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Review Paper

Membrane Technology for Water and Wastewater Treatment in Ethiopia: Current Status and Future Prospects

Misgina Tilahun Tsehaye [1], Aymere Awoke Assayie [2], Abreham Tesfaye Besha [3], Ramato Ashu Tufa [4], Abaynesh Yihdego Gebreyohannes [5,*]

[1] *Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, Grenoble INP, LEPMI, 38 000 Grenoble, France*
[2] *King Abdullah University of Science and Technology (KAUST), Biological and Environmental Science and Engineering Division (BESE), Red Sea Research Center, 23955-6900, Thuwal, Saudi Arabia*
[3] *Department of Chemistry, College of Natural and Computational Science, Jigjiga University, P.O. Box 1020, Jigjiga, Ethiopia*
[4] *Department of Energy Conversion and Storage, Technical University of Denmark, Building 310, 2800 Kgs. Lyngby, Denmark*
[5] *King Abdullah University of Science and Technology (KAUST), Biological and Environmental Science and Engineering Division (BESE), Advanced Membranes and Porous Materials Center (AMPM), 23955-6900 Thuwal, Saudi Arabia*

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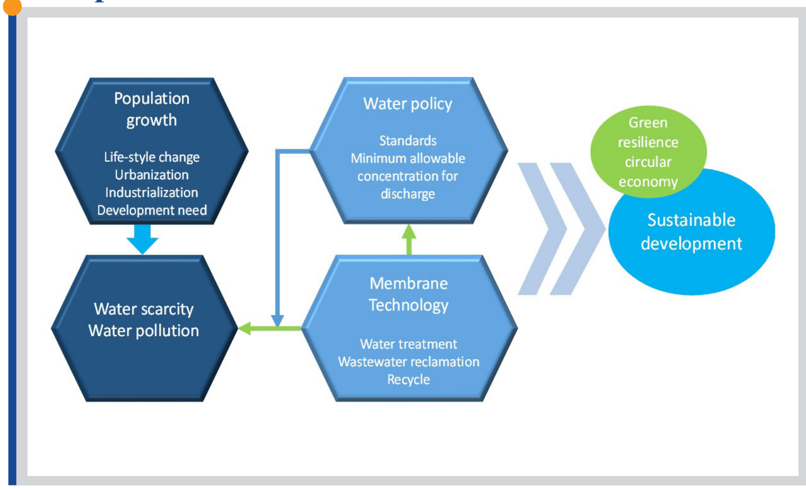
Highlights

- Water pollution and national water policy in Ethiopia are discussed.
- Linking water policies practice with water pollution and water scarcity economies is vital.
- Status of membrane processes for water treatment in Ethiopia is presented.
- Membrane is useful for multi-sectoral water protection and provision programs.
- Hybrid membrane for low pollutant concentration and circular economy.

Graphical abstract



Abstract

In this paper, we appraised the link between policy and research advancement in the area of membrane technology to maximize its application in developing countries. First, the water pollution and water scarcity challenges in Ethiopia are discussed together with the national policy. The minimum allowable concentration for pollutants set by the Ethiopian water resource authorities is significantly higher than the one set, for example, by WHO due to lack of suitable wastewater treatment technologies. To support population growth, Ethiopia urgently needs stringent legislation backed up by alternative treatment technologies in order to implement multi-sectoral water protection and provision programs. The current-status of membrane technologies and the availability of raw materials for membrane fabrication are presented. Key types of membrane technologies that are currently practiced and the obtained merits compared to traditional treatment strategies are thoroughly reviewed. Membrane technology can be used as a two-way tool: (i) to fill gaps in policy implementation with more stringent minimum allowable pollutants concentration and (ii) to reduce water pollution and scarcity. Implementing hybrid membrane process for resource recovery and wastewater reclamation can lead us towards a green resilient circular economy. We strongly believe that this work provides useful information for membrane researchers as well as water managers thereby motivating further research and planning on membrane processes in water and wastewater treatment in Ethiopia and other developing economy countries.

Contents

* Corresponding author: abaynesh.gebreyohannes@kaust.edu.sa; abayneshy@yahoo.com (A.Y. Gebreyohannes)

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Abbreviations

BOD	Biological oxygen demand,	MBR	Membrane bioreactor
COD	Chemical oxygen demand	NF	Nanofiltration
DO	Dissolved oxygen,	RO	Reverse osmosis
EEPA	Ethiopian Environmental Protection Authority	TN	Total nitrogen
		TP	Total phosphorus,
EU	European Union	TSS	Total suspended solids,
FO	Forward osmosis	SRP	Reactive soluble phosphorus,
MF	Microfiltration	UF	Ultrafiltration
MABR	Membrane Aerated Biofilm Reactor	USEPA	US Environmental Protection Authority
MAL	Maximum allowable level	WWTP	Wastewater treatment plant

1. Introduction

There have been various instances around the world where water bodies have been overused and pressured to the point of vanishing. The Aral crisis in central Asia is considered as one of the biggest catastrophes humans brought to themselves in the near past, causing the freshwater Aral sea to almost completely drain, largely due to mismanagement [1,2]. In this crisis, which involved two major river water bodies, the world has lost considerable endemic fish species that are not found anywhere on the face of the earth [3]. Lake Chad, in central Africa, has shrunk by more than 90% in about four decades because of overuse aggravated by frequent drought [4]. Similarly, in Ethiopia, Lake Haramaya is reported to be extremely stressed and disappeared [5]. The discharge of untreated wastewater from the nearby University and suburban residents might have contributed to this effect. There are also reports indicating the degradation of ‘Boye’ pond and Gilgel-Gibe dam [6], the complete dry out of Lake “Aba Samuel’ [7] and the vast invasion of Lak Tana by water Hyacinth [8]. Other researchers also presage similar incidents to several water bodies in Ethiopia if proper measures of wastewater treatment are not in place [9,10]. Water pollution is widespread in Ethiopia, as it is in many other African countries, mainly due to untreated or insufficiently treated wastewater discharge. Studies, which were conducted in Ethiopian, indicated a severe impact of water pollution on water quality [6,11–14].

In the policy regard, Ethiopia is praised for its fascinating, what is called ‘climate-resilient green economy’ strategy [15]. In this strategy, the country set the agenda for developing a climate-resilient green economy by 2025, which is also the time-frame put for Ethiopia to become middle-income country. The strategy explicitly states to achieve the set development goals, Ethiopia will not follow the classical development ways much criticized for leading to unsustainable use of water as one of the natural resources. Therefore, the government put forward the climate-resilient green economic strategy for Ethiopia aiming to meet economic development goals via sustainable and environmentally friendly ways. However, this is not changing the rising environmental degradation mainly related to water pollution, in the country. This might be attributed to lack of an appropriate link between policy and scientific activities [16,17]. It is often the case that, the scientific advancements in water and wastewater treatment technologies and water quality monitoring strategies to avert pollution are far known by the policy makers and implementers [17]. For instance, membrane technology is a growing alternative solution, in the past two decades, to help achieve fine objectives in terms of water and wastewater treatment [18]. However, its application in developing countries, such as Ethiopia, is little known.

Membrane technology is increasingly used in many industries to replace conventional unit operations due to its ease of use, adaptability, uniqueness of process or product, better competitiveness, and eco-friendliness [19–23]. The history of membrane technology dates back as far as the middle of the 18th century; when Abbe Noilett discovered osmosis phenomena in the natural membrane [24]. The technology has gone through various developments and improvements since then [25]. In 1950, Hassler introduced the concept of membrane desalination for the very first time [26]. Later in 1962, the first asymmetric membrane, consisting of a thin top layer and porous support layer, was invented by Loeb-Sourirajan [19,24]. Since then, membrane technology has seen widespread industrial applications, including seawater desalination, the treatment of municipal or industrial wastewater, the recovery of valuable constituents, the concentration of products, the purification or fractionation of macromolecular mixtures in food and drug industries the separation of gases [27,28], energy conversion and storage system, such as fuel cells and batteries [29,30], Drug delivery systems and artificial organs [19,31–33].

