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A Synthesis of Surface Water Quality in Awash Basin, Ethiopia

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Developing countries like Ethiopia are grabbling with rapid population growth, urbanization, agricultural intensification, and climate change which put intense pressure on the availability and quality of water resources. The surface water quality degradation is exacerbating due to increasing urbanization and agricultural activities. The average annual fertilizer use in Ethiopia increased from 132,522 metric tons (mt) in 1996 to 858,825 mt in 2015. Pesticide use also increases significantly from 3,327.7 mt/y in 2006 to 4,211.5 mt/y in 2010. The Awash river is one of the most affected rivers by intensified irrigation schemes, industrial, and urbanization pollution. The Awash river and its tributaries are used for domestic, irrigation, industrial, and recreational purposes. However, as per Canadian water quality indices for the drinking and irrigation water quality, the upper Awash basin scored 34.79, and 46.39, respectively, in the poor and marginal categories; whereas the middle/lower basin indicated 32.25 and 62.78 in poor and marginal ranges, respectively. Dissolved phosphorous in the headwater tributaries is about 0.51 mg/l which is beyond the threshold (0.15 mg/l). The surface water quality impairment is severe in the upper Awash basin where more than 90% of Addis Ababa's industries discharge their waste into nearby waterways without treatment; about 30% of the population lacks access to a liquid waste disposal and treatment facility; only 16% of the population is connected to sewage system, and 25% of the total waste generated enters freshwater systems without treatment. Many studies on surface water quality are reviewed and many of them are inconclusive for a number of reasons. For example, no comprehensive surface water quality research, lack of detailed combined spatial and temporal surface water quality data, and analysis to show the overall picture of the basin are a few of them. Despite the existence of the policy and legal tools, enforcement is lacking. Improving the ecological health of rivers necessitates policy revision as well as increased knowledge and engagement among implementers.

Keywords: pollution, water quality, water quality monitoring, point source, non-point source, Awash basin, Ethiopia

INTRODUCTION

Water is an essential requirement for all living forms on Earth, as well as the most crucial irreplaceable natural resource on which a country's socio-economic growth and long-term development are heavily reliant. Despite its importance to humans, water is the world's most poorly managed resource, particularly in developing countries, and is under serious threat from a wide range of anthropogenic activities (Kumar et al., 2021). The water quality degradation is exacerbating in Ethiopia due to increasing urbanization, and agricultural intensification. Poor urban water quality remains a concern, especially with rising population, the presence of new and uncontrolled substances, a higher value attributed to ecosystem services, and uncertainty about the effects of climate change on controlling factors of water quality such as temperature and environmental flows (Miller and Hutchins, 2017). The effects of urbanization on water quality vary widely, depending on a variety of factors such as the age/type of urbanization (existing urban center vs. suburban development), the existence of wastewater treatment, storm water infrastructure, legacy land use, vegetation, and hydrologic regime (O'Driscoll et al., 2010). Urbanization degrades water quality in three ways: point source pollution discharge, diffuse source pollution mobilization, flow changes, and temperature changes in receiving watercourses. Each of these will be determined by the shape and function of future urbanization, as well as the controls and management of potential pollutant discharges (Miller and Hutchins, 2017). For example: the population and built up area of Addis Ababa is rapidly expanding as a result of urbanization. The area downstream of the city that is affected by industrial and domestic pollution seems to be growing as well (Mekonnen et al., 2020).

Land and surface water quality degradation in Ethiopia was minimal before the last 30 years due to the low population density that practices slash and burn agriculture with minimum agricultural inputs (Ligdi et al., 2010). However, due to natural and anthropogenic sources, Ethiopia's land and surface water quality has recently been vulnerable to a wide range of pollution, including organic matter, salts, nutrients, sediments, heavy metals, and so on. Recent increases in sedimentation biodiversity loss in Ethiopia have been driven by rapid ecosystem loss and land use change, which is partly attributable to agricultural intensification (Moges et al., 2017). Although the United Nations General Assembly resolution 45/94 (1990), which reaffirmed the Stockholm declaration, advises that "all individuals are entitled to live in an environment adequate for their health and well-being," most of the Ethiopian people could not have access to clean water due to increasing environmental degradation. The right to have clean water and a healthy environment for all is also included as part of the Federal Democratic Republic of Ethiopia (FDRE's) constitution [Article 44(1)]. Accordingly, developing countries like Ethiopia have policies, laws, and formal administrative mechanisms in place to monitor and manage pollution, they fail to put them into practice and enforce them to safeguard the environment (Awoke et al., 2016). Likewise, the Ethiopian Public Health Proclamation (EFDR, 2000) prohibited the discharge of untreated waste generated from domestic and industries into freshwater bodies. Although the freshwater policies are in place, the enforcement was weak and freshwater pollution has been predominant in Ethiopia (Berg et al., 2019). Despite the severity, there is no systematic and comprehensive surface water quality assessment in Ethiopia that clearly presents the surface water quality challenges to policy makers and practitioners.

Agriculture releases non-point source pollutants causing significant pollution to the aquatic ecosystems (Awoke et al., 2016). The main source of pollution in agricultural fields are increased use of fertilizer, and pesticides that are aimed to improve agricultural production (Wondie et al., 2007; Emama et al., 2010). The average annual fertilizer uses in Ethiopia increased from 2.5 million decitonnes in 2003/4 to about 8.5 decitonnes in 2015/6 (Legesse et al., 2019), which is fivefold increase in a period of less than 10 years. Subsequent demand for pesticides in the agriculture and flower sectors, pesticide use also increases significantly [3,327.7 metric tons per year (mt/y) from 2006 to 4,211.5 mt/y in 2010] in which the country imports more than 3,346.32 mt annually (Begna, 2014). There is also an increase in land use conversion to agricultural land (from natural or native vegetation) which is reducing biodiversity in the landscape that undermines other ecosystem services such as pollination, medicinal plants, etc.

Growing number of evidences showed the severity of non-point source pollution in Ethiopia (Tafesse et al., 2015; Moges et al., 2016). Tafesse et al. (2015) showed that the contribution of overland flow to dissolved phosphorus is high in most of Lake Tana Basin catchments mainly due to fertilizer application in agricultural fields. Similarly, Moges et al. (2016) reported substantial amounts of available phosphorus in the Awramba watershed in the Lake Tana basin, which was related to use of DAP fertilizer use. Alemu et al. (2017) measured dissolved phosphorous (DP) concentration at various sampling locations at the tributaries of the Lake Tana basin in which the DP concentration was 0.09 mg/l for samples from the lake and 0.51 mg/l for the headwater tributaries.

DP of greater than 0.15 mg/l is considered to cause an adverse water quality problem responsible for the eutrophication in freshwaters. In fact studies highlight that such non-point source pollution flowing into the Lake Tana basin may contribute to the existing water hyacinth infestation in the Lake (Moges et al., 2016). Water hyacinth infestation is also observed in other lakes in Ethiopia, for example the Aba-Samuel Dam, Koka reservoir, Lake Ellen, and Wonji in the Awash River system alone (Alemu et al., 2017). Surface water quality problem is, however, sever in some basins in Ethiopia. For example, the water quality of the Rift Valley Lakes is severely compromised due to horticultural, soda abstraction, and industrial activities (Ayenew and Legesse, 2007).

Textile pollution has a particularly negative impact on freshwater environments, with certain parts of the world being more affected than others. Streams and rivers often provide huge volumes of water for textile manufacturing while also acting as key consumers of industrial effluents, carrying contaminants to groundwater and marine habitats (Stone et al., 2020). Most of the industries in Ethiopia often discharge their wastewater into the freshwater system without any treatment (Girma, 2016). Mehari et al. (2015) conducted a study to determining the effects of

Bahir Dar textile factory effluents on the water quality of the Blue Nile river and reported that dissolved oxygen was higher at the upstream site where the effluent joins the river, whereas BOD, TDS, and total alkalinity values were higher at site downstream of the site where the wastewater effluent joins the river.

Awoke et al. (2016), applying physicochemical and biological analysis, showed that there is significant surface water quality deterioration in agriculture, coffee processing, and urban landscapes in the Nile, Omo-Gibe, Tekeze, and Awash River basins compared to corresponding pristine (or reference sites) in basins (Awoke et al., 2016). The TN and TP estimates in the impacted sites were 100- to 1,000-fold to that of the European WFD, and US-EPA standards, respectively. Exhaustive list of the surface water quality studies in Ethiopia are summarized in the **Supplementary Table S2**. The Table also presents the study sites with the studied parameters, and standards in which the parameters were evaluated. This indicates river water pollution in the agricultural and urban environment in Ethiopia is a growing challenge and needs urgent action to avoid negative environmental consequences.

