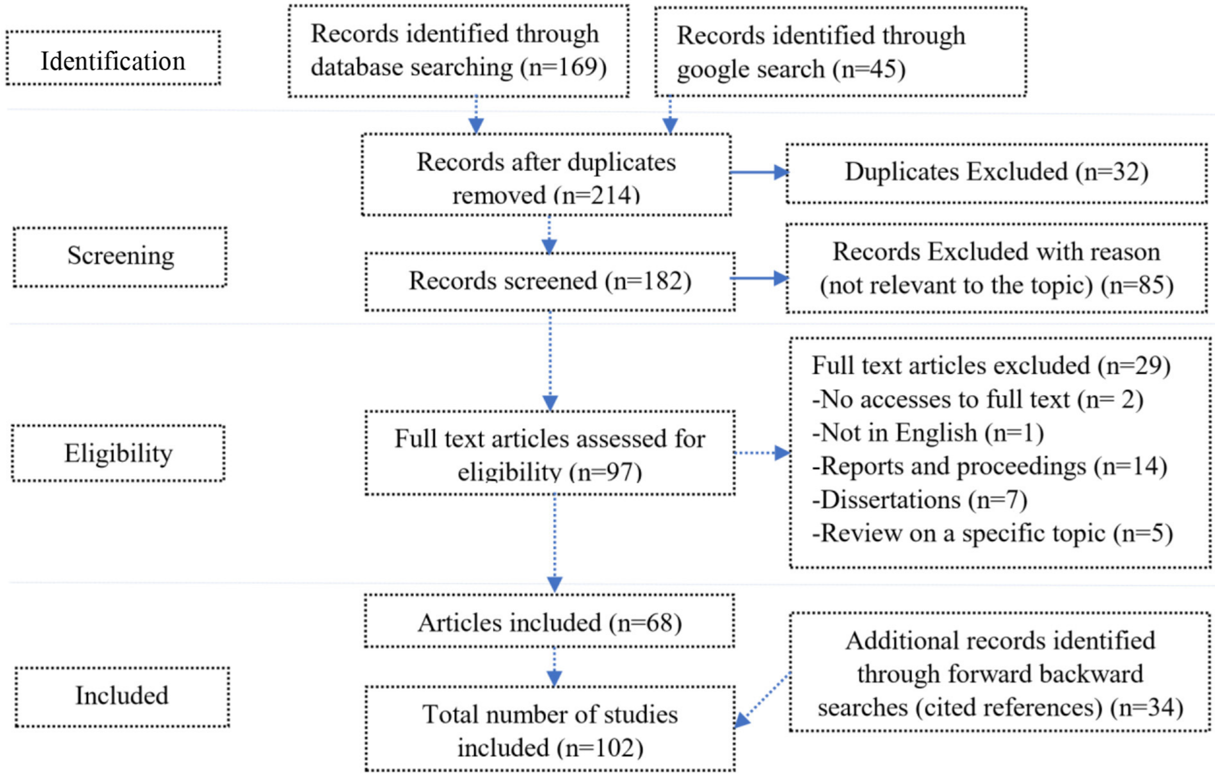


**FIGURE 1 |** Literature search and evaluation process and decision making for inclusion.

the Ethiopian boundary. Elevation in the basin ranges between 250 and 3,000 masl. The basin covers the central highlands of Ethiopia including west of Addis Ababa and the north-eastern part of the Ethiopian Rift Valley system. The main river's length is about 1,200 km (Taye et al., 2018).

The basin has varied topography, vegetation, rainfall, temperature, and soils. The climate ranges from semi-arid lowlands to cold highland mountains. The average total rainfall in the highlands is 1,600 mm, while in the lowlands it is 160 mm (Taye et al., 2018). Awash is fed by several major tributaries in the upper, middle and lower parts of the basin. Ginchi, Berga, Holleta, Bantu, Leman, Akaki, Mojo, Hombole, Arba I, Arba II, Keleta, Kesem, Najeso and Logia are the major tributaries of the upper Awash (Amenu, 2013). Land use in the basin is mainly agricultural which is used for rain-fed crops, shrub land, and grazing land. The basin accounting over 60% of the irrigated agriculture in the country (Keraga et al., 2017b). Crops cultivated in the basin include cereals (e.g., teff, beans, wheat, barley, and oilseeds), vegetables, flowers, cotton, perennial fruit trees, and sugarcane (Tufa, 2021). The other land uses/covers include urban areas, industrial zones, forests, and swamps. Major cities in Ethiopia such as Addis Ababa, Dire Dawa, Adama, Bishoftu, Dessie, and Semera are located in the basin. More than 65% of the national industries are located in the basin (Keraga et al., 2017b). The Awash River Basin is one of Ethiopia's 12 major river basins, which is shared by five administrative regions (Amhara, Oromia, Somali, Afar and the Southern Region) (Mersha et al., 2018).

## WATER QUALITY ISSUES IN THE AWASH RIVER BASIN

The purpose of this systematic review was to discuss the current situation of water quality in the Awash Basin. It evaluates the principal impacts of contaminated water in the Awash Basin on the biological aquatic environment, toxicity, health, irrigated crops using contaminated surface water and soil, and socio-economic impacts of trace metals in lakes and reservoirs.

### Water Quality Status of Rivers in Awash Basin

The population living in the Awash River Basin was estimated to be more than 18.6 million (FAO and IHE Delft, 2020) with a population density > 6452.4 persons/km$^2$, in Addis Ababa and 0-10 persons/km2 in the low land areas (Andualem and Takele, 2018). Substantial rain-fed and commercial agricultural farms, and several industries exist in the basin that is sources