Membrane technology has the capacity to solve a wide-range of water-related problems in a society. Interestingly, the falling cost of membrane over the last years even made it more convenient especially in the water sector. Additionally, their market share is increasing. For example, the global market of ultrafiltration (UF) membranes was predicted to grow by 6.9% per year from $3.3 in 2016 to $4.6 billion in 2020 [34]. Figure 1 represents the number of publications on wastewater applications of microfiltration (MF), UF, nanofiltration (NF), reverse osmosis (RO), forward osmosis (FO), electrodialysis, membrane bioreactor (MBR), and membrane distillation. Over the previous 20 years, the number of publications published in this topic has clearly increased, demonstrating that membrane techniques are becoming more widely used in wastewater treatment.

Despite the growing adoption of membrane processes in wastewater treatment and water purification around the world, they are still understudied and underutilized in developing countries such as Ethiopia, where water-related challenges are becoming increasingly severe. Aiming at raising awareness among researchers and decision makers in applying membrane technology as an alternative solution for drinking water purification and wastewater treatment in developing countries, in this review paper, we first selectively assessed the relevant Ethiopian water and environmental policy documents in relation to existing water pollution, and we appraised the suitability of membrane technology for filling policy implementation gaps. Moreover, we discussed the state of the art of membrane processes used in wastewater treatment and water purification in Ethiopia. To the best of our knowledge, this is the first review work focusing on the current status of membrane technologies for water and wastewater treatment for developing countries, especially in the African continent. We are confident that this will help policymakers understand the policy implications of treating water/wastewater with membrane technologies, which will lead to recycling opportunities. In accordance with, we have recently critically reviewed the state and prospects of membrane-based technologies in Ethiopia’s energy sector [35].

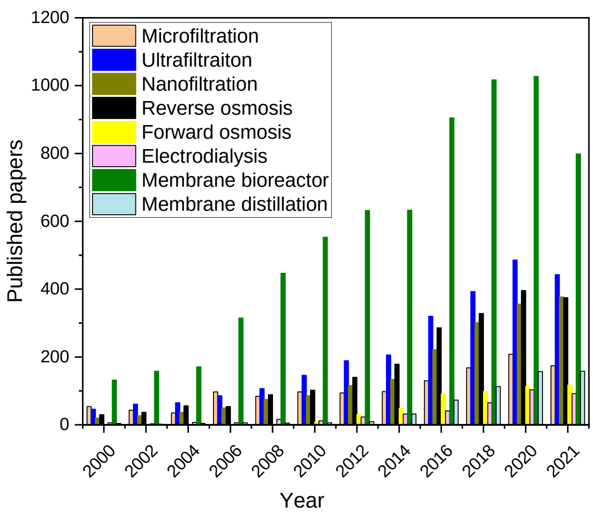

Fig. 1. Number of publications per year from 2000 to 2021 mentioning the term "microfiltration" and "wastewater", "ultrafiltration" and "wastewater", "nanofiltration" and "wastewater", "reverse Osmosis" and "wastewater", "electrodialysis" and "wastewater", "forward osmosis" and "wastewater", "membrane distillation" and "wastewater" and "membrane bioreactor" or'' MBR'' and "wastewater" as derived from Web of Science database (accessed on November 18, 2021).

2. Water pollution, scarcity and policy in Ethiopia

2.1. Water pollution and water scarcity

The lifestyle of the population in the urban and industrial setting of Ethiopia is drastically gearing in the direction of utilizing ample amount of water for various uses and this in turn results in a huge amount of wastewater. In the absence of sufficient wastewater treatment, as is the case in most developing nations, this massive amount of wastewater enters the water ecosystem, often causing water pollution. This leads to a two-face problem of water shortage and water pollution. The growing necessity for more water, as well as the massive generation of wastewater, clearly poses a challenge to the traditional treatment technologies, mostly primary and rarely secondary, which are widely employed in Ethiopia. As a result, in addition to improving the efficiency of water use, it is vital to integrate and implement appropriate wastewater treatment systems, to treat as well as return the treated water back to the water cycle. This necessitates the recycling of as much water as possible for which technologies that involve membrane filtration has proven success [18,25]. Therefore, advanced treatment systems, such as membrane technology become imminent in such scenarios.

From the two types of water scarcities (physical and economical) described by Viala [36], Ethiopia can face economic scarcity. Economic water scarcity can be caused by inappropriate or poor management of water resources. This implies that Ethiopia has the capacity to achieve its water demand requirement with natural sources. Despite this ample potential, the country is and will be suffering from water scarcity due to improper management of water and wastewater. When attempting to address the issue of water shortage, it is critical to first determine which form of water stress a given location is experiencing [37].

Rapid urbanization without preparedness for remedying the related environmental pollution is also challenging the water quality domain in Ethiopia [38]. Most cities and towns do not have safe and adequate provision of water and proper management of wastewater [13,14,39]. These existing problems call for better water/wastewater management at all levels.

Waste overflow from institutions, residential areas and industries is a common phenomenon. In Addis Ababa, the existing waste treatment plants, which are mostly primary treatment technologies, treat only less than 10% of the estimated wastewater, leading to a discharge of much-untreated sewage [40]. The discharge of untreated waste to a nearby river resulting in gradual degradation of the water quality of the receiving river is also reported in Jimma area [6]. In 2014, a study was conducted on wastewater management in seven Ethiopian Universities [41]. The study reported that only two of the universities have functional wastewater treatment plants (WWTPs), and yet none of them meets effluent standards set by the EEPA. The efficiency, functionality and long-term viability of these WWTPs were questionable. Cost, lack of qualified personnel for operation and maintenance, limited public acceptance and possible environmental impact were discussed as possible reasons for the lack of sustainability. This implies that to address some of these problems, technological assessment (targeting the type of wastewater, the effluent quality, the number of populations, the influent flow rate, the type of technology employed) should be conducted and based on that, appropriate advice should be provided to the stakeholders to consider alternative treatment processes such as membrane technology.

In general, despite reports of increasing levels of water pollution in Ethiopia [11,13,14,17,42], little is known about the suitability of the policies and the efficiency of traditional and rarely implemented advanced treatment technologies to limit the problem. This implies that either the policies relevant in averting and controlling these problems are absent or the focuses of the policies and/or implementations are inapt [43]. Hence, an appropriate technology supported by effective up-to-date policy instruments should be introduced. Without these technologies, the ambition and efforts of the country to eradicate poverty and to fulfill a green resilience economy is challenging if not impossible.

2.2. Ethiopian water and environmental policy

A selective review of Ethiopian water sector policy and environmental policy documents [17], reveals key gaps in the policies, particularly in terms of ensuring water quality in all forms of water bodies. The Ethiopian water sector policy aim to address the objectives listed in the document, including the sustainable and efficient use of water resources, as well as their protection [44]. An excellent indicator of the entire document in this regard is Article '2.1.3'. This article has indicated the need for developing and adapting water quality standards and evaluation techniques and gives recommendations on how to achieve them. However, scientifically proven technologies for treatment and protection, which are recognized as vital for successful prevention and management of water pollution [17] are in nowhere mentioned or suggested in the document and so are critically missing.

On the other hand, the overall objective of Ethiopia's Environmental Policy is to promote and improve the health and quality of life of Ethiopian residents through fostering sustainable development. The articles in this policy try to address the protection of all environmental compartments including water resources, at least in principle. There are also some sections that, if explored, can be used as motivation to advocate water and wastewater treatment technologies. A good example is a goal presented in section five, "preventing the pollution of water" which invites several water treatment technologies including membrane technology to achieve these objectives [45]. To accomplish this goal, the Ethiopian Environmental Protection Authority (EEPA) has been given additional authority to establish environmental norms and regulations based on scientific methods and ecological concepts [45].