The Awash River originates from the Ethiopian central highlands and drains some part of the endorheic river system in Ethiopia. It has no outlet to an ocean; it joins Lake Abe at the Ethio-Djibouti border. The catchment area of Awash basin upstream of Lake Abe is ∼113,304 km^2, which is almost within the Ethiopian boundary with negligible contribution from Djibouti. Its elevation is between 250 and 3,000 meters above sea level (masl). The main river length is about 1,200 km (Taye et al., 2018).

The Awash River basin is divided into four major stretches based on altitudinal variation, i.e. Upper basin which represents the areas from the head water to the Koka Dam (>1,500 masl); Upper Awash Valley which ranges from Koka Dam 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 to Lake Abe (<500 masl) (Duguma et al., 2021; Jin et al., 2021).

The Awash basin has varied landscape, vegetation, rainfall, temperature and soils across the basin. For example, the climate ranges from semi-arid lowlands to cold highland mountains. The mean annual rainfall varies from ∼1,600 mm at Ankober to ∼160 mm at Asayita (Tufa, 2021). Land use in the basin is mainly rain fed agriculture which is used for rain fed crops, shrub land and grazing land. There are some irrigated lands in the basin, which are mainly developed by the government. In fact, a large part (∼60%) of the large-scale irrigated agriculture in Ethiopia is located in the Awash basin (Keraga et al., 2017a). Crops cultivated in the basin include cereals (e.g., teff, beans, wheat, barley and oil seeds), vegetables, flowers, cotton, perennial fruit trees and sugarcane (Tufa, 2021). The other land use includes urban areas, industrial zones, forest, and swamps. Major cities in Ethiopia (e.g., Addis Ababa, Dire Dawa, Nazert, Debrezeit, Dessie and Semera) are located in the Awash basin. More than 65% of the national industries in Ethiopia are located in the Awash basin (Keraga et al., 2017a). Administratively, the basin is shared by Afar, Amhara, Oromia and Somali Regional States, and Addis Ababa and Dire Dawa City Administrations (**Figure 1**). The population living in the Awash River Basin was estimated to be more than 18 million with population density greater than 6,452 persons/km^2 (Aklilu and Necha, 2018). Such evidence shows that the Awash basin is enduring extensive socio-economic pressure existing that threatens the surface water quality and quantity in the basin.

The Awash basin is home to extensive smallholder rain fed and large scale agricultural farms, and large industries, it has been exposed to sever pollutant sources (Eliku and Leta, 2018). Although the pollution situation in the Awash basin is sever, pollution of fresh water systems in developing countries is becoming prevalent due to rapid urbanization and industrialization (Tamiru, 2001; Gebre et al., 2016; Keraga et al., 2017b). Such surface water quality degradation issues are alarming in the developing countries as limitation to access to clean water exist, people will be compelled to consume such polluted water for domestic consumption (Tamiru, 2001; Keraga et al., 2017b; Olbasa, 2017), which has critical public health consequences.

The Little and Tiliku Akaki rivers are major tributaries of the Awash River which joins the Awash river system at the Aba-Samuel lake. Tinishu Akaki includes Burayu, Gefersa, Leku, Qille, Gerbeja, Worenchiti, Melka Qorani, Kera as its tributaries and while Ginfile, Kebena, Kechene, Kurtume and Yeka are tributaries to the Tiliku Akaki (Tufa, 2021).

The objective of this paper is, therefore, to review surface water quality related literature in the Awash basin to understand the biogeochemical pressures identify research gaps. The review focused on non-heavy metals and biological parameters.

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). A synthesis of Water Quality Researches in the Awash Basin has been 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, water pollution, point source pollutants, and non-point source pollutants. All searches included journal articles, books and book chapters. The selection criteria were based on the PRISMA checklist 2009. The search mainly focused on the mapping existing literature on the water quality, water pollution, and sources of pollution 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 12 research articles were excluded at this stage. There were 171 records extracted at this stage.

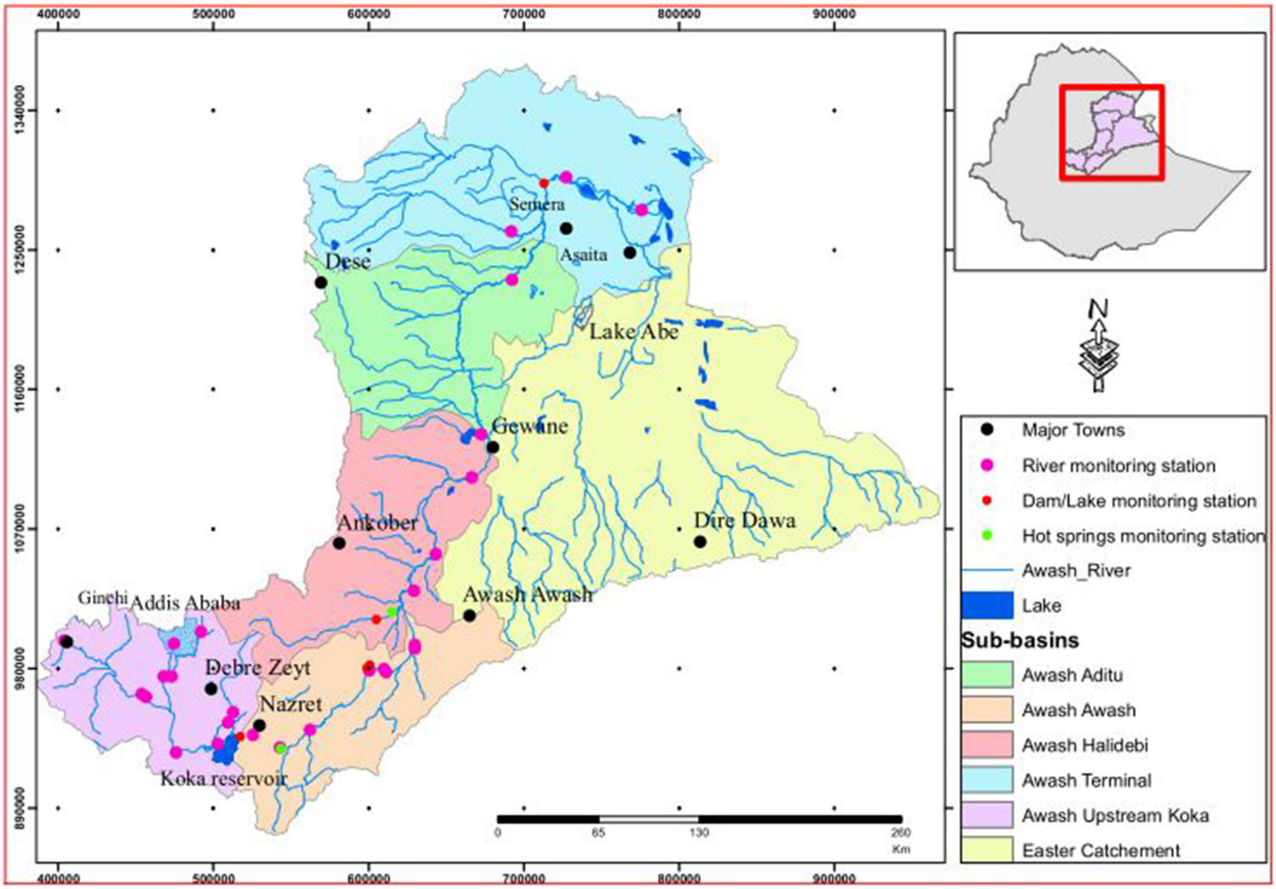

FIGURE 1 | Map of Awash Basin with administrative, monitoring sites and sub basin boundaries.

We extracted information on the following subtopics from each study: status of surface water quality monitoring, status of surface water quality, causes of surface water quality impairment, and surface water quality impairment indicators in Awash basin. All data extraction and coding were performed using Microsoft excel and medley reference manager.

All duplications were extensively examined to maintain the review's quality. 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 the 159 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 135 studies were deemed relevant. A later stage a careful examination of each study publication was carried out. We looked through the full-text publications to assess the studies' quality and relevance. 41 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 94 papers. The literature inclusion and removal at each level is depicted in **Figure 2**. 94 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 3 studies. In total, 97 studies were considered in this review.