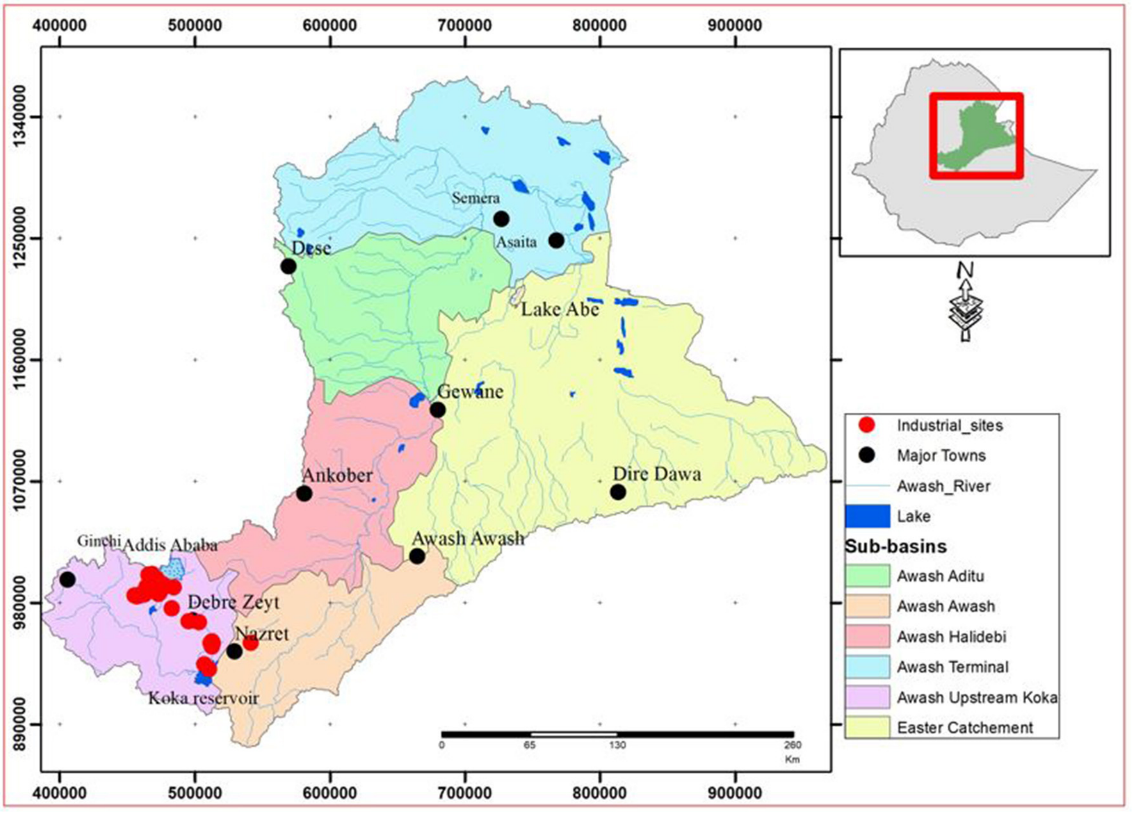


**FIGURE 2 |** Map of the Awash River Basin with administrative and Basin Management boundaries. The river basin is divided into four major stretches based on altitudinal variation, i.e., Upper basin which represents the areas from the headwater to Koka reservoir ( >1,500 masl); Upper Awash Valley which ranges from Koka reservoir to Awash Station (1,500–1,000 masl); Middle Awash Valley which represents the area from Awash Station to Gewane (1,000–500 masl), and; Lower Awash Valley which is the area that extends from Gewane up to Lake Abe (<500 masl) (Duguma et al., 2021; Jin et al., 2021).

of pollutants (Eliku and Leta, 2018). The basin is experiencing severe point source water pollution due to rapid urbanization and industrialization (Gebre et al., 2016) and non-point sources from agricultural fields (Alemayehu, 2001; Keraga et al., 2017a). The Akaki catchment is located in central Ethiopia along the western margin of the main Ethiopian Rift Valley. Addis Ababa, which lies within the Akaki catchment. Tinishu Akaki River contained a higher load of trace metals than the other regions, which is due to the existence of most of the industrial establishments and commercial activities (Kassegne et al., 2018). The Akaki River is heavily polluted, owing to the emission of harmful industrial effluents with little or no treatment (Abebe, 2019). Untreated pollutants from industries, residential, and commercial activities are discharged into the Tinishu Akaki River, which runs through the Addis Ababa City Administration. Several studies have found that discharges of inadequately treated and untreated industrial wastewaters, residential wastes, and sewerages into waterways pollute rivers and streams (Abebe, 2019; Mekuria et al., 2021). **Figure 3** shows water quality monitoring stations used by different studies in the Akaki sub-basin. Another main tributary of the Awash River is the Mojo River. Shoa and Ethiotanneries, Mojo oil mill plant, abattoir houses, and poultry farms are major sources of wastewater effluents downstream of the Awash River, which release their raw effluent directly into the Mojo river, a tributary of the upper Awash and eventually into the Koka Reservoir. The Akaki River is a major tributary of the Awash River, which drains its effluents from its source to the Koka reservoir (Degefu et al., 2013).

Kassegne et al. (2018) reported that trace metals occurred in varying concentrations along the course of the sampling stations in Tinishu Akaki River and Aba Samuel reservoir. Relatively lower levels of trace metals were recorded at Aba Samuel reservoir due to the lower residence time of the sediment. Ecological risk assessment using USEPA sediment guidelines, geoaccumulation index, contamination factor, and pollution load index revealed the widespread pollution by Cd and Pb, these were followed by Mn, Ni, and Zn.

In addition, mean concentrations of heavy metals including Mn, Cr, Ni, Pb, As and Zn were also above their allowable limits in these rivers (Keraga et al., 2017a). Arsenic and zinc were found higher in irrigated areas using water from the Akai River (Itanna, 2002) than rain-fed agricultural areas. Beyene et al. (2017) on these Tinishu and Tiliku rivers reported that Cu, Cr and Pb concentrations were greater than the standard limit set by the European directives for soil contaminants.