However, only limited number of pollutants found in wastewater discharged by specific industries were targeted by the EEPA-issued rules and guidance [46]. Moreover, this guideline allowed relatively, very high concentrations as maximum allowable limits (Table 1). This is due to a lack of scientific data and collaboration between policymakers and researchers on how to reduce/avoid water pollution and achieve pollutant levels in effluents that are close to zero. This might also be due to the concern from the EEPA side that lower concentrations may not be practically achievable based on the currently employed treatment technologies by the industries and other emitters/polluters [17]. The provisional standard for industrial pollution control set by the Ethiopian Environmental Authority [47] have identified eight categories of factories that will be subject to the standards. The category includes the existing and expected-to-flourish factories like Tanning and Leather finishing, Textile, Processing of iron and steel, "Metal working, plating and finishing", Breweries, "Manufacture of sugar", "Cement manufacturing" and "Pharmaceutical Manufacturing". The treated wastewater from those factories need to meet a maximum concentration limit indicated in the provisional standard, if the factories generating them are to discharge their effluent to the Environment weather Water or Land (in most cases it is the rivers and lakes that are receiving them). Of these eight categories, the standard for the tanning and leather processing is presented in Table 1 as an example as this is the stricter limit the provision has set.

In Addis Ababa alone, about 400, 000 m^3 mixed municipal and industrial wastewater is discharged daily, with just 7.2% is collected and treated at the Akaki wastewater treatment facility [48]. This is the only centralized wastewater treatment facility available in Ethiopia. The most common wastewater treatment strategies currently under practice are waste stabilization ponds [49]. Potential treatment technologies investigated so far include electrochemical coagulation, adsorption for textile and distillery wastewater, microbial fuel cells for brewery wastewater etc. [50–53].

However, if technologies like membranes were considered as alternative solutions, it could be possible to go to the minimum low level that can safeguard the life of aquatic organisms and the possibility of reusing. As to the efficiency of membrane technologies, there are studies, which reported up to 99% removal efficiency of wastewater pollutants by different types of membrane technology and from varying waste sources [54,55].

2.3. Currently employed membrane technologies in Ethiopia

The current membrane technologies in Ethiopia for wastewater treatment is minimal. Additionally, the research and development made with regard to membrane technology is rather low. Only some authors reported the applications of membrane processes for different purposes. In 2006, Assefa [58] reported the defluoridation of raw ground water from the Ethiopian rift valley region by using RO. Another study was performed dealing with the application of RO driven by solar energy system for desalination systems [59]. A master thesis conducted at KTH royal institute of technology proposed that a renewable energy-powered membrane distillation could be suitable for drinking water purification (removal of fluoride) in the main Ethiopian rift valley [60].

Recently, some progress has been made with regard to the applications of membrane technologies, especially for wastewater treatment. In 2016, the Israeli wastewater treatment company, Emefcy, in collaboration with its local partner TodayTomorrow Ventures Inc, signed a contract to install Membrane Aerated Biofilm Reactor (MABR) at Ayder Referral Hospital, Mekelle University in Tigray, Ethiopia. The capacity of the plant is 320 m^3/day and will treat wastewater from the Hospital. The effluent will be employed for irrigation and toilet flushing within the University [40]. Later in 2017, this company secured the second MABR project in Addis Ababa, Ethiopia. The 185 m^3/day capacity MABR worth US$400, 000 will treat wastewater from one condominium complex consisting 32 buildings and 7,000 residents [40]. In 2015, the Addis Ababa Water and Sewerage Authority (AWSSA) announced the deployment of ten mobile MBRs as liquid waste treatment plants at seven condominium sites at Addis Ababa [61]. Accordingly, the MBR units will add 20, 000 m^3 to the existing 7,500 m^3 of treatment capacity. The currently available membrane technologies in Ethiopia, for which we found information, are summarized in Table 2.

2.4. Opportunity for the application of membrane technologies in Ethiopia

Despite the use of certain membrane technologies in Ethiopia (Table 2), primarily RO and MBR, in limited areas, the technology has yet to be investigated, researched and widely used. The installed systems mainly lack sustainability due to problems related to raw materials, affordability and technical skills.

Generally speaking, the key to improving membrane technology's development and competitiveness, as well as the sustainable manufacture of high-performance membranes for a variety of applications, is a resource-based sector that ensures a steady supply of high-quality raw materials. This priority is based on the demand for basic chemicals and the availability of raw materials locally. For instance, wheat and rice husk has been used to prepare silica-based hollow fiber membrane for various application [63–65]. These materials, huge waste from wheat and rice production in Ethiopia, can be valorized to ceramic membrane. There are already reports by several authors on the production of porous ceramic membrane from Kaolin [66,67]. The availability of large amount of Kaolin resources in Ethiopia is described in the US Geological Survey Minerals Yearbook report. However, its annual output is capped at around 3300 metric tons, with local ceramic businesses consuming the most of it. It is only recently that Ethiopian Kaolin was tested for the synthesis of zeolite [68]. Kaloline from Debre Tabor (Ethiopia) was used for low-cost ceramic membrane fabrication after purification including physical beneficiation and chemical leaching processes [69]. The presence of such material in high amounts in Ethiopia can open doors for research and development in membrane technology and for high-profile companies to open membrane-manufacturing industries.

To benefit from the ever-growing membrane technology, the government of Ethiopia should proactively implement radical changes and increase its competitiveness in the international market. Based on such policies and directions, the development of membrane technology can concentrate on three aspects:

Table 1
Guidelines for selected water pollution parameters extracted from EEPA, US Environmental Protection Authority (USEPA) and EU.

Parameter	**Maximum possible limit**		
	US-EPA [56]	**EU** [57]	**EEPA** [46,47]
pH	6-9	6-9	6-9
Conductivity (μS/cm)	NA	250	1000
SS (mg/L)	100	20	50
DO (mg/L)	5	5	4
BOD (mg/L)	30	30	200
SRP (mg/L)	0.1	0.1	NA
TP (mg/L)	5	1	10
NO_3-N (mg/L)	10	10	50
Ammonium-N (mg/L)	0.5	NA	30
TN (mg/L)	100	10	60

Abbreviations: TSS = Total suspended solids, DO = Dissolved oxygen, BOD = Biological oxygen demand, SRP = Reactive soluble phosphorus, TP = Total phosphorus, TN = Total nitrogen and NA = data not available.

Therefore, Ethiopia urgently needs comprehensive legislation backed up by alternative treatment technologies in order to implement multi-sectoral water protection and provision programs. This concept is the motivation to examine the state of the art of membrane technology, give an insight of possible areas of use and raise awareness among researchers and managers in the region. Membrane technologies are among the best options to consider when it comes to treating, recycling/reusing and protecting the environment from pollution.

Table 2
A summary of the deployed membrane technologies in Ethiopia.

Membrane type	**Location in Ethiopia**	**Treatment capacity (m^3/day)**	**Application**
MABR	Ayder Hospital, Mekelle University* [40]	320	Wastewater
MABR	A Condominium with 32 buildings, Addis Ababa* [40]	185	Wastewater
MBR	Kality condominium building, Addis Ababa* [61]	27,500	Wastewater
MBR	Yerer Condominium, Addis Ababa* [61]	180,000	Wastewater
MBR	Akaki Cheffe Condominium, Addis Ababa* [61]	24, 000	Wastewater
MBR	Akaki South Condominium, Addis Ababa* [61]	50,000	Wastewater
RO	Mekelle University, Tigray [59]	0.946-26.5	Brackish water
RO	Afdera, Afar [62]	120	Brackish water
RO	Mekelle Tissue Culture, Tigray	NA	Tissue culture
RO	Bottled water factories	NA	Bottled drinking water
RO	Afar, region**	15.6	Brackish water

* Under construction,
** The plant is no more functional. NB: It should be noted that this list may not contain all of the country's deployed membrane technologies due to the difficulty in gathering information across the country.