RESULTS

Status of Surface Water Quality Monitoring

Water quality monitoring provides an reliable assessment of water quality enabling decision-makers to understand, interpret, and apply this information in support of management activities aimed at conserving the resource (Behmel et al., 2016), surface and ground water quality monitoring in Ethiopia has been incipient in most of the rivers (Graichen, 2011). If monitoring exists, the monitoring is very infrequent, for example, twice in a year in Ginchi river at Ginchi town, Awash river at Asaita. For proper surface water quality monitoring, samples should be collected at least once in a month to have a better understanding of the surface water quality situation in the watershed (Graichen, 2011). In order to monitor water quality, the following factors must be taken into account: determining a sampling site network for lakes and rivers; determining monitoring objectives (e.g., the

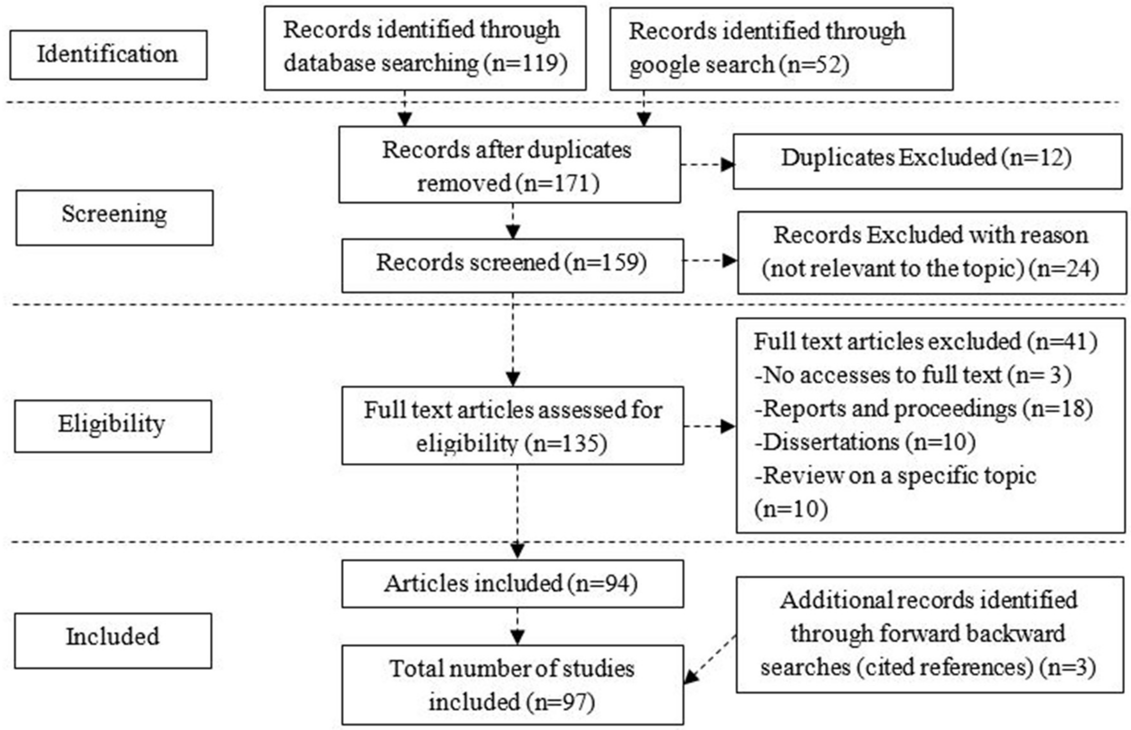

FIGURE 2 | Literature search and evaluation process and decision making for inclusion.

information that must be provided); selection of water quality parameters (WQP); frequency and recurrence of sampling; estimation of human, technical, and financial resources; logistics planning (e.g., field work, laboratory work, quality control and assessment, data handling, data storing, data analysis); and the identification of information dissemination pathways (Behmel et al., 2016). In Ethiopia, poor technical and financial capabilities restrict monitoring of rivers and sediments and understanding on the effects of pollutants (Zinabu et al., 2019). Moreover, consistent monitoring over a long period of time helps to acquire extensive surface water quality data that can be used to better understand surface water quality status of river basins (Vega et al., 1998) and thereby helps to take appropriate measures.

Currently, relatively better surface water quality monitoring exists in few water and environmental agencies, such as the Ethiopian Environmental Protection Agency (EPA) and Addis Ababa City Environmental Protection and Green Development Commission. The Awash basin authority (AwBA) also started monitoring surface water quality in the Awash basin in 2004 over 35 sites. Of selected thirty-five monitoring stations three trend, three impact and seven flux monitoring stations have been collected data monthly since July 2011. Quarterly surface water quality monitoring has been conducted in eight trends, four impact and five flux monitoring stations since July, 2011. There are also stations that measure twice per year, which are located at Ginchi, Saburie, Deho, Logia, and Affambo towns (**Figure 1**) but all these efforts are not in a comprehensive way as stated by Jin et al. (2021).

Surface water quality parameters collected in the Awash basin include pH, turbidity, electric conductivity, TDS, TS, TH, Alkalinity, Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, Fe, Mn, Cl^{-}, F^{-}, NH_3, NO_3^{-}, NO_2^{-}, SO_4^{2-}, PO_4^{3-}, HCO_3^{-}, and CO_3^{2-}. The data collection was conducted both in the wet and dry seasons although there is an emphasis to the dry season data collection. Fifty percent of the researchers collected their data both in dry and wet seasons (e.g., Masresha et al., 2011; Prabu et al., 2011; Awoke et al., 2016; Keraga et al., 2017b; Mengesha et al., 2017; Eliku and Leta, 2018; Kassegne et al., 2018; Adugna et al., 2019) while about the remaining 50% collected only dry season (Jebessa and Bekele, 2018; Kassegne et al., 2018; Tarekegn and Truye, 2018). However, there are few studies that monitor surface water quality only in the wet season (e.g., Eskinder, 2019). There are also studies that do not report periods of monitoring of their surface water quality data (e.g., Itanna, 2002; Awol, 2018; Bedada et al., 2019; Zinabu et al., 2019).

There are limited surface water quality monitoring at a finer temporal resolution, e.g., at biweekly (Akalu et al., 2011), monthly (Tesfay, 2007; Degefu et al., 2011; Abhachire, 2014; Keraga et al., 2017b; Dirbaba et al., 2018; Yimer and Jin, 2020), quarterly in Ginchi and Awash Below towns and in Awash river at the inlate of koka reservoir stations (Chernet et al., 2001; Akalu et al., 2011; Degefu et al., 2013). Dirbaba et al. (2018) collected 10 years monthly surface water quality data, which were helpful to assess trends of Hg, As, Pb, Ni, Cu, Cr, Zn and Cd at different stations of Awash river in Awash-Awash, Awash Halidebi and upper Awash sub basins. There is also seasonal basis (both dry and wet season) surface water quality monitoring as shown in **Supplementary Table S1**.

Surface Water Quality Status

Recent studies on freshwaters and river basins all around the world have found that river water pollution from organic and inorganic contaminants has gotten significantly worse over time (Kumar et al., 2021). Although water quality problem is apparent to most Ethiopian Rivers, Awash leads in the extent of impairment due to its service as a sink for the basin-wide urban, industrial and rural wastes (Keraga et al., 2017a). Land deterioration, high population density, natural water degradation, salinity and wetland degradation are all problems in the Awash River Basin (Tufa, 2021). Due to the repeated and poor irrigation practices and the increasing amount of Beseka Lake water flow to the downstream area, soil salinity becomes a challenge especially in the middle and lower Awash River Basin areas (Aregahegn and Zerihun, 2021).

Some of the most important services given by the Awash River water are irrigation, electric power generation, fish production, and serving as a water source for domestic consumption for residents living near the river course, as well as for domestic and wild animals in the area (Degefu et al., 2013). However, water quality index based evaluation showed that the water is below the standard for these purposes e.g., WHO and Canadian water quality ranking (Keraga et al., 2017a). Keraga et al. (2017a) showed that drinking and irrigation water quality indices of the upper basin were 34.79 and 46.39, respectively, which were in the poor and marginal categories of the Canadian water quality ranking. While the drinking and irrigation water quality indices of the middle/lower basin (which were 32.25 and 62.78) fall in the poor and fair ranges of the ranking. Surface water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels of the ratings (Davies, 2006).

Non-point source pollution was severing in the Awash basin due to the presence several irrigation schemes that produce banana, sugar and cotton. Because of poor irrigation practices and drainage in these irrigation schemes, salt and hazardous materials have accumulated in the irrigated fields, where they were easily carried into freshwater habitats (Tufa, 2021).

Untreated domestic, industrial, commercial, and institutional liquid waste discharged into rivers harmed the rivers' water quality. Because the city's solid and liquid waste treatment systems are poor and ineffective, all point and non-point sources in the city release their effluents directly or indirectly into surrounding rivers, which eventually joins the Awash River (Yohannes and Elias, 2017). About 30% of the City's inhabitants do not have liquid waste disposal and treatment facility. Of the total waste generated in the City, only 65% is collected and disposed of while about 10% of the waste is recycled and composted; and the remaining 25% join freshwater systems without any treatment. Besides the liquid waste, the City produces about 0.45 kg/capita/day of solid waste (Mohammed and Elias, 2017).