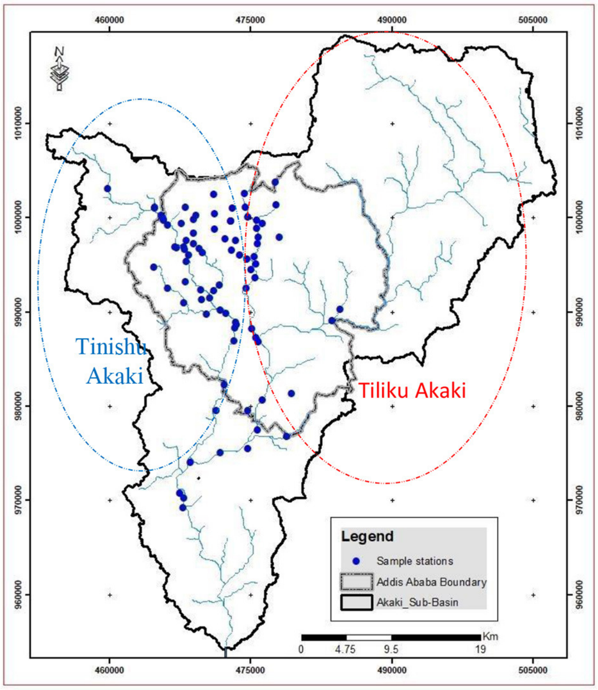


**FIGURE 3 |** Water quality monitoring stations used by several studies in the Akaki sub-basin.

The water quality of the Tinishu and Great Akaki river basins has been classified, according to the WHO drinking water guideline (WHO, 2004), as "badly polluted" to "very badly polluted," making the water non-suitable for drinking. The presence of trace metals in the tested samples indicates that industries have a significant contribution to surface water pollution. Gebre and Rooijen (2009) reported that E-coli bacteria concentrations in Tinishu and Tiliku Akaki rivers were 6.68 x $10^9$ and 6.61 x $10^9$ CFU 100 ml/L, respectively. The mean E.coli and Non-E.coli values in the measured water in Akaki river were 2.09 and > 3.48 log10 CFU 10 $mL^{-1}$, respectively, which were higher than the WHO recommended standard (WHO, 2006; Mengesha et al., 2021). The presence of trace metals in the tested samples indicates that industries have a significant contribution to surface water pollution and the high concentrations of E.coli bacteria indicate fecal pollution (Gebre and Rooijen, 2009).

Rooijen and Taddesse (2009) also reported that heavy metal concentrations that exceeded the natural levels were observed from vegetables grown in Tinishu and Tiliku Akaki Rivers and found that Cd, Cr, Cu, Hg, Ni, and Zn in potato; Zn and Hg in Cabbage; and Cr in onion and red beet. Water quality studies in different parts of Awash Basin are summarized in **Supplementary Table S2**. Another study by Itanna (2002) showed that cabbage was, in general, the least accumulator of metals/metalloids compared to other leafy vegetables with the exception of Ni and Cr. Lettuce had the highest concentrations of Cd, Co, Cr, Fe, and Mn; while Swiss chard contained the highest concentrations of As, Cu, Ni, Pb, and ZN (Itanna, 2002). Observed concentrations of As, Cr, Fe, and Pb were also greater than the maximum permitted levels in leafy vegetables and pose greater health concerns.

Fecal coliform levels in most vegetables in the Akaki River, except swish Chard, cabbage, and spinach in the wet season, were higher than the World Health Organization (WHO) and International Commission on Microbiological Specifications for Food (ICMSF) recommended level of 103 fecal coliform g/L fresh weights in both dry and wet season campaigns (Beyene et al., 2017). This was attributed to the Akaki River water, which is higher than the WHO recommended standard used for irrigation of vegetables particularly in dry seasons due to flows from upstream through the major industrial, commercial, institutional, and residential areas of the town. In addition, the application of organic manures is a common practice of farmers for the production of crops in that area.

## Seasonal Fluctuations of Trace Metals in Lakes and Reservoirs in the Awash Basin

Rivers pick up heavy metals as they carry surface water through areas with a variety of human induced inputs. Changes in the spatial distribution patterns of heavy metals in surface water and sediments may result as a result of this (Kumar et al., 2021). The presence, transport, and fate of toxic and persistent heavy metals and organic compounds in water bodies is a major area of concern around the world (Edokpayi et al., 2017). One of the world's greatest worries is the contamination of the environment with hazardous heavy metals (Kumar et al., 2021). Because of their non-biodegradability, extended biological half-lives, and water solubility, the majority of heavy metals are extremely toxic (Naser et al., 2014). The buildup of high levels of Pb, Cd, Cr, Ni, and Zn in river basins is most prevalent in areas with a lot of industrial and commercial activity (Islam et al., 2020). Most lakes and reservoirs in the Awash Basin are experiencing water quality degradation. There are 22 lakes and reservoirs within the Awash Basin. This section summarizes the water quality status of selected lakes and reservoirs within the basin. Speciation of selected trace elements on samples collected from the Koka reservoir showed that Cr, Mn, Co, Ni, Cu, Zn, and Pb were predominantly present at high molecular masses (HMM), i.e., > 10 kilo Daltons. The presence of trace elements at higher masses during the wet season suggests the reduced mobility of elements along with colloids and particles (Masresha et al., 2011).

Because Lake Beseka water is saline (EC$\sim$6.3 dS $m^{-1}$), sodic (SAR$\sim$300), or alkaline (pH$\sim$9.6), it cannot be used for irrigation or drinking (Dinka, 2012). The drastic expansion of the lake has led to many problems in the surrounding area, and is a severe threat to the well being of the indigenous people and the economic welfare of the nation in general. Between 1960 to 2015, salinity and alkalinity levels in Lake Beseka showed decreasing trends in ionic concentrations of quality parameters due to the dilution effect (Dinka, 2017). In general, the water quality of the Awash river downstream of Lake Beseka has deteriorated between 2013 and 2017 due to the release of unregulated Lake Water into the Awash River (Yimer and Jin, 2020). At the Awash inlet, Koka reservoir and Awash outlet, reported that the mean

**TABLE 1 |** Lake Koka cations and heavy metal study result by different studies.

| Parameter | Unit | Parameter value | Compared to WHO guideline |
|---|---|---|---|
| $Ca^{++}$ | (mg/L) | 31.6 dry season, 22 wet season (Masresha et al., 2011) | |
| $Mg^{++}$ | (mg/L) | 6.9 dry season, 8.2 wet season (Masresha et al., 2011) | |
| $Na^{++}$ | (mg/L) | 46.6 dry season, 11 wet season (Masresha et al., 2011) | |
| K++ | (mg/L) | 6.4 dry season,11 wet season (Masresha et al., 2011) | |
| Fe | (mg/L) | 6.8 dry season,37 wet season (Masresha et al., 2011) | (0.3)* |
| Cr | (µg/l) | 27.8 dry season, 50.9 wet season (Masresha et al., 2011), 1.7-4.2 (Dsikowitzky et al., 2013) | (50)* |
| Mn | (µg/l) | 303 dry season, 422 wet season, (Masresha et al., 2011) | (400) |
| Cu | (µg/l) | 15.5 dry season, 20.8 wet season, (Masresha et al., 2011) | (2,000) |
| Co | (µg/l) | 4.8 dry season,7.7 wet season, (Masresha et al., 2011) | (110) |
| Zn | (µg/l) | 48 dry season, 98.4 wet season, (Masresha et al., 2011) | (3,000) |
| Pb | (µg/l) | 4.9 dry season,8.5 wet season, (Masresha et al., 2011), 0.24–0.68 (Dsikowitzky et al., 2013) | (10) |
| Ni | (µg/l) | 22.4 dry season, 39.4 wet season, (Masresha et al., 2011) | (20)* |
| As | (µg/l) | 2.8 dry season, 2.9 wet season (Masresha et al., 2011), 0.57-3.0 (Dsikowitzky et al., 2013) | (10) |
| Cd | (µg/l) | 0.04 dry season, 0.06 wet season, (Masresha et al., 2011), <0.1 (Dsikowitzky et al., 2013) | (3) |
| Se | (µg/l) | 0.63 dry season, 1.2 dry season, (Masresha et al., 2011), <0.1–0.12 (Dsikowitzky et al., 2013) | (50) |
| Hg | (µg/l) | <0.1 (Dsikowitzky et al., 2013) | (6) |
| Viruses | (ml/l) | 800E + 07 (Fasil et al., 2011) | |
| Bacteria | (ml/l) | 502E + 06 (Fasil et al., 2011) | |