(i) **Research on organic/inorganic membrane materials fabrication**: it is an important step toward the use of the available raw materials for low-cost membrane fabrication. Ethiopian raw resources with the potential to be utilized in the preparation of ceramic membranes or as nanofillers in mixed matrix membrane range from the vast naturally available Kaolin deposit to environmental polluters like agricultural residues, khat waste, water hyacinth from different water bodies, etc.

(ii) **Chemical industry advancement**: availability and production of some of the most important raw materials at large quantities for membrane fabrication are also dependent on the advancement and capacity of other chemical industries. The country should facilitate or promote the industrial sectors for the production of raw materials necessary for membrane technology for different applications.

(iii) **Development of integrated/hybrid membrane process using commercially available membranes**: Thanks to the EU commissioned European Membrane Engineering Master (http://www.em3e-4sw.eu/em3e/) and PhD (http://eudime.unical.it/) programs, the country has large number of Membrane Engineers, who can be actively recruited to design and operate hybrid membrane technologies at various sectors as well as massively train young generation. Few examples both in the domain of membrane fabrication and application include: Pervaporation membrane was used to upgrade the quality of ethanol obtained after fermentation of dried coffee pulp [70]. Commercial NF was also assessed to reclaim textile wastewater after removing reactive dye from Yirgalem textile factory wastewater [71].

All these aspects should be properly investigated through a well-organized research centers mainly focused on the merits of membrane technology for sustainable development.

3. Membranes for water and wastewater treatment

Despite the huge importance of clean drinking water for human development, water scarcity is still a big challenge to human beings [72]. Water pollution and shortage is also threatening the sustainable development of a worldwide economy. Similar to many other under-developed and developing countries, 43% of Ethiopians lack access to safe drinking water [73]. Population overgrowth, industrialization, water pollution and waste products are further complicating the existing problem [74]. As a result, the demand for freshwater is accelerating [74,75] and a significant increase in global water demand over the coming decades is predicted [76].

On the other hand, the production of enough and clean drinking water requires extending the possible water resources and solving water-pollution-related problems, such as the treatment of industrial wastewaters. Strategic investment on improved wastewater treatment technologies is an efficient way to tackle river water pollution in Ethiopia [77].

Membrane technology is the most rapidly evolving and promising separation technique since it is more energy-efficient, simple and compact [78], easy to operate, scale up and scale down [79,80]. For instance, NF [81], is rapidly emerging for wastewater treatment and water purification [82–86] and increasingly used in water desalination [87–89]. To fabricate NF membrane, both ceramics and polymers have been employed [90]. Apart from being brittle and expensive, ceramics NF membranes are well-known for their thermal (up to 500 ºC), chemical and mechanical stability [91,92]. However, for water treatment applications, polymers are the most extensively used type of membrane material due to their easy pore-forming mechanism and increased flexibility [93]. Another mature membrane technology, which involves a selective ion exchange membrane to move ions and desalinate brackish drinking and/or wastewater, is electrodialysis [94,95]. In such a system, the salt ions and charged organic matter can be removed under the influence of electric potential. Membrane distillation, on the other hand, is a separation method that is based on a vapor pressure difference caused by a difference in temperature across a hydrophobic membrane [96]. Membrane distillation, driven by solar thermal energy presents a promising sustainable solution for countries like Ethiopia with limited electrical energy grid [97].

In this section, the issues of wastewater from various sectors in Ethiopia will be assed together with examples on the use of different membrane technologies implemented worldwide to limit their environmental impact.

3.1. Membrane technology for drinking water purification

Despite the fact that water is a source of life, millions of people around the world lack access to safe, fresh water. Generation and dumping of massive amounts of toxic industrial wastes into the environment have been one of the main causes for fresh water pollution.

Conventionally, surface water is treated using coagulation, flocculation, sedimentation, filtration and disinfection. On the other hand, membrane technology has become a more appealing water treatment technology as it offers consistent quality of produced water, easy automation and less sludge production [98,99]. UF process can remove microorganisms and some viruses. Currently, membrane technology is widely used to produce drinking water in many countries.

A gravity-driven UF hollow fiber membrane pilot plant was used to treat local spring water and produce potable water for Tshaanda community, rural village in South Africa [100]. The water samples taken were characterized in terms of its turbidity, pH, electrical conductivity, *E. coli*, total coliform and enterococci. The permeate (treated water) was reported to be in line with the WHO and South African water quality guidelines.

Surface water, which has a low osmotic pressure, can be treated using a low-pressure operation of NF [101] or FO. To remove organic molecules, dissolved salts and nearly all viruses, usually NF is employed. It is used to produce high-quality drinking water in industrialized nations. Similarly, it was found to produce enough quantity of drinking water for a village (with around 600 inhabitants) in developing countries, such as Ghana at a cost of less than 0.01 Euro/L [101]. Furthermore, in addition to producing drinking water from surface water sources, NF has been found to produce drinking water from deep well water [102]. NF is commonly used for the removal of pollutants from both surface water and groundwater [103]. The cost of clean water from ground water produced using NF was estimated to be around €0.2/m^3 for a plant with capacity of around 2000 m^3 per day [102].

Softening of hard waters can also be performed using NF membranes. The use of NF for softening groundwater treatment in comparison with lime softening in Florida has been investigated [103,104]. Figure 2 represents the NF membrane softening plant used. Another interesting related application of NF membrane, in the purification of drinking water, is defluoridation of water. Fluoride removal from brackish water using membrane technology has been discussed in the literature [103,105]. For exemple, Kettunen and Keskitalo reported 76% removal of fluoride removal from groundwater sources in Finland using NF 255 membrane (Filmtec) [106].

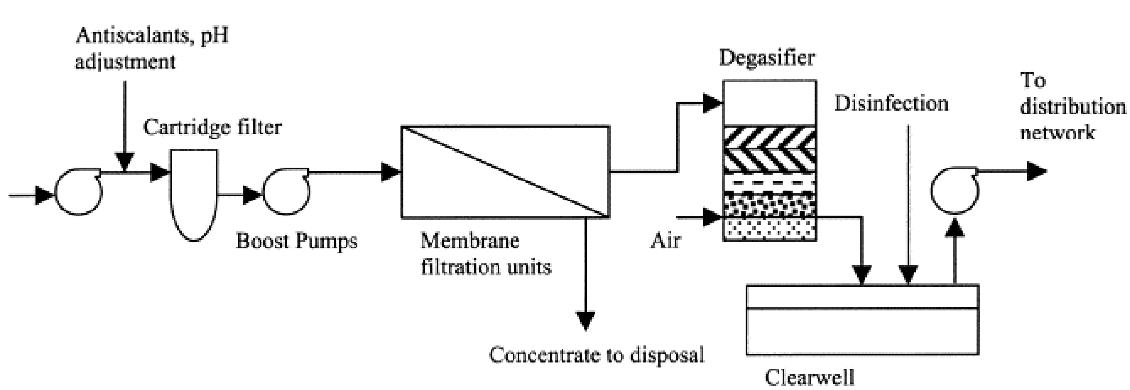

Fig. 2. Typical NF softening plant, reprinted with permission from [103]. Copyright Elsevier 2002.

A high fluoride concentration level is expected in the Ethiopian Rift Valley, since it is an active volcanic region. In this region, deep wells are the major source of drinking water. In a study conducted in the Ethiopian Rift Valley to determine the fluoride in ground water, it was found to be 6.03 mg/L, which is three times higher than the WHO standard value (1.5 mg/L) [107]. The fluoride concentrations in about 270 water sources in 126 local communities in the Rift Valley and Highlands have been reported elsewhere [108]. To address this issue, it was recommended to employ appropriate defluoridation techniques. A two-step electrodialysis has been used to effectively remove fluoride from an ammonia-based flue gas desulfurization slurry elsewhere [109].

