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RESEARCH ARTICLE

MANAGING WATER SCARCITY IN AN ERA OF CLIMATE CHANGE IN DEVELOPING COUNTRIES: THE CASE STUDY OF KENYA

Joan Nyika*, Megersa Dinka

University of Johannesburg, CNR Kingsway and University Roads, Auckland Park, Johannesburg, 2092, South Africa
****Corresponding Author Email: joashmada2011@gmail.com***

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ABSTRACT

Kenya is one of the water-scarce nations in the sub-Saharan Africa region that is seeking for alternative water sources to meet the ever-rising demands of the resource for its growing population amidst climate variability. Desalination is one of the viable alternatives since it has no effect on the hydrological cycle. This research discussed the methods used for desalination, the gains, opportunities and challenges that Kenya is facing in adopting this technology. The adopted methodology involved evaluation of pre-existent literature from databases and organizations championing for desalination. Findings showed that membrane and distillation processes are used to purify saline water independently or as hybridized systems in addition to alternatives such as freezing, solar humidification and deionisation. These methods have been implemented in Kenya at varied scale and their expansion is growing with the availability of renewable energy sources including solar, wave and geothermal power with high potential in the country. The sustainability of the desalination processes is however challenged by high implementation costs, high energy consumption and negative environmental effects due to fossil fuel use and production of brine among other wastes. Future prospects should prioritize on using safe and sustainable desalination processes to offset its affiliated costs and negative environmental effects as suggested in this review.

KEYWORDS

Climate change, Desalination, Kenya, Seawater, Sustainability, Water scarcity

1. INTRODUCTION

Water is an essential but finite resource in sustaining life. Its distribution globally is variable temporally and spatially. In particular, freshwater resources are depleting despite the fact that the resource cannot be made or substituted. According to Liu et al. (2017), all sectors including agricultural and energy sectors are enduring water scarcity, wherein the demand and environmental needs cannot be met satisfactorily (Liu et al., 2017). More than 3.6 billion people equivalent to 47% of the world's population live in areas experiencing water scarcity at least once annually (Boretti and Rosa, 2019; Maingey et al., 2022). The number is expected to grow to 57% (4.3 billion people) by 2050 as a result of rising demand for the resource prompted by population increase (Boretti and Rosa, 2019). The situation has been exacerbated by economic development, population growth, climate variability and a dietary shift where there is high preference for animal products. By including the aspect of deteriorating water quality, the average global water scarcity increased to 40% from the 30%, which only considers physical rather than economic water scarcity (Van Vliet et al., 2021). Consequently, many regions particularly in Africa are consuming freshwater beyond sustainable levels as the Water Research Commission (WRC, 2018) reported. Another study attributed the growing water scarcity to a 6-fold increase in demand for the resource in the past century as economies strife to grow and populations rise (Vanham et al., 2021). The high demand amidst depletion of water resources is evident from the recurrence of sanitation problems, waterborne diseases, inter and intra-community conflicts as well as food and energy insecurities (Niyitunga, 2019).

Although the sixth sustainable development goal (SDG 6) focuses on universal provision of water and sanitation, realisation of this goal remains elusive. Statistics showing that most water abstractions in river basins exceeded recharge rates, 90% of people in poor developing nations are exposed to untreated sewage and 1.8 million people are consuming water contaminated by faecal matter attest to this trend (Bhaduri et al., 2016). In Kenya for instance, water scarcity has persisted for a long time due to the spatial and temporal variability of the water resources and their poor management (Nyika, 2018; Maingey et al., 2022). Slightly more than 40% of the total population in the country did not have access to safe drinking water, 70% did not have access to safe sanitation and 86% did not have access to appropriate handwashing facilities in 2017 (Bukachi et al., 2021; WHO, 2017). A studies reported that the Kenyan government is yet to meet its water access goals claiming that the country had targeted to provide access to safe water for 75% of its rural population by 2015 but only managed 57% (Chepyegon and Kamiya, 2018). This could be because of the country's low renewable freshwater supply rated at less than 1000 m^3 per capita per year (Mulwa et al., 2021). Mekonnen and Hoekstra (2014) also shared the view that Kenya is a water-stressed country whose blue waters estimated at 20.7 km^3/year cannot sufficiently meet the rising demands that are pressured by both population and economic growth. The rural areas and informal settlements of urban areas are worst hit due to their low resilience, non-preparedness and infrastructural limitations to deal with the water stress situation (Nyika, 2018; Bukachi et al., 2021). The apparent trend has disrupted the water-food-energy (WFE) nexus making it difficult for the country to meet its needs (Nyika, 2020). In recognition of the water stress problem, an interdisciplinary and sustainable approach to the problem seeking to find alternative water resources such as reprocessing grey and black water and desalination is increasingly being preferred (Francisco et al. 2018).