The Akaki River is the country's most contaminated river system. Almost all of the assessed locations along the Akaki rivers had poor water quality and did not meet the river water quality criterion. This degradation was caused by a variety of contaminants both point (factories discharge, urban waste water discharges, garage wastes, hospital wastes, etc.) and non-point sources (e.g., different sewages runoff, agricultural runoff). The most common sources are industrial wastes (Yohannes and Elias, 2017). Water pollution in the Tinishu Akaki River is higher than in the Tiliku Akaki River, owing to industrial units located in and around the city, intense farming activities along riverbanks, and indiscriminate disposal of domestic and municipal wastes (Melaku et al., 2004). Similar to the Tinishu and Tiliku Akaki river, the Mojo river sub basin in Awash river basin consists of several industries, which dispose directly into the river and subsequently to the Koka reservoir without appropriate treatment (Gebeyehu and Bayissa, 2020). However, the water quality deterioration of Tinishu Akaki River is highly sever than Mojo River due to alarming municipal and industrial wastes from Addis Ababa (Mulu et al., 2013).

Surface Water Quality Impairment Indicators

Evaluations of the water quality in the Awash rivers using indicators showed that it is above global and Ethiopian minimum standards of water quality. For example, mean value of phosphate, ammonia, nitrite, COD and BOD of the upper stream of Gullele in Shankela river were above the permissible limit of the WHO and Ethiopian standards. Likewise, TDS in Shankela river exceeded the permissible limit. Concentration levels of the nitrogen and phosphate compounds of PO_4^{-3}, NH_3 and NO_2^- ion in Shankela river were above the standard limit WHO and Ethiopian EPA standards (Tarekegn and Truye, 2018).

Turbidity, DO, BOD, COD, NH_3 and TH did not meet the WHO's requirement for DWQG. F^-, alkalinity, and PO_4^-. Likewise, TN, SO_4, NH_3, TH in the UB and F^-, alkalinity, HCO_3^-, PO_4^-, did not meet FAO's irrigation water quality guideline (**Figure 3**). It is generally believed that the water quality of the Awash river is below the required standard. As such the Awash river water did not meet the surface water standard of Ethiopia (Tarekegn and Truye, 2018).

Bussi et al. (2021) examined under population growth scenarios, water quality is expected to deteriorate significantly, particularly in the Akaki River, which drains Addis Ababa, where nutrient loads could increase by up to one-third (nitrate) and more than 50% (phosphorus) compared to baseline conditions, greatly increasing the risk of eutrophication. In the eutrophication of aquatic bodies, dissolved phosphorus plays a critical role (Moges et al., 2016). Phosphates from detergents, urban areas, industrial waste (such as sugar cane production), and intensive agriculture (Girma, 2016; Moges et al., 2016) can cause nutrient levels in the water to rise, resulting in algal blooms (Girma, 2016).

Mengesha et al. (2017) reported that nitrite, phosphate, COD, BOD concentrations from sampling sites on the Akaki river exceeded the minimum standard levels. Likewise, a study in

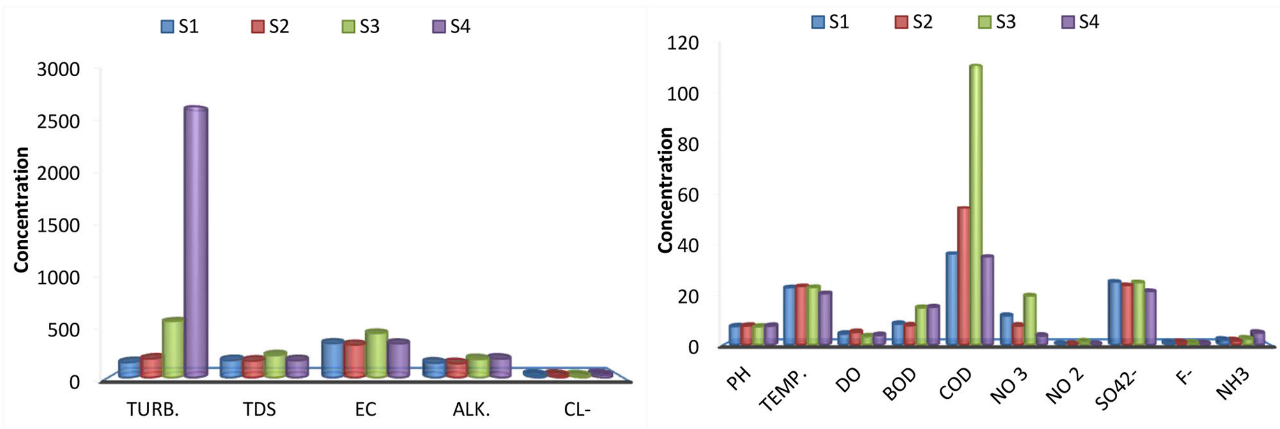

FIGURE 3 | Mean concentrations of water quality parameters in five selected sites of upper Awash river. S1 = after Lake Koka, S2 = at Koka Dam, S3 = before Lake Koka, S4 = at Melka Kuntire.

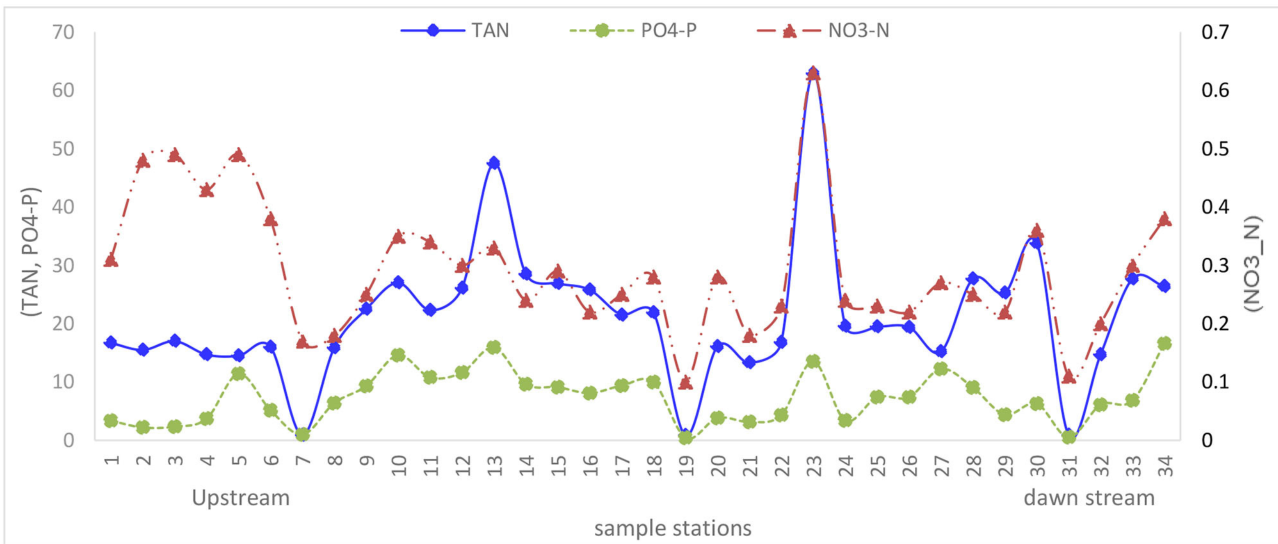

FIGURE 4 | Addis Ababa rivers water quality in terms of total ammonia nitrogen (TAN), NO_3-N, and PO_4-P (mg/l) and pH P (mg/l) (Eriksson and Sigvant, 2019).

the Tinishu and Tiliku Akaki Rivers showed that the dissolved oxygen was very low for aquatic species to survive (Eshetu et al., 2004; Melaku et al., 2007; Angello et al., 2021). Major pollutants of concern are sediment, nutrients, biodegradable organic wastes, and salt. According to studies, the Lake's expansion has impacted the soil salinization of a nearby sugarcane plantation (Yimer and Jin, 2020).

Eriksson and Sigvant (2019) studied the concentrations of phosphate and total ammonia nitrogen in the rivers of Addis Ababa (e.g., Kebena, Little and Tiliku Akaki rivers) and reported that the nutrient levels can lead to eutrophication. The study showed that concentrations of total ammonia nitrogen, NO_3, and PO_4 were lower in the upstream part of the city, higher within the dense parts of the city, but lower in the downstream part of the city around Akaki-Kaliti area. High concentration of TAN and NO_3-N was found in Kebena river in station 22 locally known by Abuara area near by Abune Gorgorios School (**Figure 4**). Similarly, the mean concentrations of NH_3-N, PO_4^{3-} and BOD_5 levels were significantly lower in the headwaters than the other sites especially dense part of the city; the mean concentrations of NH_3-N, PO_4^{3-} and BOD_5 decreased in the lower reaches of the city (Akalu et al., 2011). The main reason for this spatial variation is the dense part of the city poorly served with sanitation facilities and solid waste collection systems; second, the lower concentration downstream possibly from dilution effects of increasing discharge. Usher and van Biljon (2006) pointed out that the dominance of impervious surfaces, coupled with the altitude difference between upper and lower reaches, increased the discharge of rivers in the lower reaches of the city.