To solve drinking water scarcity, seawater desalination using RO is the most viable option [102]. Tajura seawater desalination plant was constructed in 1984 with the aim of producing potable water by using a spiral-wound polyamide membranes RO technique. It is able to produce 10,000 m^3 potable water per day with a salinity level of under 500 ppm on continuous operation basis [110]. Similarly, graphene-based membrane was found to desalinate sea water into drinking water [102]. The rejection for NaCl was reported to be 97%.

Hollow-fiber membrane (MF/UF) is used in Singapore's largest wastewater reclamation plant (288,000 m^3/day capacity) to produce drinking water (NEWater). This enabled the country to diversify its sources of water supply. Overall, NEWater covers 30% of the country's current water demand [111,112]. Similarly, pressure-driven membranes processes are playing an important role in drinking water production in the United States [113].

Similarly, membrane technology applications to produce drinking water from ground and surface water can be expected in Ethiopia. As discussed in section 2, there is currently no large-scale application of membrane technology in Ethiopia, which aims at producing or purifying drinking water.

3.2. Membrane technology for industrial wastewater treatment

3.2.1. Food industry wastewater

Due to change in life style and adopted modern life, food in the current era is being processed into different forms. Food processing, in a country like Ethiopia, where food security poses a big problem, is a key strategy to help with long-term food preservation and fair distribution throughout the country. As a result, there is a fast progress in the number of food processing industries including breweries, bakeries, wineries, fruit juice clarification, soft drinks, dairy and poultry farming and other food canning.

Ethiopia is an agrarian nation with a population of over 110 million people, with over 80% of the population engaged in agricultural activities such as arable, pastoral, and plantation farming. Huge quantities of these agro-raw materials are squandered due to a lack of post-harvest management due to a lack of infrastructural facilities such as suitable roads, processing and storage equipment, as well as poor marketing information. Using proper processing technologies to transform agricultural (food) raw materials into intermediate or completed products could improve the value of agricultural (food) raw materials, among other things. Food processing can reduce waste, raise economic gains, ensure long-term availability, lengthen shelf life, prevent import dumping and capital flight, and improve nutritional quality by transforming agro-raw materials into varied food products.

Post-harvest management through food processing can reduce dependency on imported goods and aid agencies, which often fail to fulfill the needs of the society due to their intermittent funding nature. Currently, Ethiopia has many large-scale and small-scale food processing industries.

The food industry has been globally the largest consumer of potable water per kg of food product. Water is used in many processes and unit activities, including rinsing, washing, heating/cooling and general cleaning, sanitation, and disinfection, to mention a few. Ethiopia currently lacks sufficient water storage facilities to meet the increased demand for water resources resulting from its rising economy. On the top of that, more than half of the consumed water eventually leaves these plants as a wastewater reach in organic matter, which requires an end-of-pipe treatment [114]. The total amount of this wastewater is about 500 million m^3 per year worldwide [115]. Table 3 shows that dairy processing produces the most specific wastewater globally, whereas olive oil extraction has the highest chemical oxygen requirement (COD).

A variety of wastewater treatment technologies with varying degrees of treatment efficiency, including flocculation and coagulation [117], bioremediation [118,119], biophysical treatment [120] and advanced oxidation processes [121] are used to treat food wastewater. However, the majority of these technologies require a significant investment and frequently often fail to account material resource efficiency. As a result, their practical application is often limited because cost factors prevail their pollution abating capacity [122]. Moreover, they also mostly produce concentrated waste (sludge) that requires further abatement.

Table 3
Food processing industries, amount of wastewater released and with its COD. Adapted from [116].

Food processing	Wastewater (m^3/ton of product)	COD (g O_2/L)
Fruit juice general	3.1	2.5-11
Olive mills	5	200
Potato starch	1.1	5.4
Frozen carrot	30	5
Beer production	4.2	2.5
Fish industry	10	7
Dairy industry e.g. whey	90	50
Meat processing	0.9	8.3

Effluents from food processing include a wealth of useful organic chemicals, including high added value molecules, which are non-commercially not available, in sufficient concentrations to stimulate recovery [123,124]. In the wine industry, for example, products lost to wastewater are valued about $2.4–3.4 million per year. Membrane-based recovery and valorization of these chemicals may reduce their pollution load while partially compensating their management costs. Several investigations have been conducted on the recovery of natural pigments with proven antioxidant properties like β-carotene and lycopene from tomato industry waste [125,126], as well as carotenoids from carrots, polyphenols from olive mill wastewater [127], valorization of py-products from soybean oil to produce antioxidants, such as vitamin E [128], biogas [129], lactic acid production [130]. Food wastewater also reaches today's society's most needed functional foods, such as nutraceuticals, which can be easily recovered [131,132]. Therefore, viewing food wastewater as a potentially inexpensive source of materials rather than simply waste can assure long-term sustainability driving us towards circular economy.

Recycling of water and nutrient recovery through electrodialysis from RO concentrates of food industry wastewater was investigated in the literature [133]. In this study, the initial pH and current density were varied to investigate the separation efficiencies of ions through a nonselective anion-exchange membrane (AEM) and a monovalent selective AEM. It was reported that to improve the selective AEM's perm-selectivity, lowering the current is more beneficial than increasing pH. In another study, a sequentially integrated membrane process was employed for the recovery of commercially unavailable phytotherapeutics from olive mill industrial wastewater [127]. The integrated enzymatic MBR with forward osmosis and UF/NF was able to provide biophenolic compounds (ingredients in pharmaceutical and cosmetic industries), purified water and an organic sludge useful for compositing.

3.2.2. Dairy and breweries wastewater

Dairy and breweries are also another food industry that consumes a large amount of water. For instance, to produce 1 m^3 of beer, about 4 to 11 m^3 water is consumed [134,135]. In 2010, Ethiopia's St George Brewerys was producing around 107.7 thousand hectoliter (hL) beer. Out of the 7.5 million hL/yr water consumed for brewing and other purposes, about 6.47 million hL was leaving as wastewater and through evaporation. The factor thus released about 18,000 thousand hL wastewater to the nearby river without prior treatment [136]. This amount of effluent was formerly released into aquatic bodies, potentially polluting the Akaki River.

In Ethiopia, the increased dumping of untreated/partially treated industrial wastewaters is a major environmental issue. The most popular way for industries to dispose of untreated wastewater is to dump it into surrounding rivers. Around the capital, Addis Ababa, the Luna and Kera slaughterhouse releases wastewater with chemical oxygen demand (COD) as high as 11,5 g/L, which is 100 times higher than the discharge limit [46]. Discharge of this wastewater to the nearby Akaki and Mojo rivers has caused significant eutrophication and impacted their use for domestic activities. Indeed, treatment of these streams with lagoons is able to remove these components by up to 90%, although the factories showed less tendency to use their treatment facilities due to many reasons.

The Ada milk factory in Bishoftu town has been a source of environmental pollution since its establishment due to the discharge of its odorous waste stream. Organic debris, suspended particles, nitrogen, and phosphorus are all present in high concentrations in the wastewater, posing major health risks to animals and humans (Table 4). According to Solomon Ali [137], the factory was able to reduce the concentration of some of its pollutants by utilizing horizontal subsurface flow constructed wetlands. Although these treatment strategies are popular in developing countries due to their low cost and ease of maintenance, they are ineffective at removing organic pollutants.