Desalination of seawater is more viable for the populations living at the coast that contend with ocean waves and sea overflows despite the lack of fresh and clean reliable water (WRC, 2017). Other studies have reported

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that desalination is a sustainable solution to freshwater scarcity in arid lands of developing nations (Nirajan et al., 2022; Esmaeilion et al., 2021; Pistocchi et al. 2020). According to Angelakis et al. (2021), desalination is a smart technology to wiser water use and should be properly implemented to beneficial in water stressed regions. The technology is a possible response to sustainable water provision amidst climate hydro-variability though water desalination consumes energy (Van Vliet et al., 2021). Consequently, it affects the WFE nexus and therefore the three sectors should be viewed as inextricable to balance the amount of water diverted to desalination, the energy used and the output particularly in the agriculture sector towards sustainable growth realization (Francisco et al., 2018). This review aimed at evaluating the methods applied for desalination, the gains, opportunities and challenges in taking up water desalination practices in developing countries with the focus on Kenya as a case study. The significance of the study is to identify desalination methods that are practical to adopt in Kenya, the achievements gained in taking up the technology and the challenges encountered and how best to manage them towards enhanced desalination uptake and universal access to safe water.

2. Methodology

To meet the objectives of this study, articles from international databases such as Scopus and Web of Science were evaluated for article journals on desalination in general. Keywords used were *desalination methods* and *desalination techniques*. The search was further specified to desalination in Kenya. The search terms used were *sea water desalination in Kenya* and *desalination in Kenya*. Other websites such as the World Health organization official website with information on desalination were evaluated. This was done after a preliminary search on the databases resulted to few publications on desalination in Kenya. Results and discussion presented showed the global trends on desalination, the techniques used in desalinating sea water global and a discussion on the state, gains, opportunities and challenges of applying the technique to alleviate water scarcity in Kenya.

3. Global Desalination Statistics

Desalination practice dates back to the World War II in the Middle East and was prompted by lack of water. The practice has been more acceptable in water-stressed regions of the world (Angelakis et al., 2021; Esmaeilion et al., 2021; Pistocchi et al., 2020). Water supplied from desalination activities rose from 326 m³/day to 5, 000, 000 m³/day and to 35, 000, 000 m³/day in 1945, 1980 and 2004, respectively (Zolatis et al., 2014). In 2008, 14, 000 desalination plants across the globe processed more than 52, 000, 000 m³/day and the capacity increased to 67, 000, 000 m³/day in 2011 and 79, 000, 000 m³/day in 2012 from more than 16,000 plants (Voutchkov et al., 2012). In recent statistics of 2020, more than 20,000 desalination plants had been set up and out of this total, more than 15,000 were operational with a capacity to desalinate over 100 million m³ of seawater daily (Angelakis et al., 2021). The Middle East, Mediterranean, America and Asia had the highest number of desalination plants in respective order while South America, Australia and Africa had the lowest values. Table 1 shows the distribution of desalination plants globally.

Table 1: Distribution of Desalination Plants Around the World (Zolatis Et Al., 2014)

Region	Desalination Plants (%)
Middle East	53
North America	17
South America	1
Africa	6
Asia	11
Australia	0
Central America	2
Europe	10
Total	100

The global capacity to desalinate further increased by 9% in 2010-2016 with the market being spread in developed countries and emerging economies particularly, US, China, Saudi Arabia and United Arab Emirates. Previous studies noted that 54% of the growth was in the Middle East and North Africa, where 21 million m³/day of water was desalinated by Saudi Arabia, Kuwait, Algeria and Libya (Zotalis et al., 2014). A recent research also established a similar trend in their chronological study on the growth of desalination noting that the growth in use of the technology since the late 1960s has been exponential due to increased capacity of the plants (Angelakis et al., 2021). Majority of the large-scale plants used seawater and were located in the Middle East as outlined in Table 2.