**Higher than the WHO standard.*

concentrations of metals ranked (high to low) was Fe > Cr > Cu > Zn > Pb > Cd > Ni and Fe > Cu > Zn > Pb > Cr > Cd > Ni during dry and wet seasons, respectively. Overall, concentration of heavy metals during dry season was higher than the wet season except for Fe. Increases in concentration of Fe during the wet season was attributed to increased runoff during the rainy season that eroded the soil particles containing iron (Eliku and Leta, 2018). Some heavy meatal related water quality studies in lakes, reservoirs and rivers in different parts of the Awash basin is annexed in **Supplementary Table S2**.

Masresha et al. (2011) also observed differences in metal concentrations in Koka reservoir during dry/wet seasons with reported dry/wet season values (mg/L) of 46.6 /11, 6.4/1, 31.6/ 22, and 6.9/8.2 for $Na^{++}$, $K^{++}$, $Ca^{++}$ and $Mg^{++}$, respectively. In addition, heavy metals like Fe, Cr, and Ni were in higher concentrations than the WHO limit (**Table 1**). The lakes have primarily been used for commercial fishing, irrigation, recreation, and residential uses. Although these limited water resources are critical to the population's survival, there are signs that Koka reservoir is undergoing changes that could lead to water quality degradation.

The temporal and regional fluctuations of trace heavy metal concentrations in Mojo river in the extreme wet rainy season, semi-wet and semi-dry period (autumn), and extreme dry season (winter), according to Tamene and Seyoum (2015) showed that the level of As rises as the year progress from wet to dry, indicating dilution effects. Except for one result, all of the assessed As results are higher than the WHO Drinking Water Guidelines (DWG) (0.01 mg/L) (WHO, 2004). In all study locations and sampling periods, the average Cd pollution load was found to be 0.12 ± 0.075 mg/L. All of the Hg experimental results are significantly higher than the WHO guidelines for fresh water (0.05 mg/L) and maximum allowable DW for livestock (0.003 mg/L), respectively (Carr et al., 2004). More than half of the examined results of Pb was above the WHO's maximum acceptable limit for DWG (0.01 mg/L).

Dagnachew et al. (2019) observed higher concentrations of Cr (VI) in Tinishu Akaki and Jemo rivers. **Figure 4** shows Cr (VI), CU, Mn, and Zn concentrations from studies conducted on different rivers. Overall, Cr (VI) and Mn concentrations exceeded the Ethiopian standard in both the dry and wet seasons in most locations. However, concentrations were greater during dry seasons compared to the wet season. This is probably due to the dilution effect of the wet season. In the different studies, there is very limited temporal heavy metal load analysis in rivers as well as in reservoirs/lakes in the different parts of the basin. The three rivers are the western side of the Akaki catchment **Figure 2** which receives untreated wastewater from industries as well as from urban waste.

## Point Source Pollution

Water contamination is caused by a variety of factors, including industrial wastewater and hazardous chemicals. Although Ethiopia has a small number of industries, its pollution impact

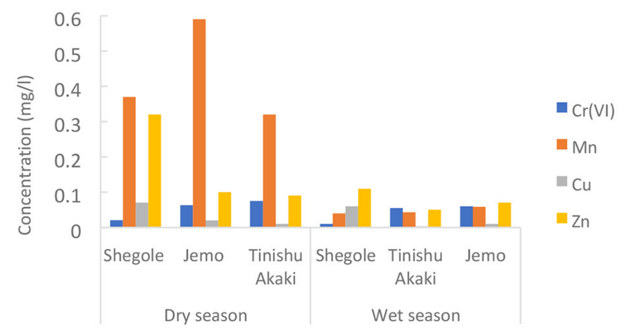


**FIGURE 4 |** Trace metal content in Addis Ababa rivers in dry (D) and wet (W) seasons. Sources (Dagnachew et al., 2019).

is substantial. Industrial waste from poorly managed industries is a major source to water pollution, particularly in Ethiopian rivers. This is because most Ethiopian factories lack wastewater treatment facilities (Menbere, 2019). In Ethiopia, most industries just dump their untreated toxic wastewater into adjacent rivers, lakes, and streams. Pollution from industrial wastewater discharge has increased as a result of hazardous chemicals (Alayu and Yirgu, 2018). The city of Addis Ababa hosts about 65% of industries in the country and more than 90% of those industries discharge their waste to the nearby river without proper treatment (Yohannes and Elias, 2017). However, in recent years, industrial activity is extending beyond Addis Ababa into towns like Mojo, Debrezeit and Nazret, increasing the influence of industrial pollution to the Awash and the Mojo rivers, and Koka reservoir as shown in **Figure 2**. The Awash River is polluted by liquid and solid effluents released from industries and households that release untreated their domestic and industrial effluents (Teshome, 2019). One of the major sources of pollution for the Awash River is untreated domestic discharge from the city of Addis Ababa. In Addis Ababa, for example, there are roughly 1,200 significant industrial enterprises, which combined with institutions, commercial centers, and hotels generate 18 percent of the city's entire solid wastes (Menbere, 2019). The majority of the waste produced by residents and industries is deposited in the city's streams and rivers, which are consumed by livestock and also used for various purposes like as irrigating vegetables and crops (Weldegebriel et al., 2012).

Mengesha et al. (2021) reported the Akaki River, like many Addis Ababa streams, is heavily contaminated by anthropogenic influences from upstream to downstream. The causes are specifically indiscriminate dumping of refuses into the river, indiscriminate dumping of industrial wastes (Mekonnen and Amsalu, 2018). The majority of pollutants are discharged into a single collection location, such as reservoirs that can act as a sink for a variety of contaminants. Heavy metal concentrations in stream sediments are relatively high, according to several studies, due to significant anthropogenic metal loadings carried by tributary rivers. As a result, surficial sediments may act as a metal puddle, releasing metals into the underlying water and potentially harming riverine ecosystems (Astatkie et al., 2021).