Water reuse has also become more technically feasible due to rapid economic growth, stricter environmental regulations, and the availability of more effective purification strategies [138]. Depending on the kind and size of the food processing plant, it is possible to reduce fresh water use by 20% to 50% by implementing water reuse/recycle solutions inside the production line. This water reclamation strategy can be easily combined with the recovery of high added value components resulting eventually in near zero liquid discharge [139,140]. For instance, the St. George brewery factor in Addis Ababa (Ethiopia) implemented anaerobic treatment technology to valorize its wastewater and was able to produce 487 Nm^3/day methane yield. Likewise, Kera and Luna slaughterhouses and Ada milk factory, main polluters of Akaki and Mojo River were estimated to have a maximum methane production potential of 4.6, 0.18, and 0.99 L, respectively, hence potential sources of biogas production. This potential can be easily integrated with membrane process aiming at zero liquid discharge.

Membrane filtration, such as NF, MBR and RO, has been shown to be effective than other systems at removing physical, microbiological, and chemical pollutants, hence it is an important aspect of the brewery wastewater treatment process. Many studies have been published on membrane technology for brewery wastewater treatment, with nearly all reporting more than 90% COD removal [141,142]. For instance, COD, Na^+, and Cl^- were all efficiently removed by NF, with an average removal rates of 100%, 55%, and 70%, respectively [143]. In another study, MBR applied for the reclamation of brewery bio-effluent, was able to reduce the COD from 900-1300 mg/L to 30 mg/L with 100% retention of suspended solids [144]. Dai et al. [145] used MBR in a side-stream configuration, using an upflow anaerobic sludge blanket (UASB) reactor, to treat brewery wastewater, achieving about 96% COD removal.

3.2.3. Oily wastewater

Another group of wastewaters, which have been labelled as one of the main causes of water pollution is oily wastewater, which comes from metal cleaning fluid, food and beverage, shipping and maritime, oilfield produced water and the waste emulsion in Fe and steel works. Different treatment and separation methods, such as simple physical processes and biological treatments are usually employed. However, membrane technology is believed to be the most efficient methods to treat these wastewater because of its relatively simple operation process and high separation efficiency [147,148]. PVDF-based UF membrane [149,150] is one of these processes, which has been used to treat such water. For instance, a hybrid UF-aerobic bioreactor was used to treat rapeseed oil wastewater [151]. The UF substituted settling tank, which often suffers from elongated sedimentation rate due to the presence of oil. The hybrid MBR showed better treatment efficiency than the secondary settling tank for the same loading rate of reactors. The COD/BOD removal was about 20% higher than the traditional configuration. To solve the membrane fouling problems associated with pressure-driven membranes, recently membrane distillation has been emerged as a potential candidate for treating oily wastewater [152,153].

3.2.4. Textile and garment industries wastewater

Ethiopia is regarded as the hub for textile sourcing and production due to its low labor wage in comparison to competing countries and abundant resources for cotton farming. According to the Textile Industry Development Institute (ETIDI), In 2010 only, the textile industry contributed 1.6% of nominal GDP and 12.4% of industrial output [154].

The textile industry consumes a lot of water. Moreover, it is one of Ethiopia's most polluting industries, as its wastewater contains a variety of hazardous additive chemicals and dyes [39], which most of them cannot be easily degraded. As a result, the garment and textile sector generate a large amount of wastewater. Many of Ethiopia's textile and garment factories do not have proper WWTPs as part of their waste disposal systems. There are legal procedures and regulations in place to control the environmental consequences of industrial waste in the country. However, because of a lack of strong commitment to enforcing them and inadequate government oversight, industries do not feel obligated to treat their toxic streams. Often, the effluent is simply discharged into the surrounding environment, which is usually a river.

Case studies made at Bahir Dar textile industry by Mehari et al [155], indicated that the effluent discharged by this facility poses a significant threat to aquatic habitat, putting downstream users of the Blue Nile River at risk. Indeed, pollution of this river and its surrounding could also be a major cause for the alarmingly declining water quality of Lake Tana and Blue Nile River, which in turn may harm mega projects, such as the Great Ethiopian Renaissance Dam (GERD) and downstream countries, including Sudan and Egypt, whose lives mainly depend on the flow of water from these bodies. Additionally. a study by Dadi et al. [156] looked into the environmental and health effects of wastewater from four textile and garment plants located in the towns of Gelan and Dukem, and found that these facilities posed risks to communities and the environment. According to a detailed analysis of samples of effluents from these streams, the wastewater contains physiochemical and bacteriological contaminants that exceed the EEPA's allowed limit. Similarly, the physiochemical parameters of Hawassa Textile Industry’s effluents and nearby water bodies were well beyond the permissible limit [157]. Although river water is the major source of domestic water supply for the country's rural areas, the mean values of DO, for example, at the head of Blue Nile River, were not suitable for drinking (Table 5).

Globally, coagulation-flocculation, adsorption and oxidation processes techniques are used to treat wastewater produced from the textile industry. The conventional treatment methods poorly remove the reactive dyes and are less efficient in decolorizing the effluents [158,159]. Membrane technology, including loose NF-based electrodialysis [160], UF [161], membrane distillation [162], RO [163] and MBR [164,165] have been reported to effectively to treat various types of textile dyeing wastewater.

3.2.5. Leather processing industries wastewater

Ethiopia is the first in Africa and the 10th in the world in livestock population. There are plenty of leather and tannery factories that operate in the country. These industries are other groups of main contributors to the wastewater discharge. The type and characteristics of the wastewater from some of these industries is summarized in Table 6. An integrated UF followed by NF was effective to recover chromium salt from spent tanning liquors. The recovered Chromium solution (10 g/L NF concentrate), showed better tannage performance than the regularly used basic chromium sulfate powder. This integrated approach also allowed the reuse of the NF permeate in the pickling step since it has high chloride content [166].

Table 4
Wastewater composition of food breweries and dairy processing industries in Ethiopia.

Wastewater composition	Kera abattoir [146]	Luna abattoir [146]	Ada milk factory	St. George brewery [136]	Standard	
					EEPA	WHO
DO/COD (mg/L)	3.75/11546	4752	1.3/2520	2676 (COD)	150	DO > 10/COD < 160
BOD_5 (mg/L)	4000	2110	506.2	1505	50	<4
pH	7.3	7.2	5.7	9.9	6-9	6.5-8.5
TSS (mg/L)	3835	1111	318	686	2100	<500
Conductivity (μS/cm)	1614	1251	1187	3037	NA	400-800
TP (mg/L)	202	55	10.2	57.3	-	-

Table 5
Effluent characteristics of various textile and garment industries in Ethiopia.

Wastewater composition	Bahir Dar Textile [155]	Hawassa Textile [157]	DH-GEDA [156]	NOYA [156]	ALSAR [156]	ALMHADI [156]	Standard	
							EEPA	WHO
DO (mg/L)	3.7-7.8	190-330†	130±33	733±7	143±31	470±289	150	DO<10 & COD<160
BOD5 (mg/L)	5.3-40-3	93-188	139	91	84	252	50	<4
pH	7-8.7	8-11	8	8	8.4	7.89	6-9	6.5-8
TDS (mg/L)	100-600	277-900	511	186	500	292	2100	<500
Conductivity (µS/cm)	141-1050	31-46					NA	400-800
Total hardness (mg/L)	84-110						NA	NA
Total alkalinity (mg/L)	91-247		-	-			NA	<75

† is COD in mg/L.

Table 6
Wastewater in various leather processing industries of Ethiopia.