Table 2: Statistics on Some of The Largest Desalination Plants in The World (Zolatis Et Al., 2014)

Name of the Plant	Location	Water Source	Capacity (m³/day)	Commissioning Year
Al-Zour North	Kuwait	Seawater	567, 000	2007
Jebel Ali	UAE	Seawater	600,000	2011
Al Jubail	Saudi Arabia	Seawater	730, 000	2007
Ras Al-Khair	Saudi Arabia	Seawater	800, 000	2007
Shuaiba	Saudi Arabia	Seawater	880, 000	2007

In the past decade, there has been notable growth of desalination practices globally and the practice will play an important role in meeting water demands in the future (Angelakis et al., 2021). In 2010, the growth rate for desalination plants was 6.8% annually and a production capacity of 4.6 million m³ daily (Jones et al., 2019). In 2017, water produced from desalination plants was more than 99 million m³/ per day from 18,500 plants according to the International Desalination Association (Virgili et al., 2018). By 2020 more than 20, 000 desalination plants across the globe and 16, 876 of them already installed and having a 97.2 million m³/ day production capacity had emerged (Jones et al., 2019). The desalination capacity had risen to 100 million m³/day (Angelakis et al., 2021). The desalination plants were spread across 150 countries and provided water to more than 300 million people. It is projected that the technology will provide water to more than 1 billion people across the globe by 2050 (Angelakis et al., 2021). In recent statistics, desalination was reported as a common practice in the Middle East where Qatar, Kuwait, the United Arab Emirates (UAE) and Saudi Arabia accounted for 55% of all global desalination activities (Markets, 2021). Regionally, Middle East and North Africa contributed the largest share of desalination activity with 47.5% while sub-Saharan Africa had the least contribution at 1.9% (Do Thi et al., 2021). The regional distribution in terms of desalination capacity and number of plants was as shown in Figure 2. The distribution trend and water desalination capacity were associated with availability of oil and fossil fuels as sources of energy for consumption during water desalination, which is energy intensive.

4. Technologies Used in Desalination

Two main technologies of desalination have been exploited at commercial scales (Zolatis et al., 2014; Cherif and Belhadj, 2018). First are the distillation or thermal processes such as multi-effect distillation (MED), mechanical vapour compression (MVC), multi-stage flash distillation (MSF) and thermal vapour compression (TVC) technologies. Second are the membrane processes such as electrodialysis (ED) and reverse osmosis (RO). A third category, which uses renewable energy to offset the high demand for power (electricity) in the first two categories of desalination technologies through hybridization has been proposed (Francisco et al., 2018). Based on these technology categories, their desalination capacity in million m³/day and percentage capacity in 2019 was as shown in Table 3.

Distillation or thermal processes of desalination are based on fluid evaporation then condensation where the product of the latter process is freed from salt. Through the MSF distillation, salty water is subjected to heat and boils at low pressure (Saadat et al., 2018). The resultant vapour is then condensed on surfaces whose contact is away from the feed-water to recover vaporisation heat and re-heat the feed-water. This process is repeated sequentially in the presence of treatment chemicals until freshwater is recovered. The MSF being a heat transfer-based technology is electricity and heat intensive. In this case salty water is evaporated severally in a series of interconnected chambers at low pressure before separating the salt content from the water (Markets, 2021). The technology has varied applications due to its desalination efficiency, easier processing, low demand for additives and long-term operation success although corrosion has been reported if non-stainless-steel equipment are used (Kress, 2019). The MED applies a sequence of vessels (effects), which are at low temperatures to recover vapour from saline water (Zolatis et al., 2014). Vapour used for boiling in one vessel is reused in the next since water temperature is directly proportional to pressure. The desalination processes involved in MED are either thermal or mechanical vapour compression (Saadat et al., 2018). For MED-TVC, a thermos-compressor is fitted to enhance the unit's performance by sucking more steam to maintain low pressure of the system. The MVC serves the same purpose in an MED system but uses electrical energy to compress vapour and lower pressure mechanically and also avail heat for re-distillation sequences (Kress, 2019).