**TABLE 2 |** Metals and heavy metals Anmol product paper factory.

| Parameter | Concertation range (mg/L) | | Standards | |
|---|---|---|---|---|
| | Raw effluent | Treated effluent | WHO limit | EPA limit |
| Na | 140–900 | 130–800 | 400 | 400 |
| K | 2.9–12.1 | 2.1–11.6 | – | – |
| Ca | 11.09–1,150 | 8.71–1,104 | 200 | 200 |
| Mg | 5.23–110.4 | 6.18–66.24 | 150 | 150 |
| Fe | 0.27–2.77 | 0.18–1.67 | - | - |
| Cu | 0–0.03 | 0 –0.03 | 2 | 2 |
| Zn | 0–0.59 | 0.13–0.55 | 10 | 6 |

*Sources: Adapted from Zerihun and Eshetu (2018).*

Most industries in Gelan and Dukem have established neither treatment plants nor adequate storage or discharge channels for their wastes. As a result, polluted liquids are directly discharged into the open landscape (Dadi et al., 2017). A study by Dadi et al. (2017) on the environmental and health impacts of effluents from textile industries in the Gelan and Dukem watersheds of the Upper Awash river showed the presence of substantial concentrations of Zn in industry effluents. Zerihun and Eshetu (2018) reported that both raw and treated effluents from the Anmol product paper factory contained higher concentrations of heavy metals that significantly deteriorated the water quality of the Awash river (**Table 2**). The study found that, very high Na and Ca concentrations, greater than the national and WHO discharge limits, in both raw and treated effluents.

The Mojo watershed is one of the sub-watersheds of the Awash Basin. The Mojo river Basin is experiencing rapid population growth, industrialization, and agricultural activities, all of which are potential causes of surface and groundwater contamination. Residents along the Mojo River use the river water for many purposes. However, the discharge of domestic and industrial pollutants of the town severely restricts the use of surface water (Tamene and Seyoum, 2015). Kolba Tannery, Ethio-Japan Textile, Soap factory, Gelan Tannery, Organic Export Abattoir, Derartu Tannery, Mojo Tannery, and Food and Oil Complex drain their influent into the Mojo river. A study by Gebre et al. (2016) found that mean concentration values of Cr in water samples ranged between 0 and 8.02 mg/L. Cr concentrations downstream of the Mojo, Kolba, Gelan and Derartu Tanneries were greater than NEQS standard (1 mg/L).

## IMPACTS OF WATER POLLUTION

Water quality affects the economic, social and political development of society (Mekonnen and Amsalu, 2018). This article focuses on the effects of water quality on biological, toxic, health as well as vegetable production and soil.

### Biological Effects

Nutrient loadings affect water quality throughout the world and have resulted in the eutrophication of many fresh water lakes (Ligdi et al., 2010; Jonathan et al., 2012; Alemu et al., 2017).

Water pollution in the basin is found to have contributed to the disappearance of aquatic species (Rooijen and Taddesse, 2009). Dissolved phosphorus plays an important role in the eutrophication of water bodies (Moges et al., 2016). Phosphates entering the water from detergents urban areas, industrial waste (such as sugar cane production), and intensive agriculture (Rooijen and Taddesse, 2009; Girma, 2016; Moges et al., 2016) can cause the nutrient levels in the water to rise and lead to algal blooms (Girma, 2016). A study by Ingwani et al. (2010) describes eutrophication from anthropogenic drivers as the main cause for the rapid spreading of water hyacinth over reservoirs. Water hyacinth is one of the biodiversity issues that contribute to the degradation of aquatic ecosystems. This is a case in Ethiopia where by degradation in water quality results in water hyacinth (Eichhornia crassipes) invasion (Hailu et al., 2020). This can increase the incidental occurrence and spread of water hyacinths in Lake Tana (Moges et al., 2017), as also observed in Lake Koka and Aba Samuel Lakes are indictors of the effect. Similarly, very high chlorophyll *a* values were observed upstream of Sebeta River (Tassew, 2007). The most severe area coverage by water hyacinths in Lake Tana was noticed at the mouth of the Megech River, which stretched both east and north with an estimated area coverage of 80–100 ha and wide distribution of daughter plants that pushed forward with the wave's assistance (Tewabe, 2015).

When nutrient-rich effluents enter a lake, it overloads the ability of the lake to provide oxygen to aquatic lives in it. This is a eutrophication process in which there is an upsurge of algae growth in the lake, which then results in the depletion of oxygen and fouling up of the lake water (Rooijen and Taddesse, 2009; Girma, 2016). This, in turn, can alter the food chain and ionic composition of the water, increase organic matter in the sediment, decrease metalimnetic and hypolimnetic oxygen (which causes fish suffocation), and cause changes in the water temperature (Girma, 2016).

In many places of the world, the occurrence of harmful toxic algal occurrences has increased over the last three decades. Many bloom-forming algae species can produce biologically active secondary metabolites that are extremely harmful to humans and other animals (Reddy and Mastan, 2011; Edokpayi et al., 2017). Water pollution in the basin is found to have contributed to the disappearance of aquatic species (Keraga et al., 2017b).

Heavy metals concentrations in water and tissue samples from edible fish species from Hwassa and Koka lakes showed that metal concentration in Koka from highest to lowest was Cr > As > Pb > Cd > Se > Hg (Dsikowitzky et al., 2013). Metal concentrations in fish tissues also showed significant differences with average concentrations of metal in the gills from highest to lowest was: Cr > Pb > Hg > As > Cd > Se. In fish muscles, the rank was Cr > Hg > As > Pb > Cd > Se and in fish livers Cr > Hg > Cd > As > Pb > Se. Overall, Cr concentration was the highest in both water and fish tissue samples.