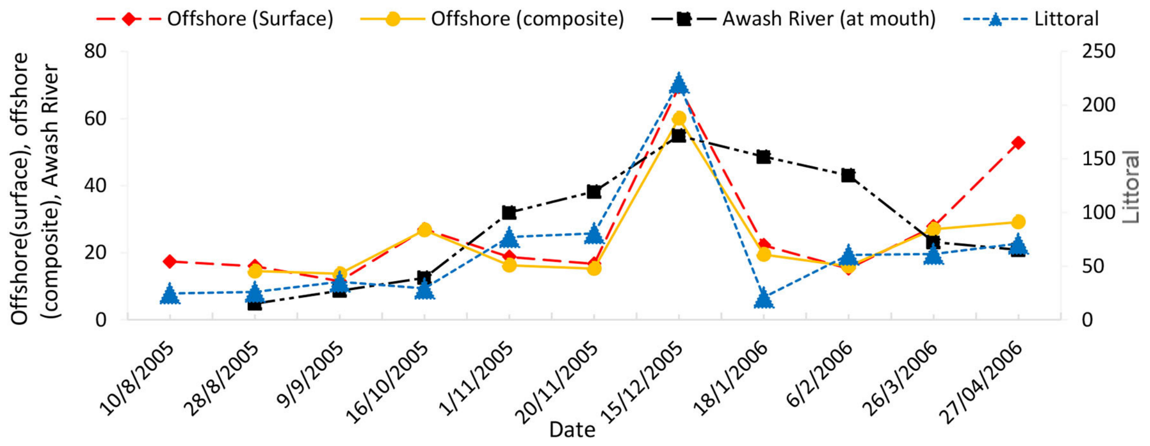

FIGURE 5 | Chlorophyll a (mg/l) from stations at the littoral, offshore, and mouth of the Awash River (Tesfay, 2007).

TABLE 1 | Status of water quality in the Koka reservoir.

Parameter	Unit	Parameter concentration (range)	References#
Temp	(°C)	21–26	Abhachire, 2014
		20.6/24*	Masresha et al., 2011
pH	–	6.13–8.6	Abhachire, 2014
		8/7.4*, 8.4	Mesfin et al., 1988; Masresha et al., 2011
DO	(mg/l)	4–11.6	Abhachire, 2014
EC	(μs/cm)	200–380	Mesfin et al., 1988
		274, 480/251*	Wood and Talling, 1988; Masresha et al., 2011
NH_3-N	(mg/l)	89.3 (μg/l)	Degefu et al., 2011
NO_3 -N	(mg/l)	0.69/1.43*, 44.4 (μg/l), 47–200	Tesfay, 2007; Degefu et al., 2011; Masresha et al., 2011
NO_2-N	(mg/l)	16.86–81.01	Tesfay, 2007
PO_4-P	(mg/l)	36.10 (μg/l)	Degefu et al., 2011
TP	(mg/l)	477.2 (μg/l)	Degefu et al., 2011
		NIL –0.14	Mesfin et al., 1988
$SO_4{}^{2-}$	(mg/l)	0.24, 6.4/6.24*	Wood and Talling, 1988; Masresha et al., 2011
		4–56	Abhachire, 2014
$CaCO_3$	(mg/l)	2.59–289	Mesfin et al., 1988
HCO_3	(mg/l)	3.22, 272/83*	Wood and Talling, 1988; Masresha et al., 2011
CO_3	(mg/l)	0.2–6.6	Abhachire, 2014
CO_2	(mg/l)	2.8–32, 0.25–0.49	Mesfin et al., 1988; Abhachire, 2014
Cl^-	(mg/l)	0.16, 15.6/5.9*	Wood and Talling, 1988; Masresha et al., 2011
		24–221.01	Tesfay, 2007
Chl *a*	μg/l	214.1, 22.4**	Mesfin et al., 1988; Degefu et al., 2011

**Dry/wet time data; **1984; #Reference arranged in respected order of parameter concentration (range).*

The accumulation of the nutrients translated into eutrophication in some freshwater systems in the Awash river basin. For example, blue-green algal bloom was observed in the Koka reservoir (Abhachire, 2014). Samples from Koka reservoir offshore zone at a depth of 6 m, littoral station at a depth 2 m, and Awash River mouth station at a depth of 2 m showed that the Chlorophyll *a* concentration was relatively high in the littoral station (**Figure 5**), which indicates there is spatial and temporal variation in the Chlorophyll *a* concentration in the reservoir. In addition to this there is high concentration of chlorophyll *a* in all station in the month of December (Tesfay, 2007). The algal biomass (chlorophyll-a, 214.1 μg/l) in Koka reservoir may likely occur due to high concentrations of nitrate (NO_3-N, 47–200 mg/l), (NO_2-N 16.86-81.01 mg/l) phosphate (PO4-P, 36.1 mg/l), (TP, 477.2 μg/l) and ammonia (NH_3-N, mg/l) (**Table 1**). Stations of Littoral and Awash river (at mouth) showed an increment in Chl a concentration from September to December. Awash river (at mouth) showed a

TABLE 2 | Mean concentration of different parameters from Mojo river.

St.	NH_4-N	NO_3-N	NO_2-N	PO_4-P	pH	TDS	BOD*	COD	Tem	EC	Turbidity
1	0.11	0.74	0.12*	0.29	7.7	384	61.2	86.3	–	–	–
2	0.18	3.23	0.22*	0.69	6.69	487	132	181	–	–	–
3	35.12*	5.44	0.12*	0.63	8.83	388	354	461	22	419.5	366.6
4	0.36*	0.726	0.14*	0.77	8.28	263	111	151	22.6	211.4	438.4
5	0.43*	0.71	0.22*	0.75	8.16	550	81.7	95.7	22.6	236.2	830.45
6	0.35*	4.23	0.18*	0.18	8.46	549	85.8	131	23.6	218.4	718.45
7	0.24*	3.44	0.08	0.27	8.14	506	61.8	111	23	307.3	669.85
8	39.1*	6.45	0.35*	0.88	9.93*	566	162	254	23.5	394.3	564.6
9	29.85*	7.84	0.08*	19.15	11.1*	395	231	342	23.8	427.6	763.95
10	4.45*	5.92	0.58*	0.52	8.85	855	221	342	23.2	238.2	619.25

**Above Ethiopian EPA and WHO standards.*

decreasing trend from January to July. The Offshore (surface) and offshore (composite) sites showed fluctuating concentration in different time period.

The concentration of some water quality parameters of Koka reservoir showed temporal increment. Some of the evidences by different researchers (**Table 2**) showed that the parameters like Cl^-, SO_4^{2-}TP, EC, NO_3, PO_4-P, NH_3-N, DO and Chl *a* concentrations increased in the different time periods.

The Mojo River serve as a good example to demonstrate water pollution due to industries since it has water quality monitoring stations (**Figure 6**) along the river course at eight industries (i.e., Kolba Tannery, Ethio-Japan Textile, Soap factory, Gelan Tannery, Organic Export Abattoir, Derartu Tannery, Mojo Tannery and Food and Oil Complex). Most of the measured water quality indicators showed that the minimum acceptable limit was exceeded (Gebre et al., 2016). The mean concentration of NH_4-N and NO_2-N in all stations were exceeded Ethiopian EPA and WHO standards (**Table 2**).

There is a distinct seasonal variability in water quality in the Awash river basin. During the dry season, all the sampling sites of the basin showed a decrease in EC, TH and Cl^- from upper to lower parts of the basin (Keraga et al., 2017a). However, TDS, Cl^-, and SO_4^{2-} decreased in the rainy season. Both seasons, maximum Cl^- and EC/TDS/SO_4^{2-} were observed at Beseka and before Beseka lake, respectively. On the other hand, in both seasons TH was at its absolute minimum at Beseka station. Beseka, before Beseka and Sodere spring sites were accountable for the spatial variation of water quality, for example EC, TDS, TH, Cl, and SO_4^{2-} showed major differences in these sites (**Figure 7**).