In membrane-based desalination processes, a sheath is used to divide the system in two phases whereby some components are readily transported compared to the others. Unlike the distillation and thermal technologies, membrane processes are non-phased procedures. Electrical potential, concentration, temperature and pressure gradients are the transport driving forces (Ullah and Rasul, 2018). The RO technology uses a water-permeable membrane to allow the separation of dissolved salts from a saline solution using pressure (Pangarkar et al., 2011). The pressure difference created by the product and feed-water in between the membranes enhances liquid flow. This pressure is near atmospheric conditions while the initial pressure applied on the feed-water ensures that the process is running as long as the pressure gradient between it and the product water exists. The reverse energy processes are high-energy consuming though improvement of membrane characteristics and including an energy recovery system to redirect hydraulic energy back to the system's feed-stream could improve energy efficiency (Do Thi et al., 2021). Electrodialysis (ED) on the other hand, applies direct current through water to drive its ions into membranes and oppositely charged electrodes. Unlike distillation and RO processes, ED drives ions from saline water solutions since its electrical field is the driving force. An ED system applies electromotive force to electrodes next to the membrane to enable ion-water separation at cell pairs (Pangarkar et al., 2011). The method is preferred in desalination since it consumes low energy quantities considering that water phases do not change during processing. For these reasons, the method is suited in desalinating low salt content water with a few thousand mg/kg of dissolved salts (Do Thi et al., 2021). However, the process only removes ions and cannot free water off suspended solids, colloids and organic matter.

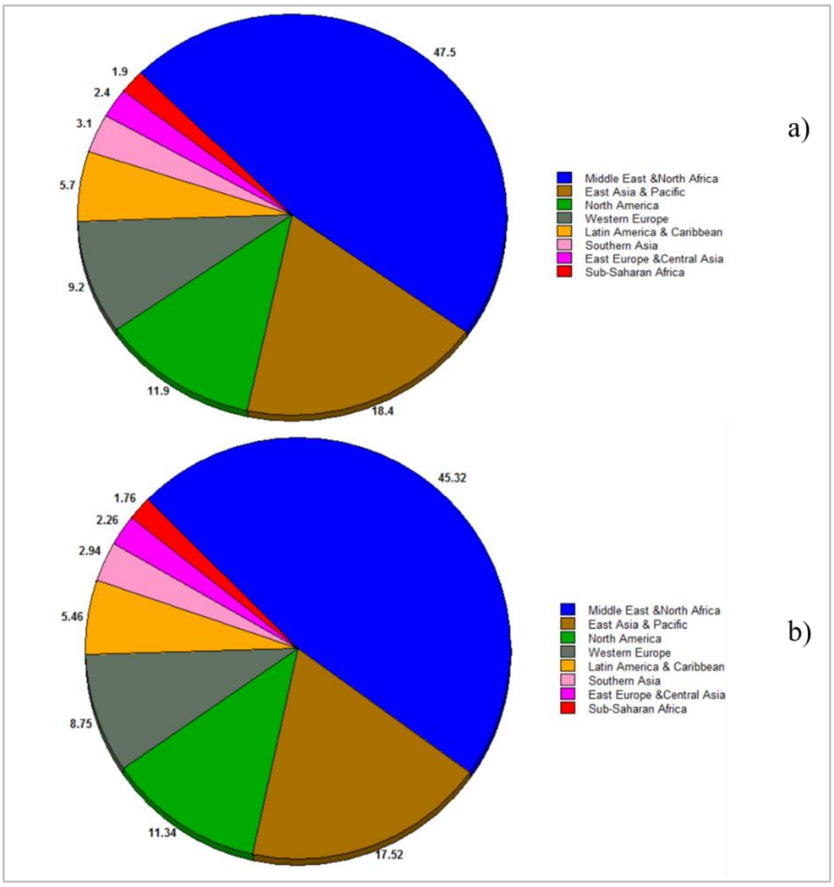

Figure 1: Global desalination capacity based on regions showing a) percentage number of desalination plants per region and b) their production capacity in m^3/day (Markets, 2021).