## Toxicity Effects

Toxic substances from farms, towns, and factories readily dissolve into and mix with it causing water pollution. Heavy metals are known to pose a variety of health risks such as cancer, mutation (Itanna, 2002). Metals such as arsenic, lead,

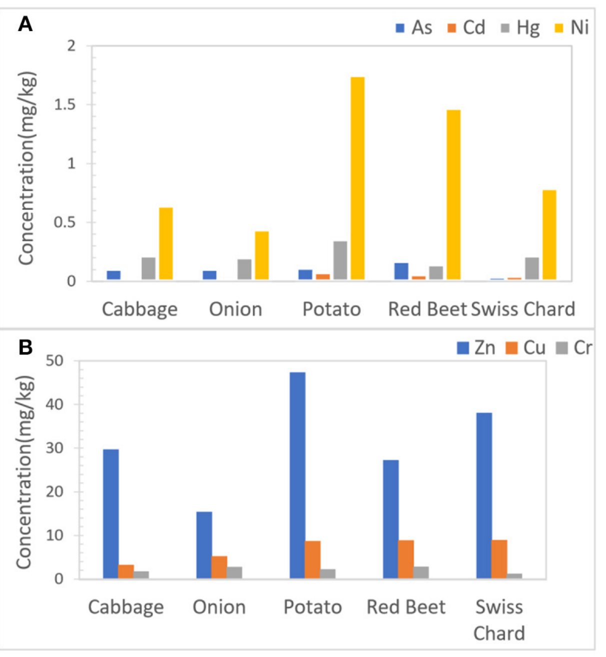


**FIGURE 5 |** Trace metal levels in vegetables (Gebre and Rooijen, 2009). **(A)** Concentration of As, Cd, Hg and Ni in vegetables and **(B)** Concentration of Zn, Cu, and Cr in vegetables.

cadmium, nickel, mercury, chromium, cobalt, zinc and selenium present in natural waters are highly toxic even in minor quantities (Masindi and Khathutshelo, 2018). Long-term exposure to heavy metals can cause significant toxicity in the dermal and ingestion pathways of contaminated materials (Islam et al., 2020). Some of the cations and heavy metal investigation results by different researchers in Lake Koka are shown in **Table 1**. For example, Fe, Cr, and Ni are higher than the maximum permissible limit of the WHO standard. The investigation made by Bahiru (2021) showed that concentrations (mg/L) of metals in the Akaki river water samples were found to be in the ranges of 0.18–0.28, 1.40–2.67, 0.97–1.40, 0.037–0.087, 0.037–0.080, and 01–0.14 for Fe, Zn, Cu, Cd, Pb, and Cr, respectively. All are above the recommended limit of both (Fewtrell and Bartram, 2001).

The Tinishu Akaki catchment area has a high influx of trace metals. High levels of trace metals in sediments probably have adverse effects on the bottom-dwelling aquatic organisms as well as to the health of the people who depend on the water for various activities (Kassegne et al., 2018). The poor quality of river water in Addis Ababa cause and affect the production of different crops/vegetables (Bedada et al., 2019); this is justified by an investigation made by Gebre and Rooijen (2009) trace metal content in vegetable leaves (Cd, Cr, Cu, Hg, Ni and Zn in potato and Cr in onion and red beet in Addis Ababa). The concentrations of trace metals in vegetables cultivated with wastewater are shown in **Figures 5A,B**. Although all of these metals have not yet reached phytotoxic levels, some plants have exceeded the normally occurring amounts. This is especially true in the case of Cd, Cr, Cu, Hg, Ni, and Zn in potatoes, as well as Cr in onion and red beet.

## Health Effects

Excessive anthropogenic activities, such as the discharge of industrial effluents, agricultural waste, and toxic waste into surface waters, have a negative impact on human health (Islam et al., 2021). Typhoid, cholera, encephalitis, hepatitis, skin infection, hair loss, liver cirrhosis, renal failure, and neural disorder spread through dermal and oral ingestion of metals contaminated water (Islam et al., 2021). Virological Quality of Addis Ababa rivers and Hospitals total coliphages enumerations ranged from <1 pfu/100 ml to 5.2×103 pfu/100 ml for urban rivers and <1 pfu/100 ml to 4.92×103 pfu/100 ml for hospitals wastewaters. Coliphages were detected in 44 (52.4%) and 3 (10%) samples of 30 streams and rivers and four hospital waste waters, respectively.

Novel contaminants continue to pose new challenges to monitoring and treatment regimes in urban settings, where a variety of contaminants have an impact on water quality (McGrane, 2016). For example, as a result of fast population growth, uncontrolled urbanization and industrialization and poor waste management practices Addis Ababa's water resources are highly polluted which threatens 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 (example, Nazareth town) and irrigation, public health risks are high (Rooijen and Taddesse, 2009). Contaminated drinking water has been linked to substantial illness and mortality around the world. It is used to spread communicable diseases such as diarrhea, cholera, dysentery, typhoid, and guinea worm infection (Wolde et al., 2020). For example, the negative impact on human health and the ecosystems as a result of the elevated level of several pollutants and irrigation products (vegetable) will ultimately affect the people that depend on the Akaki River water (Zinabu and Desta, 2002). An investigation conducted by Bedada et al. (2019), in nine sub-Cities of thirteen rivers and four hospitals wastewaters of Addis Ababa, reported poor water quality in all rivers and one-half of the hospitals (detection of coliphages) will continue to cause a major health risk and will result in more number of deaths and also will affect the aquatic life and drinking water.

The overall mean count of *E. coli* and Non *E. coli* from water samples from Akaki River was 2.09 and >3.48 log 10 CFU 10 $mL^{-1}$ which is higher than the WHO recommended standard (Beyene et al., 2017). A high level of total *E. coli* was recorded in effluents from ALSAR and ALMHADI textile industries in Gelan and Dukem (Dadi et al., 2017). Downstream residents use river water for domestic and agricultural purposes. Such practices have created major health risks to people who rely on the river for their livelihood. Despite the varied character of the Kebena River's and its neighboring buffer zones' environmental concerns, pollution remains the dominant worry (Asnake et al., 2021). Consumption of heavy metal-contaminated food crops is one of the most common routes for harmful compounds to enter the human body, with some symptoms appearing only after several years of exposure (Srinivasan and Reddy, 2009). The existence of total coliforms across the River has been a major threat to human health. Water pollution does not only have adverse health impacts, but it also imposes medical expenses to the population (Gebre and Rooijen, 2009). According to the World Health Organization (WHO), around 80% of diseases are transmitted through water, making surface water a major source of infection for marine species and humans (Islam et al., 2021). Some research activities around Addis Ababa recognized there is a signal that human health and life are threatened due to crop production using polluted water (EFDR, 2000). The negative impact on human health and the ecosystem as a result of the elevated level of several pollutants and irrigation products such as vegetables will ultimately affect the people that depend on the river water (Zinabu and Desta, 2002).

The local environment, people, and livestock of Gelan and Dukem towns are exposed to highly contaminated effluents. For example related to skin allergies and stomach health problems in humans and bacteriological infections specifically "Salmonella" in cattle and donkeys diagnosed in veterinary clinics (Dadi et al., 2017).