Wastewater composition	Modjo tannery [167]	Batu tannery [168]	Haffed Tannery Privately Limited Company [169]	Standard	
				EEPA	WHO
DO/COD (mg/L)	-/2000	-/4487-18578	-/	150	DO>10/COD<160
BOD5 (mg/L)	900	277-1710	361	50	<4
pH	9	3.25-12	7.87	6-9	6.5-8.5
TSS (mg/L)	4979	172-9093	1430	2100	<500
EC (µS/cm)	15670	-	-	NA	400-800
TP (mg/L)	30	-	4.55	10	-
Total nitrogen (mg/L)	720	-	239.8	60	-
Chloride (mg/L)	6111	2666-31127	NA	1000	-
Sulphides	36	0.035-2.27	1.6	1	-
Chromium (as Cr VI) (mg/L)	1.46-4	0.06-1.22	NA	0.1	-

3.2.6. Healthcare wastewater

Healthcare wastewater poses a greater risk of infection than municipal wastewater because it may include a wider range of disease-causing organisms than municipal wastewater. The presence of these pathogens in poorly handled hospital wastewater contributes significantly to the spread of drug-resistant diseases into the environment, where they can become emerging contaminants. These situations can cause pollution of food, water, and other environmental bodies, which can be a huge public health issue, especially in developing nations like Ethiopia. As a result, the management of healthcare wastes necessitates special attention and must be given top importance.

Due to rapid population growth and the consequent demand for health services, the amount of healthcare waste has increased dramatically in developing countries in recent years. Healthcare waste management is the most neglected activity of most health service providers in Ethiopia, despite considerable investments in building public and private healthcare facilities. Due to a lack of extensive research, it's difficult to anticipate how much and what kind of healthcare waste will be generated. As a result, reducing selective pressure by regulating antibiotic use is a critical step in slowing the spread of resistance in hospital wastewater. Furthermore, wastewater must be cleaned using various methods in order to decrease the occurrence of drug-resistant strains in the environment.

Generally, due to rapid advances in advanced techniques for identification and quantification of vast range of chemicals, the focus of environmental study in the water has been switched to the problem of emerging polar organic contaminants. Emerging micropollutants include manmade or naturally occurring organic trace pollutants that are not-regulated and/or newly introduced/detected [170]. Their presence, wide spread distribution, environmental fate and concentration in both aquatic and terrestrial environment and their polluting capacity is only now being clarified. In the EU, there are over 100,000 registered chemicals, of which 30,000 to 70,000 are used on a daily basis [171]. Thus, components, which are available in healthcare wastewater, are major parts of emerging micropollutants. These are barely eliminated during conventional WWTPs, and they have been found in the effluent of municipal wastewater [172,173], thus believed to enter rivers and lakes after the sludge WWTPs [171].

So far, the most common method of hospital wastewater treatment strategy in Ethiopia is, using waste stabilization ponds. It is an effective method of hospital wastewater treatment with up to 99% faecal coliform reduction. However, various studies showed that certain resistant bacteria persist after waste stabilization ponds, making the effluent water unsuitable for reuse or discharge to the environment. Beyene and Redaie [174] investigated the treatment of Hawassa University Referral Hospital wastewater using a series of facultative and maturation ponds. On a daily basis, the hospital produces 470 liters of wastewater per occupied bed. The removal efficiency (%) of the pond was determined to be BOD (94), Sulfide (88), TSS (87), COD (86), Nitrate (69), Nitrite (55), Total Nitrogen (55), TDS (32), conductivity (18) and chloride (11). In the pond's effluent, however, there was a 204.85% rise in total ammonia and a considerable increase in the concentrations of Zn, Cd, Fe, Pb, Co, and Cr. The BOD/COD ratio was 0.46, and the organic loading rate was 678.7 kg/he/day. The effluent, however, still contained a substantial number of bacteria, making it unfit for irrigation or aquaculture, as suggested by WHO.

The ponds were also not efficient to treat some selected physicochemical substances. It is therefore highly imperative to design and employ reliable pretreatment for the raw wastewater and onsite containment and segregation and treatment to reduce the toxicity of the wastewater. This will further help to reduce the release of emerging micropollutants and multi-drug resistant microorganisms, which put further pressure on the receiving surface water, Lake Hawassa.

The environmental behavior of micropollutants, which are present at extremely low quantities, is still unknown [175]. They interfere with aquatic life in the same way that they were designed to do. For instance, presence of endocrine substances may reduce the fish productivity of the lake as it affects the fish reproduction. The effect varies depending on the degradability and bioavailability of the micropollutants and susceptibility of the environment.

In this regard, membranes can play a key role in effectively treating healthcare wastewater either sequentially integrated with different membrane operations or as hybrid with the conventional treatment strategies. For instance, MBR can be effectively used to treat hospital wastewater, since it has high bacteria removal efficiency [176]. Membrane process, such as FO or membrane distillation can be employed to up concentrate these micropollutants, to make them suitable to be degraded by conventional systems. MBR can remove hydrophobic (17β-estradiol) and readily biodegradable hydrophilic (ibuprofen) micropollutants [55,177]. The removal efficiency of each of the micropollutants (which ranges from zero to 100%) varies depending on the different membrane technology used. However, for some of them, MBR alone or in combination with other technologies can achieve up to 99% removal efficiencies [54,55].

In the current Ethiopian situation, in addition to treatment strategies, effective tools for identifying sources, assessing environment impact, remediation and appropriate treatment technologies must be explored and implemented [171]. A comprehensive study by Tesfahun et al. [174], identified the various categories of wastes generated by government and private hospitals. However, detailed identification and quantification of the composition of the wastewater remains required.

3.3. Integrated/Hybrid membrane process

Membrane operations are subject to a number of inherent limitations including concentrations of suspended solids, viscosity, temperature and osmotic pressure in order to achieve a target quality. As a result, in many cases, the best separation process may be a membrane system combined with traditional separation technologies [178]. Membrane processes are frequently used as integrated systems to replace conventional unit operations or to design innovative processes in order to increase their competitiveness.

Hybrid membrane process is the combination of one membrane process with another membrane and/or conventional unit operations (Table 7). Due to the synergistic influence of various unit operations, the integration can increase performance depending on the desired product quality and/or feed characteristics [132,179,180]. A hybrid of UF membrane and fermentation process for recycling a distillery waste was reported to have zero discharge for an alcohol fermentation system [139].

The hybridization of unit operations with membrane processes can also help in reducing (direct and indirect) energy consumption. A hybrid system combining RO with evaporator, for example, is intended to reduce the amount of energy required to concentrate corn steep water [187]. The water initially containing 6 wt.% solids should be concentrated to 50 wt.% using minimal energy. In order to achieve this, the solution is first concentrated using RO to 15 wt.% and then a subsequent evaporator to bring it to the desired concentration. Only a third of the energy consumed by an evaporator alone was used by the hybrid system.

Hybridization also reduces the size of equipment, capital costs, footprint and emissions [132]. As a result, it can be considered one of the major aspects that has contributed to the widespread usage of membranes [179]. Among the various membrane hybrid system, MBR take the lead in wastewater treatment [37,188]. MBR has emerged in the last years as a reliable and an efficient choice for municipal and industrial wastewater treatment technology over the conventional activated sludge process [189,190]. MBR produce high effluent quality with a greater reuse potential. Gebreyohannes et al. [127] used sequentially integrated enzymatic MBR with NF, UF and forward osmosis (Figure 3) to valorize olive mill wastewater. This hybrid system enabled the recovery of pure water, commercially unavailable biophenolic compounds and sludge free from toxic components that can potentially be used for composting.

Although Ethiopia falls under the category of energy-deficient economies in the world, it has a huge potential of unexploited energy (45 kMW from hydropower, 10 kMW from wind, 5 kMW from geothermal, and an average of about 5.26 kWh/m^2 per day from solar energy) [191]. As such, the abundantly available renewable energy resources could potentially reinforce the integration of the existing membrane technologies with renewables towards more sustainable water and wastewater treatment in an eco-friendly manner. Moreover, such hybrid membrane processes have the advantage of alleviating the energy constraints associated with conventional desalination technologies, among others [192]. Therefore, integration of hybrid membrane process using alternative green energy sources can be employed to achieve sustainable development through circular economy. A best example in this is the Hawassa Textile and Garment Industrial Parks' circular economy solution. The park utilizes a zero liquid discharge (ZLD) system, which comprised membrane process, for 100% reclamation of wastewater (Figure 4).