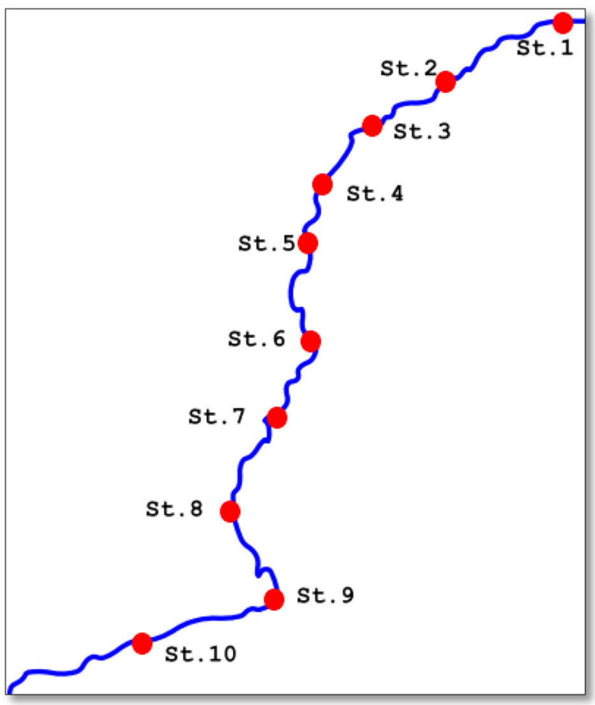

FIGURE 6 | Sketch map of Mojo river. St. 1: upstream, St. 2: food oil complex, St. 3: Mojo tannery, St. 4: Japan textile, St. 5: soap factory, St. 6: Derartu tannery, St. 7: organic export abattoirs, St. 8: Gelan tannery, St. 9: Kolba tannery, St. 10: Dawn stream.

Causes of Surface Water Quality Impairment

The Awash River Basin is Ethiopia's largest, most developed, and most extensively utilized river basin. Furthermore, the Awash River basin contains the bulk of irrigated farmland in the country (Keraga et al., 2017a), with a variety of small-, medium-, and large-scale irrigation projects, industries positioned along the river, a significant rural population, and rapid urban development (Aregahegn and Zerihun, 2021). The water quality of the Awash River has been harmed by numerous types of pollution resulting from waste generated from various socioeconomic activities, poor farming practices, and large-scale irrigation intensified irrigation schemes throughout the basin (Tamiru, 2001; Keraga et al., 2017b). This is due in part to the fact that the main sources of water pollution in the Awash River Basin include excessive irrigation pumping and overflowing, discharge of saline Beseka Lake water and hot spring water from various

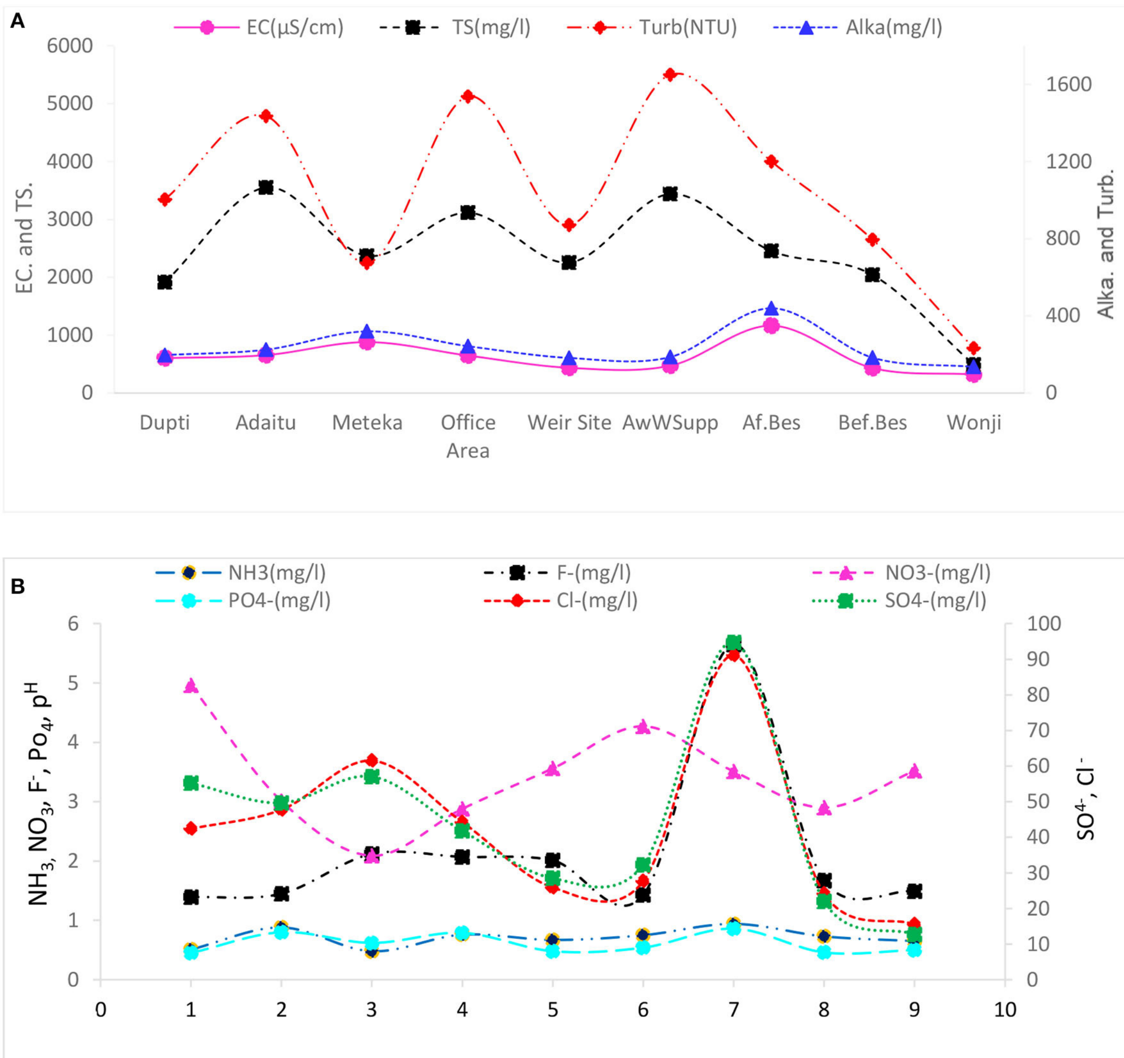

FIGURE 7 | Mean values of water quality parameters for nine sampling sites of Awash river 2005–2013. **(A)** is for parameters EC,TS, Alkalinity and Turbidity and **(B)** is for parameters NH3, NO3, PO4, pH, SO4 and CL (Keraga et al., 2017a).

places to the river, urbanization, and industrial waste (Taddese, 2019; Aregahegn and Zerihun, 2021).

The Awash River is polluted by liquid and solid effluents released from industries (Eliku and Leta, 2018) and households (Abebe, 2019) and runoff from agricultural and urban areas, irrigation drainage and Lake Beseka (Elias et al., 2016). One of the major sources of pollution for the Awash River is untreated domestic discharge from the city of Addis Ababa (Worku Giweta, 2018) and upstream effluents from industries (Itanna, 2002). For example, Large and small factories around Addis Ababa, Mojo and Adama, Wonji, and Metehara sugar factory are among the upper basin's industrial operations, while Kesem Kebena and Tendaho sugar factory are the middle and lower basin's important industrial activity, respectively (Aregahegn and Zerihun, 2021).

The water quality of the Awash River has been affected by various types of pollution caused by waste produced from various socioeconomic activities, as well as inadequate agricultural and irrigation management in the basin. Excess pumping and overflowing during irrigation, discharge of saline Beseka. Lake water and hot spring water from various places to the river, urbanization, and industrial waste are the main sources of water pollution in the Awash River Basin (Taddese, 2019; Yimer and Jin, 2020; Aregahegn and Zerihun, 2021).

The Upper Awash River Basin has poor water quality, which was largely mainly due to poor farming, untreated industrial effluents, and a lack of sanitation facilities for riparian communities (Degefu et al., 2013). There is extensive agricultural intensification (Alemu et al., 2017) and industrialization (Degefu et al., 2013) which has been exacerbating the surface water quality impairment. Besides receiving all industrial and domestic pollutants from the Upper Awash region, the middle Awash experiences substantial soil erosion and other non-point source pollution due to inappropriate agricultural practices.

Addis Ababa's water resource is extremely polluted as a result of rapid population increase, unregulated urbanization and industrialization, and inadequate waste management methods, affecting human health and ecosystem function as a whole. Addis Ababa's rivers are simply used as a dumping ground for all of the city's waste (Yohannes and Elias, 2017). Several studies have found that untreated and inadequately treated industrial wastewaters, household wastes, residential and commercial activities, and sewage discharged into waterways pollute Akaki river (Mekuria et al., 2021). According to Tarekegn and Truye (2018), the causes like indiscriminate dumping of refuse into the river, indiscriminate dumping of industrial wastes, scattering settlement or urbanization and others like vehicle washing effluents released into the Shankila river.

Anthropogenic activities account the lion's share of surface water quality deterioration in several rivers (Degefu et al., 2011; Abhachire, 2014) where indiscriminate dumping of domestic and industrial wastes, and wastes from other sources such as agriculture, petrol stations, health facilities, and garages, etc. are rampant. Textiles, slaughterhouses, tanning, leather products, and other activities, among others, are located in this basin (Aregahegn and Zerihun, 2021).