## Impact on Vegetable and Soil

Urban and industrial wastes are common sources of anthropogenic metal pollution in soils. Because of the negative impacts on food quality, crop growth, and soil environmental health, heavy metal deposition in soil is a key concern in agricultural production (Naser et al., 2014). The use of water with poor quality for agricultural activities can affect crop yield and cause food insecurity. Several studies have reported higher levels of heavy metal concentrations from different part of the country (Edokpayi et al., 2017). Heavy metals are easily accumulated in the edible parts of leafy vegetables compared to grain or fruit crops (Mapanda et al., 2005). Heavy metals accumulate in the edible and inedible sections of vegetables in sufficient concentrations to induce clinical issues in animals and humans who consume these metal-rich plants (Arora et al., 2008). Haile and Mohammed (2019) reported that Cr, Zn, Fe, K, Cu, and Mn exceeded the (WHO, 2008) standards in lake Hawassa. Abate and Fitamo (2015) stated that the concentration of $Na^{+}$ and $K^{+}$ >200 mg/L permissible limit by WHO (2008). Worako (2015) also showed that Total Coliform and Fecal Coliform were greater than the acceptable limit of 1,000 MPN/100 ml set by WHO (2008) and CCME (1999); and above the 14 MPN/100 ml recommended limit by USEPA (1976).

Due to the high metal retention capacity of agricultural soil, it has been suggested that it is the most important sink for heavy metals. As a result of increased anthropogenic activity, there is evidence to suggest that agricultural soil has elevated amounts of heavy metals. The chemical contents of irrigation water can affect plant growth directly through toxicity or inadequacy, or indirectly by influencing plant nutrient availability Due to the high metal retention capacity of agricultural soil, it has been suggested that it is the most important sink for heavy metals. As a result of increased anthropogenic activity, there is evidence to suggest that agricultural soil has elevated amounts of heavy metals. The chemical contents of irrigation water can affect plant growth directly through toxicity or inadequacy, or indirectly by influencing plant nutrient availability (Belay, 2019). Heavy metals are inorganic pollutants with a wide range of negative effects on aquatic organisms, plants, and human (Inyinbor et al., 2018). The heavy metal concentration of irrigation water has been demonstrated to surpass the irrigation water standard (Keraga et al., 2017b).

Excessive accumulation of pollutants in soils, such as heavy metals, causes increased heavy metal uptake by crops, affecting food quality and safety (Srinivasan and Reddy, 2009). Mean concentration of heavy metals including Mn, Cr, Ni, Pb, As, and Zn reported more in vegetables irrigated by Awash River than their allowable limits (Keraga et al., 2017b). Vegetables like, Ethiopian mustard, Lettuce and Swiss chard, were collected and subsequently analyzed for selected heavy metals, Fe, Mn, Zn, Pb, Cr, and Cd. Zn was detected in all vegetable types, where around 51% of the samples have exceeded the amount of Zn when compared to the standard limit of 99 mg/kg in Akaki Rivers (Weldegebriel et al., 2012). Some of the vegetables tested in Tinishu and Tiliku Akakai Rivers have heavy metals exceeded the naturally expected levels. Based on the investigation, Cd, Cr, Cu, Hg, Ni, and Zn in potato, Zn and Hg in Cabbage, and Cr in onion and red beet (Rooijen and Taddesse, 2009; Teshome, 2019).

The mean counts of TC, FC, and total aerobic count (TAC) on collected vegetables irrigated with Akaki River were 3.22, 1.37, and 4.72 in the dry season, and 3.87, 2.57, and 5.09 log10CFU per gram in the wet season, respectively. All fresh vegetables were contaminated with total coliform, fecal coliform and total aerobic in the dry season (Beyene et al., 2017). In addition to this, as stated by Bahiru (2021), Cd, Pb, Fe, Zn, Cr, and Cu concentration in lettuce samples irrigated by Akaki river water are in the range of (0.047–0.263), (0.42–6.55), (339.83–420.00), (2.96–13.44), (0.95–7.87) and (1.68–7.49) (mg /Kg) respectively, all heavy metal concentration are above recommended level set by WHO (2008).

The investigation made by Itanna (2002) showed that Arsenic (As) and zinc (Zn) in soil irrigated by the Akaki River were higher than the normal limit. The concentrations of Pb, Cd, Mn, Ni and Zn in sediments in the Tinishu Akaki river were relatively greater than other trace metals at levels that may have adverse biological effects on the surrounding biota (Kassegne et al., 2018). Similarly, high concentration of tributary rivers and lakes (high concentration of salt) increases the pH level of the Awash River and this affects the producing of companies that engaged in cotton production, wheat, and other cereal crops and vegetables (Teshome, 2019). Akaki river water irrigated soil samples concentration (mg/kg) was found Cd (0.47–3.47), Pb (8.00–118.00), Fe (13,557.30–16,800.00), Zn (40.00–224.67), Cr (4.91–39.36) and Cu (35.00–149.88). All metals except Cd and Fe in the soil samples are below the recommended level set by Fewtrell and Bartram (2001), Bahiru (2021). Heavy metal levels in soil samples from Mojo sub-basin farmlands were measured. In soil samples from tomato cultivation, the mean concentration of arsenic (As) was found to be 21.00 mg/kg, and in soil samples from cabbage cultivation, it was found to be 30.73 mg/kg. Arsenic levels were found to be higher than the European Union's acceptable limit of 20 mg/kg in both soil samples tested (Gebeyehu and Bayissa, 2020). According to findings in Mojo river, the mean Cr value was 2.515.794 mg/L, with half of the findings falling below the FAO standard for surface water irrigation (0.1 mg/L) and WHO DWG (0.05 mg/L) (Tamene and Seyoum, 2015).

Soil pH varied between 6.9 to 8.9 for Melka Sedi and 7.06 to 9.1 for Melka Werer farm areas. EC value ranges from 0.33 to 82.1 deci Siemens per meter (dS/m) and 0.4 to 37.5 dS/m, respectively for soil samples taken from Melka Sedi and Melka Werer farms (Abebe et al., 2015). Soil salinity and sodicity assessment by Abebe et al. (2015) in the Amibara area revealed that substantial parts of farm areas were consistently and continuously affected by salinity problems.