Table 3: Desalination Capacity in 2019 Based On The Use Of Specific Technologies In Million M^3/ Day And Percentage Share (Markets, 2021)

Technology	Desalination Capacity (million m3/day)	% Share
MSF	17.1	18
MED	6.65	7
ED	1.9	2
RO	65.5	69
Others	3.8	4
Total	94.95	100

Membrane and thermal technologies can be combined together in hybrid desalination systems. Examples of such hybrid systems are RO-ED, RO-MED and RO-MSF, which have been used in commercial and large-scale desalination plants (Al Bloushi et al., 2018). Compared to independent systems, hybridization is economical through reduced energy consumption, enhanced water quality and recovery rates hence reduced fouling and scaling pressure (Al Bloushi et al., 2018). Hybrid systems can incorporate renewable energy use rather than the usual fossil fuels. Such advances are positive efforts to climate change mitigation and adaptation considering that desalination is energy-intensive (Do Thi et al., 2021). Additionally, use of renewable energy to desalinate water could improve access of the resource in remote water scarce regions that are off-grid without any non-renewable form of energy. Hybridized desalination can be done using wind, geothermal and solar power in small-scales using distillation and membrane technologies (Angelakis et al., 2021). Of all the renewable energy hybridized systems of desalination, solar energy is the commonest in the form of solar cells or photovoltaics (Ullah and Rasul, 2018). The trend is attributable to the high potential of the sun globally and its free nature to desalinate water even at large scales. Concerns over the high capital costs incurred in setting up renewable energy-based desalination systems compared to fossil fuel-based systems have been raised despite their low maintenance and operation costs (Van Vliet et al., 2021). The author however expressed optimism that with technological advances, the costs of setting up renewable energy desalination systems is set to lower so that resultant produce can be affordable even to the poor.

In addition to commercially available desalination technologies, alternative techniques have been developed to free water from salts. One such processes is solar humidification based on evaporating saline water then condensing humid air at ambient pressure (Saadat et al., 2018). The process mimics the conventional water cycle but for shorter periods. Solar power is directed through a transparent glass and enters the device containing saline water and heats it allowing evaporation to occur. The container with saline water is black to allow more heat absorption. Evaporated water rises and cools on the glass panel where it is directed for collection and use (Saadat et al., 2018). The process is preferable since it uses renewable energy, it is simple to set up and has low operationalisation costs though it has 50% efficiency unlike distillation and membrane technologies of desalination.

Freezing is also another alternative phase-change desalination process. In the process, saline water is subjected to freezing and as its crystal structures increase in size impurities including brine, which adhere on the surface can be separated by cleaning the ice crystals (Ullah and Rasul, 2018). Freezing processes are either direct or indirect. In the former technology, feed-water is in contact with the refrigerant and in the latter, mechanical refrigeration occurs. Although the process has low corrosive potential, its high-energy use limits its applicability according. Ion exchange processes used in general water softening processes can also desalinate water. In such technologies, ions found in desalinated water are exchanged with solid chemical resins to purify the feed-water (Ullah and Rasul, 2018). The process is effective in removal of sodium and chloride ions and can be blended with RO to completely purify saline water.

5. Gains and Opportunities of Water Desalination in Kenya

Like other developing countries, Kenya's water insecurity is on the rise as reported by (Mulwa et al., 2021). The country's water availability was at 590 m^3/capita/year in 2010 and is set to lower to 293 m^3/capita/year by 2050, which is way below the internationally acceptable limits of 1000 m^3/capita/year (Nyika, 2020). As such, the ability to turn saline water at the coast and in arid areas to potable water is a water management measure with high potential to turn the tides since the areas experience severe water shortage. A case example is in the coastal town of Mombasa, which outsources freshwater from neighbouring Taita Taveta, Kilifi and Kwale counties. These counties also have inadequate supplies and only offer little of what is available (Colagrossi, 2019). Mombasa county in 2018 for instance, required about 200, 000 cm^3 of water in the month of December but could only afford 42, 000 cm^3 (Tokouleu, 2019). This observation illustrated how water scarcity is grave in the region. The water deficit in the region is further been exacerbated by climate variability and change characterized by long dry spells and extreme weather as well as escalating demand for the resource from the rising population and urbanisation trends.