Water pollution sources could be point sources (direct identifiable sources) and non-point sources (different non-identifiable sources of origin and number of ways that contaminants enter into the water body) (Singh and Gupta, 2017). Nutrients in surface water have been mainly related with land use activities (Eliku and Leta, 2018). Anthropogenic activities of point and non-point sources of pollution are the major causes for nutrient enrichment of surface water (Singh and Gupta, 2017).

Point Sources

Wastewater generated from a single source like industrial influents and municipal wastewater/wastewater treatment facility as well as leaking septic systems, chemical and oil pills and illegal dumping (Kebede et al., 2012), and certain agricultural activities, such as animal husbandry (Gebre et al., 2016) are point sources of pollution.

Historically the establishment of modern industries in Ethiopia has started one hundred years ago (in 1920s) (Gebreeyesus, 2013). However, Many Ethiopian leather processing industries, for example, lack suitable waste treatment methods. By its very nature, leather processing entails soaking, fleshing, washing, and other water-based methods for removing dirt, flesh, salt, and other foreign substances (Wassie, 2020). Many textile and garment industries in Ethiopia lack waste treatment plants, making it difficult to properly dispose of their waste. They just discharge their waste into the environment, which in most cases is a freshwater. As a result of several studies conducted on a small number of individual textile factories, it has been suggested that the textile and garment sector's wastewater is perhaps the major source of water pollution in Ethiopia (Menbere, 2019).

Along the Awash River and its tributaries, particularly the Akaki River, a number of polluting industries and flower farms have been developed in the previous two decades. In addition, these companies discharge highly polluted sewage into Lake Koka's waters (Girma, 2016). According to Yohannes and Elias (2017), Addis Ababa hosts about 65% of the country's industries and more than 90% of the industries discharge their waste to nearby rivers without proper treatment. In recent years, the expansion of industries around the cities of Akaki, Mojo, and Adama has increasing the influence of industrial pollution to the Awash River water (Aregahegn and Zerihun, 2021). Addis Ababa Tannery, Tikur Abay shoe Factory, Gulele Soap Factory, Ethio Marble Industry and Gulele Shirt Factory discharge their waste into Kera river with little or no treatment applied (Itanna, 2002). 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). There is no monitoring system that follows if industries treat their effluents before discharging it into the Awash River system.

Jebessa and Bekele (2018) studied physicochemical characteristics and impacts of raw and treated effluents from the Anmol Product Paper factory on upstream and downstream water qualities at factory and 5 different sampling station on the upper Awash river and showed that both raw and treated effluents had water quality levels that are above the WHO and Ethiopian standards (**Supplementary Table S3**).

Chemical wastes and byproducts from industry, as well as mismanaged urban trash disposal at open dump sites from major cities, continue to pollute the environment (Wassie, 2020). Despite generating large amounts of solid waste from domestic activities, Addis Ababa does not have adequate waste management facilities. As a result solid waste is often piled on available open grounds, stream banks and near bridges, where it is washed off into rivers (Yohannes and Elias, 2017). The 29 hospitals in Addis Ababa produce 430.7 tons of infectious waste each year. Laboratory cultures, wound dressings, blood and other human fluids, and needles are examples of contagious clinical waste. Despite the fact that most hospitals have waste treatment facilities, some clinical waste makes its way into neighboring tributaries (Yohannes and Elias, 2017).

Non-point Sources

Non-point source pollution (NPS) is pollute on that does not originate from a single, easily identified source and is caused by the scouring effect of rainfall and dissolved pollutant solids entering recipient waterbodies (such as rivers, lakes, reservoirs, and bays) by runoff (Liu et al., 2015). Non-point sources contribute more pollution to surface water than does point source pollution sources. Relatively little is known about the non-point source pollution in sub-Saharan Africa (Jones-Lee et al., 2011).

Water quality of surface waters is impaired by several factors such as the non-point source contaminants through runoff (Carpenter et al., 1998). This affects the impairment of surface water quality and the aquatic life in lakes especially developing countries like Ethiopia (Awoke et al., 2016).

Agriculture

Agriculture is intensifying in Africa, increasing pressure on the environment. Agriculture is a large contributor of non-point source pollution to aquatic environment. The degradation of water quality caused by widespread agricultural activities released into river water put extra pressure on surface water (Islam et al., 2020). The interaction between agricultural malpractices and the environment in Ethiopia results in relentless pollution of freshwater. Agriculture-induced pollution contributes significantly to damaging aquatic ecosystem health in the country (Awoke et al., 2016).

Pollution from agricultural activities includes nitrogen and phosphorous based chemical fertilizers, insecticides, herbicides, and organic matter. Large farms are the primary users of pesticides and herbicides (Girma, 2016). As a result of runoff or irrigation return flows, these pollutants end up in waterways (Awoke et al., 2016). For example, presumably due to pollution of the whole stream reach by the catchment nutrient sources in upper Awash (Degefu et al., 2013).

Both the main Awash River and its tributaries in Upper Awash have substantial rain-fed and commercial agricultural farms, high vegetable production, and animal husbandry activities (Eliku and Leta, 2018). Animal husbandry is dominantly found in the surrounding parts of Addis Ababa, Nazreth and Debre Zeit. As a result of these activities, it is expected that a significant amount of organic waste is generated on rainy days (in runoff). Storm water runoff or debris blown into waterways from agricultural land, inorganic fertilizers in agricultural fields and animal manure are non-identifiable sources of pollution which are responsible for nutrient enrichment in aquatic environments (Tamiru, 2001; Keraga et al., 2017a). Agricultural wastes have been polluting freshwater systems jeopardizing socio-economic and ecological assets in the river basin (Mengistie et al., 2017).

The chemical constituents of irrigation water can affect plant growth directly through toxicity or deficiency, or indirectly by altering plant availability of nutrients (Belay, 2019). The rising concentration of salt and toxic elements in the drainage waters from irrigated lands is a common awareness in middle Awash. Availability of good quality water in Middle Awash Valley due to agro-industries have created great concern on surface water quality (Taddese et al., 2007; Taddese, 2019). Loiskandl et al. (2005) point out that community-based irrigation schemes are more feasible at highlands than at lowlands due to surface water quality deterioration, this is probably linked to the original water quality of the source.

Erosion by Water

Soil erosion is very common and some of the lakes are affected by the consequences of sedimentation and increased turbidity (Abhachire, 2014; Girma, 2016). Anthropogenic forces that alter the physical landscape cause substantial soil erosion which have adverse impact on surface water bodies (Issaka and Ashraf, 2017). Soil erosion and other sediment sources can also be significant nutrient sources, as nutrients often tend to be found in particulate form. Sediment that comes from active construction sites and washes off of particulate materials from impervious surfaces is one of the most common and potentially damaging pollutants found in urban runoff (Shaver et al., 2007).

According to Moges et al. (2017) the decreasing water quality trend of the Lake Tana was attributed to the non-point source sediment and nutrient inflow to the lake with high erosion rate from the watersheds.

One of the major pollutants with regard to agriculture is associated with erosion of the soil in the upper catchments of Awash River. This is especially intense in the rainy season when there is high surface runoff. Chemical fertilizers used to boost production enter streams as a result of soil erosion. The erosion process is linked to pollution of local water bodies and wetlands. On cropland, soil erosion causes a reduction in yield potential, a decrease in surface water quality, and a breakdown in drainage systems. Non-point nutrient contaminants and chemicals are also transported with soil particles, resulting in greater sediment levels and, ultimately, water eutrophication and disruption of fragile aquatic ecosystems (Issaka and Ashraf, 2017).

Urbanization

Storm water or urban runoff contains a mixture of constituents: sediment, nutrients (nitrogen and phosphorus), Chlorides, Petroleum hydrocarbons and Organic chemicals (pesticides, herbicides, and industrial) (Shaver et al., 2007). The pollution sources of the Shankila River, one of the most dominant causes were domestic wastewater releases along the entire river course (Tarekegn and Truye, 2018).

Urbanization and industrialization significantly reduce the agricultural land and causes environmental damage in the basin. Urban areas like Addis Ababa, Dukem, Mojo, Debrezeit and Nazert increase the influence of domestic pollution to the Awash and the Mojo rivers; and Lake Koka (Melaku et al., 2020). As the number of hotels, commercial establishments, and factories grow, the amounts of solid and liquid wastes being generated are also growing (Girma, 2016).

Even though Addis Ababa is the only city with sewer networks, it has a very limited sewer network coverage that accounts for 7.5% of the built-up areas. Since only parts of the older sections of the city are connected to the central sewer system, both residential and business premises use septic tanks. There is a high amount of waste disposal in the river and riverbanks from municipal source (municipal solid and liquid wastes), liquid wastes from toilets, houses that are built at the edges of the city's rivers link their toilets directly to them (as a result, the residents use the river as toilet), open urination and defecation in and around Addis Ababa, 25% of the city's residence do not have toilet. Therefore, status of river pollution is increasing as time elapsed (Yohannes and Elias, 2017).