### Socio-Economic Effects

The economic effect of water quality can be seen in different perspectives. Decrease in water quality can lead to increased treatment costs of potable and industrial process water. Crops will be prone to hunger and quality deterioration as a result of poor water quality, resulting in a drop in agricultural yield. Water contamination has a considerable impact on agricultural economic growth, as detailed by Li and Li (2021), which is a major roadblock to China's rural revitalization plan. China's water pollution has a cumulative effect on agricultural economic growth that is increasing in time and space, harming the agricultural ecology. Agricultural economic growth in China dropped by 27.994 units for every unit increase in wastewater discharge intensity.

In case of Ethiopia, the mixing of lake Beseka (extremely saline) water with Awash river (fresh water) was done to slow down lake Beseka rapid expansion rather than to alleviate the basin's water scarcity problem. After the lake Beseka mix, the Awash River serves as an important water source for cattle, domestic use, and irrigation water for nearby wheat, vegetable, cotton, and sugar plantations. These crops are extremely important economically for both the local community and the country. The water utilized for irrigation in the downstream community has a variety of negative consequences, including decreased crop yield and financial benefits, decreased irrigable or fertile land, and increased domestic water shortages (Yimer and Jin, 2020). For example, Tadesse et al. (2018) from their study Rebu River in the Oromia region reported that Cr, Zn, Fe, K, Cu, Na, Mn and Pb concentrations were greater than the ESA (2013) and WHO (2008) standards as shown in summary of major water quality studies from different parts of Ethiopia supportive **Supplementary Table S1**. Water pollution does not only have adverse health impacts but it also imposes medical expenses on the population (Gebre and Rooijen, 2009). The town of Awash with a population of 30,000 has to shirt from abstracting water from river to groundwater primarily because of the pollution (Parker et al., 2016).

High concentration of salt in tributary rivers and lakes increase the pH level of the Awash River and this affects the production of companies that engaged in cotton production, wheat, and other cereal crops and vegetables (Teshome, 2019).

## RESEARCH GAPS AND PROBLEMS IDENTIFIED FUTURE AGENDA

This review identifies several impact-related contaminated water research efforts, but it also identifies research gaps. The most important relates to the scope and delimitation of the study. Much of the reports are either separate graduate thesis research limited to specific location and or time. Consequently, there is no thorough integrated spatial and temporal water quality impact mapping to portray the overall picture of the sub watershed or the entire basin. There is little evidence-based research on the effects of contaminated water on agriculture, health, and socioeconomics. There is limited research on the socio-economic effects of water contamination and their estimated costs, human and animal health-related impacts of contaminated water and all vegetables species grown by contaminated river waters. In addition to this, there is lack of regular biological water quality monitoring in the basin.

It is expected to participate in a comprehensive spatial and temporal study of the impact of contaminated water on irrigated vegetable production, human and animal health, socio-economic effects, and impact on living organisms living in the aquatic environment in the basin or subbasin, utilizing the gaps identified in this review effort.

## CONCLUSION

The water quality of the Awash Basin's rivers, lakes and reservoirs is deteriorating. Rapid urbanization and industrialization have resulted in serious point source water contamination in the basin and endangering the basin's socio-economic and ecological values. The majority of the factories in the basin lack wastewater treatment facilities, simply discharge their toxic wastewater into nearby rivers, lakes, and streams. There is also untreated domestic discharge. The industries in the Akaki and Mojo sub-basins discharge their waste into nearby rivers and streams. They haven't built any treatment plants, nor have they set up suitable storage or discharge pathways for their waste.

Heavy metal concentrations in rivers, as well as in plants irrigated by these river waters and in the soil, were beyond their permissible levels. Even in little amounts, heavy metals are extremely hazardous. This study found evidence of the presence of these harmful compounds over the WHO recommended limit in rivers, lakes, edible fish tissues, and vegetables, primarily in upper Awash. Despite the fact that no previous study has been conducted to determine the influence on human and animal health, it is thought that they have negative impacts on aquatic organisms as well as the health of people who rely on water for various purposes. The amounts of cations, metals, viruses, and bacteria in most water sources of the basin exceed WHO and EPA legal limits, leaving them unsafe for human consumption. Water hyacinth (Eichhornia crassipes) invasion and harmful toxic algal occurrence owing to eutrophication caused by anthropogenic factors have been observed in the Koka and Aba Samuel reservoirs, as well as the Sebeta river. As a result, the food chain and ionic composition of the water can be altered, making people and other animals particularly harmful.

A comprehensive and systematic research spanning from identifying sources of pollution and its impact the health of humans, livestock and ecosystem at regular interval is vital. Moreover, a vulnerable ecosystem, it is vital to have an institutional arrangement responsible for regular monitoring and evaluation to protect vulnerable riparian communities and ecosystems. More research is needed to fully comprehend pollution dynamics and cleaning capacity of aquatic and wetland ecosystems. including a comprehensive study of the effects of contaminated water on human and livestock health, a comprehensive spatial extent investigation of the impact of contaminated water on growing vegetables, and the magnitude of the polluted water's socioeconomic effects in the downstream community as well as the country as a whole. The novelty of this SR in 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. The output will give background information for future research as well as preliminary policy direction for water resource managers and policymakers.

This SR is unique in that there has not been such a comprehensive including the accessing reports from different institution in the country. The review also combines information from works on the impact of contaminated water on humans, vegetables, and soil, as well as toxic and socio-economic effects. The output will inform future research as well as plan management interventions. Building from narratives of different reports, the following immediate interventions: (1) absence of accountability for industries that discharge effluents directly into water bodies without sufficient treatment; (2) widespread vegetable production in the upper Awash sub-basin using contaminated water. In the last decade, the Upper Awash River Basin has experienced rapid urbanization. If things keep going this way, the dawn stream's water quality will deteriorate dramatically. Wastewater reuse, such as that from Addis Ababa, is often used by the poor for vegetable growing. This is therefore water quality protection in the basin necessitates effective management and policy guidelines.

## RECOMMENDATION

A more extensive investigation of water pollution socio-economic, human, and animal health consequences, influence on aquatic creatures, and irrigated crop productivity in the upper Awash basin is needed, based on the findings of this systematic review. It is laudable to have strong institutions capable of formulating new laws and implementing the present environmental legal framework. Wastewater reuse, such as that from Addis Ababa, is often used by the poor for vegetable growing. This is therefore water quality protection in the basin necessitates effective management and policy guidelines.

## DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

## AUTHOR CONTRIBUTIONS

EA is a researcher and lead author. GZ and TA contributed to project design, conceptual framework development, and manuscript preparation. YD, HB, and BT reviewed different versions of the manuscript. All authors contributed to the article and approved the submitted version.


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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frwa.2021.790900/full#supplementary-material

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