Faced with these challenges, the country has made gains in introducing desalination practices to meet existent water deficits. In this regard, a number of projects focusing on water desalination have been initiated in Kenya at different scales. One such project is the introduction of a new solar-powered desalination plant at Kiunga town of the coast by Give Power, which is a non-profitable organisation (Kazungu, 2019). The plant supports more than 25, 000 people by purifying more than 75, 000 litres of water daily. The plant was constructed at a cost of $US 500, 000, will be making more than $100, 000 annually through subsidized supply of water, and intends to re-channel the proceeds towards expansion and building more plants around the country (Kazungu, 2019). The GivePower desalination system uses photovoltaic power in small-scale, where the solar cells are installed in a container. In addition, it has a micro off-grid plant that depends on battery-stored power to desalinate water even after sunset or in the absence of solar irradiation. The Kenyan government has partnered with Almar Water Solutions and Aqua Swiss companies from Spain and Switzerland, respectively to construct two desalination plants (Ignatius et al., 2018). One of the plants will be at Mombasa Island and has a capacity to desalinate 100, 000 m^3 water daily while the other located at Likoni mainland, has a capacity to desalinate 30, 000 cm^3 of water daily. The project costed $157 million and was expected to be completed by 2021. Once fully operation, the two plants will provide water to more than 1 million people of the Kenyan coast.

A neighbouring county to Mombasa, Lamu, already has an operational desalination plant built through a partnership with the county government and Ente Nazionale Idrocarburi (ENI), which is an Italian oil company (Towett, 2019). The project that costed $200, 000 has been providing water to more than 10, 000 Lamu residents. In Lamu county of Kenya's coast, the uptake of desalination in small-scale by private owners and hotels is growing (Munda, 2018). The trend is affiliated with the long distances of more than 5km travelled to access clean water and the high cost associated with its desalination (Munda, 2018). A German company, Boreal Light hoped to set up 19 water desalination plants in Kenya's Nairobi and Lamu counties by 2019 to meet the rising water demands in the regions using solar power (Adele, 2019). The company is piloting similar projects in Mombasa, Nakuru, Wajir, Turkana and Kwale counties that face endemic water problems. In Kilifi, a desalination plant costing $3.2 million and a capacity of 3,000 m^3/day began operations under the Metito limited of Dubai and Centum investment firm (Gosen et al., 2018; Leijon et al., 2020). The project is providing freshwater for residents and manufacturing companies of the county's Vipingo estate. According to Adele (2019), water desalination using affordable RO systems on ad hoc basis is underway at rural areas of Kenyan coast (Adele, 2019). These systems have the capacity to produce 3, 500 litres hourly and are solar-powered.

Apart from the gains from the desalination projects by government, private and non-governmental organisations that are currently underway, the opportunities for the growth of this practice in Kenya are evident. This is through the coupling of renewable energy such as geothermal, solar, wave and wind energy in desalination systems, which hold great potential in alleviating existent water insecurities. According to (Goosen et al. (2018), Kenya and other developing countries that have geothermal power can use it for thermal desalination to supply water to small-scale users. Another study explored the use of wave power (Francisco et al., 2018; Leijon et al., 2020) and solar power (Salinas et al., 2021) to run RO desalination projects for off-grid areas of Kenya's Kilifi County. The studies reported high potential in using the renewable energy sources to enable water desalination and recommended uptake of the practice at field scale. The feasibility study specifically established that with 10 wave energy converters that have a 30% capacity and consume 3 kilowatts hourly for every m^3 saline water, more than 5, 000 residents could be supplied with freshwater (Francisco et al., 2018). For 7 kW wave energy transformers, RO systems were found to desalinate 536 litres of seawater a day (Gao et al., 2017). These projects are opportunities that the country can leverage to implement sustainable desalination and improve on its water supply and management amidst shortages due to climate variability. Overall, Kenya's seawater desalination capacity was rated among the best in sub-Saharan Africa behind South Africa and Namibia with a capacity of more than 20,000 m^3/day (Dhakal et al., 2014). The desalination systems used were based on RO and resultant water was mainly used for drinking and industrial processes in small-scale (Salinas et al., 2021; Leijon et al., 2020).

6. Challenges of Desalination

Desalination has great potential to improve water security in developing countries including Kenya since it is independent of the natural hydrological cycle making its uses diverse especially in coastal areas (Gao et al., 2017; Pistocchi et al., 2020). However, desalination processes are operationally, energetically and chemically intensive when implemented in large scale and they require high capital expenses, advanced engineering expertise and infrastructural technology to successfully run (Dhakal et al., 2014; Alkaisi et al., 2017; Curto et al., 2021) In Kenya, these technological and infrastructural advancements are not readily available and the country has to outsource expertise from other developed countries making the desalination technology used, which makes the resultant product expensive. Gao and others (2017) suggested that the main challenge in desalination implementation in developing countries is their high operation and management expenses, which are incurred by water consumers making the resultant product less affordable. Similar studies have reported that the high capital and installation costs for setting up desalination units as the limiting factor to their wide spread use in developing countries (Curto et al., 2021; Elsaid et al., 2020; Colagrossi, 2019).