Other Sources

In addition to the socio-economic pressures, environmental pressures also play a major role in the surface water quality of the basin. This is evidenced by the high fluoride concentrations in rift valley soda springs, alkaline lakes, hot springs and geological formations (Taddese, 2019; Yimer and Jin, 2020; Aregahegn and Zerihun, 2021). Other waste sources come from construction buildings, roads and dams, fuel stations, garage operations and congested settlements (Yohannes and Elias, 2017). Physical factors like heated water discharged from a power plant (Walker et al., 2019), for example as it is observed that discharge of an industry in Sebeta area (One Weha bottling and Balezafu Alcohol Industry) the temperature is about 28.2 and 32°C respectively, contribute by changing the temperature of the water body.

DISCUSSION

Gaps and Problems Identified

This review identifies several water quality 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, unpublished reports, and research limited to specific location and or time. For example, there is no a comprehensive surface water quality study, there is a lack of detailed combined spatial and temporal surface water quality data to show the overall picture of the sub watershed or the basin in general. In addition to this, there is no sound and comprehensive surface water quality information system or database at federal and local levels which is open and accessible for the public. This review work tries to focus some of these research gaps.

Assessing the relative contribution from diffuse and point sources is a major research gap in the basin. There is lack of non-point source pollution (urban based or agricultural based) investigation in a basin or country level except (Eskinder, 2019) in Kombolcha area. There is little evidence based investigation into the influence of agriculture on surface water quality impairment for example organic compounds or chemicals like herbicides, insecticides, hydrocarbons, DDT, lindane and other forms of chemicals are not investigated. For the problem of surface water quality, there is no well-coordinated research and no meaningful discussion between researchers and the community.

There is inadequate good spatial and temporal scale surface water quality data and/or monitoring in the basin. Biological parameters monitoring is very limited in the research works. This could be probably, some surface water quality parameters to be monitored are too expensive (some not available in the country) to be monitored so as to make scientific researches and to provide policy direction recommendations. In addition to this, the existing laboratory facilities are not fully equipped and not well organized to analyze the overall surface water quality parameters unless they are upgraded. Economic and financial pressures dominate other concerns and the impact of pollutants on water is neglected (Zinabu et al., 2019).

Policy responses for surface water quality drivers for the case studies have little attention. The analysis of legal, policy, and institutional framework showed a lack of cooperation between stakeholders, lack of knowledge of the policy documents, absence of enforcement strategies, unavailability of appropriate working guidelines, and disconnected institutional setup at the grass root level to implement the set strategies as the major problems (Awoke et al., 2016).

Opportunities

There are several institutions, organizations and agencies or authorities that have the mandate and responsibilities for water resource management. This is an opportunity for the sector. Revising the policy (Awoke et al., 2016) based on the research findings and participating implementers, local community, investors etc. are vibrant to improve the quality of rivers and lakes.

Out of the 14 industrial parks to be established in the country ten (71%) are to be built in the basin. Out of the total seventeen agro industry corridors, four (24%) are found in the basin thus there would be an opportunity for surface water quality improvement by applying zero liquid discharge. The Hawassa Industrial Park and Kanoria Textile Industry (the first denim manufacturing plant) which are so far operational that have a zero-liquid discharge take as a model and implement in Awash basin.

The central wastewater treatment plants of Addis Ababa are being expanded, but the sewerage network remains limited. In 2014, a decision was taken to systematically introduce decentralized waste water treatment in 15 newly built condominiums. Their combined treating capacity is over 27,000 m^3/day serving 185,000 residents if these experiences continue for the newly built condominiums and real estate it will have a good contribution to minimize surface water quality issues.

The Kaliti wastewater treatment plant has about 100,000 m^3/day (McFarland et al., 2019) capacity but currently it is working at only 40% of its capacity. This is due to different challenges of connecting the sewerage system of the city with the newly built sewerage network. If this will be solved i.e., the city wastewater network properly connected with the main Kaliti wastewater treatment plant main network line and work with its full capacity, it will have a future hope to minimize surface water quality problem. In addition to this, the riverside ongoing project by Addis Ababa city administration at the moment will likely improve the situation in part of Addis Ababa watersheds.

CONCLUSION

Surface water quality monitoring in Ethiopia has been incipient in most of the rivers this is due to poor technical and financial capabilities monitoring of rivers and sediments and understanding on the effects of pollutants becomes limited. In addition to this, surface water quality status of river basins not better understood and appropriate measures could not have been taken. There are limited surface water quality monitoring at a finer temporal resolution as well as appropriate locations so that hydrological water quality modeling in the basin is very limited.

Some of the most important services given by the Awash River water are irrigation, and serving as a water source for domestic consumption for residents living near the river course, as well as for domestic and wild animals in the area. However, water quality index based evaluation showed that the water is below the standard for these purposes; conditions often depart from natural or desirable levels of the ratings.

The Awash Basin's surface water quality is degrading. Rapid urbanization and industrialization have resulted in substantial water pollution from untreated domestic, industrial, commercial, institutional liquid waste presence, and several irrigation schemes (both point and non-point sources). The bulk of the factories in the basin do not have wastewater treatment facilities; they have not built treatment plants, nor have they established appropriate storage or discharge paths for their waste; instead, they release their wastewater into neighboring rivers, lakes, and streams. The

Akaki sub-basin (Tinishu Akaki river) is the country's most contaminated river system. Almost all of the assessed locations along the Akaki rivers had poor water quality and did not meet the river water quality criterion.

Water quality in the Awash rivers was assessed using various indicators and found to be above global and Ethiopian minimum standards for surface water quality. As such the Awash river water did not meet the surface water standard of Ethiopia.

Numerous types of pollution resulting from waste generated by various socioeconomic activities, poor farming practices, and large-scale irrigation intensified irrigation schemes throughout the basin have harmed the water quality of the Awash River. The surface water in Addis Ababa is an example of this. As a result of rapid population growth, unregulated urbanization and industrialization, and inadequate waste management systems, it is very polluted, impacting human health and ecosystem function as a whole. The rivers of Addis Ababa are simply used as a dumping ground for the city's waste. Several studies have found that untreated and inadequately treated industrial wastewaters, household wastes, residential and commercial activities, and sewage discharged into waterways pollute Akaki river.

Agriculture is a large contributor of non-point source pollutants to aquatic environment. Pollution from agricultural activities includes nitrogen and phosphorous based chemical fertilizers, insecticides, herbicides, and organic matter. Large farms are the primary users of pesticides and herbicides. Both the main Awash River and its tributaries in Upper Awash have substantial rain-fed and commercial agricultural farms, high vegetable production, and animal husbandry activities. As a result of these activities, it is expected that a significant amount of organic waste is generated on rainy days (in runoff) which are responsible for nutrient enrichment in aquatic environments. As agriculture erosion by water, storm water or urban runoff and other natural sources of pollutants like soda springs, alkaline lakes, hot springs and geological formations are sources of pollutants for surface water quality impairment.

The majority of the papers are either distinct graduate theses, unpublished reports, or studies focused on a specific location and/or time period. Furthermore, the majority of research projects are located in upper Awash this is due to the high population number and high population density (like Addis Ababa, Mojo, Debrezit, and Adama), high urbanization and comparatively large number of industries. Assessing the relative contribution from diffuse and point sources is a major research gap in the basin. There is lack of non-point source pollution (urban based or agricultural based) investigation in a basin.

RECOMMENDATION

High temporal and spatial resolution surface water quality monitoring stations and comprehensive monitoring systems need to be integrated and improved. The monitoring site selection shall consider land use/cover, drainage network, watershed size/area, as well as river junction points of the watershed outlets as a criterion. In addition to this, monitoring of the sewerage systems shall be included in the water quality monitoring system. Furthermore, individual research works of students and researchers and their data which is related to surface water quality issue shall be systematically collected and synchronized with the central database of AWBA on a regular basis. Finally, build a water quality database for better management and flow of information and water quality mapping as well as an open access for the user. Surface water quality monitoring technologies like remote sensing (satellite images) shall be practiced so as to minimize monitoring costs as well as to get high temporal resolution water quality data.

According to Awoke et al. (2016) river water pollution is a growing challenge and needs urgent action to implement intersectoral collaboration for water resource management that will eventually lead toward integrated watershed management. Revision of policy and increasing the awareness and participation of implementers are vital to improve surface water quality. Strengthen the coordination mechanism of different stakeholders who are involved in surface water quality management for continuous and structural monitoring and evaluation of surface water quality.

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.2022.782124/full#supplementary-material

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