Table 7
Hybrid membrane processes in food processing plants.

Food wastewater	Hybrid system	Ref.
Tomato	Pre-treatment (biological) and NF	[181]
Artichoke	UF and NF	[182]
Potato	Side stream MBR (UF)	[183]
Winery	RO and solar photo-Fenton process	[184]
Olive mill	Pre-treatment (enzymatic), centrifugation, MF, UF, NF, RO	[185]
Rapeseed oil mill	Side stream MBR (UF)	[151]
Palm oil mill	Anaerobic digestion, aerobic biodegradation, UF and RO	[186]

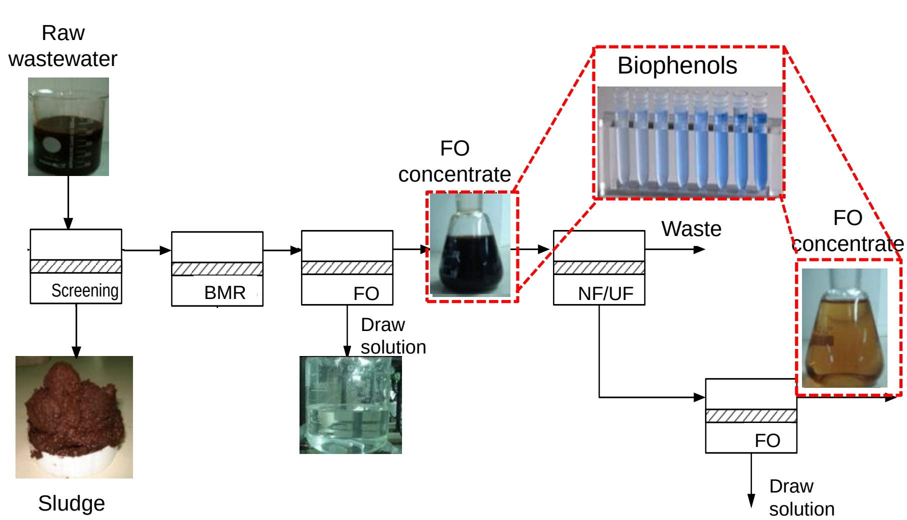

Fig. 3. Schematic representation of integrated microfiltration biocatalytic membrane reactor–FO–UF/NF for the valorization of olive mill wastewater, modified from [127]. Copyright Elsevier 2015.

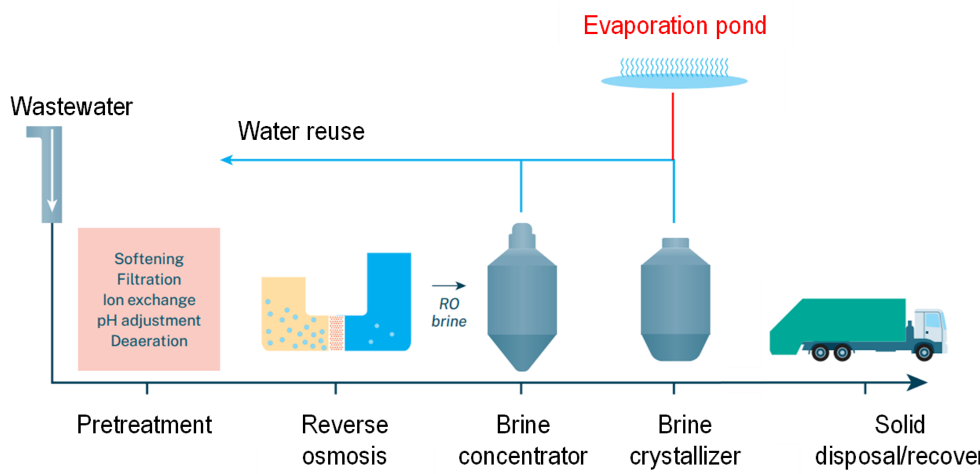

Fig. 4. ZLD system of Hawassa Textile and Garment Industrial Park, Ethiopia. Modified with permission from [193].

In this ZLD concept, a brine crystallizer is used to recover the remaining water in the concentrated obtained from brine concentrators. In the flow-sheet, evaporation ponds are suggested as competitive alternatives to brine crystallizers since they use natural solar energy and have a lower operational cost. Evaporation ponds are especially preferred when treating small volumes at locations with a high evaporation rate and inexpensive land, which is the case in Ethiopia at the specified industrial park. This centralized ZLD system powered by a renewable hydroelectric power plant, is able to save 8000 m^3/day of fresh water consumption. It also has an economic return of $4-$13 for every dollar invested in water. This hybrid system is able to provide with clean water to both industrial and residential consumers. It will also avoid the direct discharge of highly contaminated wastewater into the nearby Lake Hawassa and Tikur Wiha River [193]. Although the various membrane technologies discussed here are focused on industrial wastewater, similar strategies can be employed for low strength wastewaters like municipal wastewater [194].

It is therefore evident that a hybrid membrane technology has the potential to be a game-changer in water treatment and wastewater reclamation in Ethiopia.

4. Conclusion and future perspectives

From this review, we concluded that, comprehensive legislation supported by alternative treatment technologies is urgently required in Ethiopia and other developing countries to implement multi-sectoral water protection and provision programs.

The presence of Ethiopian Environmental Protection Authority (EEPA) set standards and guidelines of maximum allowable levels (MAL) for limited number of pollutants is encouraging for further environmental measures to protect water bodies. However, this high concentration of MALs will not safeguard the aquatic lives in the receiving water bodies nor assure the quality of the water from these water bodies for any purpose. This put the EEPA in great dilemma to set lower concentrations which will be difficult to achieve by the treatment technologies currently in use by the industries, this in turn will be a challenge to the much-needed development via industrialization.

In this regard, we suggest to introduce alternative solutions such as membrane technologies that could help to attain a minimum low level that can safeguard the life of aquatic organisms and the possibility of reusing. In general, the wide introduction of membrane technologies with their endless list of applications, not only help in solving pollution problems and provide alternative environmentally friendly solution, but also it helps to improve policies and regulations to make them more focused and specific to achieve their goals.

So far, in Ethiopia, RO appears to be the most widely used membrane technology. It is utilized to supply high-quality water to industries. Promising membrane technologies, such as gravity-driven ultrafiltration and solar-powered NF membrane processes can be easily implemented for purifying drinking waters. Similarly, the application of electrodialysis for water and food product desalination, such as milk, will revolutionize a variety of sectors. It works in tandem with the country's long-term environmental and economic strategy.

This concept was the motivation to review the state of the art of membrane technology, give insight of possible areas of use and raise awareness among local researchers and managers. Membrane technologies are of the best solutions to consider when the aim is to treat, to recycle/reuse and to protect pollution. Strategies that need consideration to facilitate the implementation of membrane technology in the developing countries include:

- Development of curriculum for membrane technology at bachelor and master level. This could include opening membrane teaching and research centers to train researchers and teachers. This would help to understand the role of membranes involving wide range of societal and community problems.
- Identifying availability of national resources and raw materials that could be used to fabricate membrane materials and processes. It is also possible to use various available waste materials to prepare low cost and green ceramic membranes as demonstrated elsewhere.
- Create functional collaboration/networking with international universities/research centers, which have profound knowledge and expertise in studying and implementing membrane technologies at various levels.
- Widely introduce and implement hybrid membrane technology such as renewable energy-based membrane desalination technologies. Ethiopia's huge reserve of geothermal energy and surplus availability of both solar and wind power can be harnessed to reduce the energy constraint of some of the key membrane technologies.
- Last, but not least it is highly imperative to prepare strong national working rule and regulations and a strict implementation of these regulations follow-up strategies.

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