Desalination processes also have negative effects to the environment including increased greenhouse gas emissions (GHGs), chemical and concentrate discharge, which is known to escalate marine pollution (Alkaisi et al., 2017). The use of fossil fuels in energy-intensive desalination processes results to emission of GHGs such as NO_x, SO_x and Co_x and therefore, the results have massive carbon footprint (Curto et al., 2021). In addition, the processes release hot brine that consists of noxious pollutants. Once disposed in the sea, the by-products increase turbidity, current, temperature and salinity of seawater in addition to harming marine environment. The presence of tiny molluscs, nematodes and algae as well as migration of fish have been associated with the effects of disposal of desalination wastes (Mannan et al., 2019). The intensity of the environmental impacts varies and is dependent on the physicochemical characteristics of the feedwater, the technology applied to desalinate and the management approach of the resultant brine (Mannan et al., 2019; Elsaid et al., 2020). Desalination processes such as RO have issues related to the materials used, chemical additives during the process, disposal of waste and recyclability of its equipment's elements (Waly, 2011). A previous studies explored the challenges of desalination processes summarises them to the problem of managing resultant brine, which causes fouling and its return to the sea that has negative effects on marine systems (Logan, 2017). In another study holding similar opinion, desalination processes around the world are reported to produce approximately 142 million m^3/day of brine whose hypersaline nature has negative impacts on the land and water resources once it is disposed (Jones et al., 2019).

To address these challenges, Kenya must increase investments towards safe and sustainable desalination techniques whose effects do not affect other environmental processes. Logan (2017) for instance suggested the preference to ED and deionisation processes rather than RO-based desalination that causes extra fouling and pushes feed-water through membranes. Jones and others (2019) suggested the need to develop desalination facilities further for sustainable practices that manage brine effectively with minimal environmental impacts. Other studies suggested the adoption of green energy sources such as wave energy, wind and solar energy in desalination processes to make them energy efficient and affordable (Angelakis et al., 2021; Leijon et al., 2020). Once powered by renewable energy, desalination technologies can be enhanced to zero carbon footprint especially if the resultant water is used for irrigation (Esmaeilion et al., 2021). This is because such advances augment the water cycle and reduce groundwater abstraction, which has positive effects to climate change adaptation and mitigation. It has also been suggested that produced brine and brine waste can be recovered for energy re-generation and use and nutrient mining to reduce volumes diverted for disposal (Sharkh et al., 20220). Apart from reducing the negative effects of wastes, such undertakings create new sources of valuable minerals, which are sustainable. In a long-term study at a desalination plant in Spain, prior planning and implementation of brine dilution before discharge was found to be environmentally friendly since it had incremental effects on fishes, plants (*Posidonia oceanica*) and animals (echinoderms) especially in the vicinity of brine disposal areas (Sola et al., 2020). If adopted, these measures will enhance the feasibility and uptake of desalination technologies in water scarcity management in Kenya while offsetting its associated high costs and the expected effects on ecosystems.

7. Conclusions

Developing countries such as Kenya face water insecurity, which is an impediment to sustainable development. The situation is propagated by both physical and economic water scarcity. To reverse the situation, advances such as desalination of seawater, which is a viable alternative source of water amidst depleting freshwater resources and with climate change effects could be used. In this study, the application of desalination technology to source for alternative water source, the methods used in the technology and its application at global and in the case of Kenya was explored. Findings showed that processes of desalination apply both membrane and thermal distillation processes as well as hybridized technologies using renewable energy sources such as solar, wind and wave power. Many water stressed nations of the world especially in the Sahel region and Asia have taken up the technology in large-scale. Many coastal counties of Kenya including Mombasa, Kilifi, Taita Taveta, Lamu and Kwale counties have taken up desalination technology at both large and small-scale capacities to improve access to clean water. The practice is also expected to expand to other offshore counties that have saline water sources. Despite the great opportunity that desalination projects provide with reference to enhanced clean water access, such initiatives incur huge capital and installation costs, are energy intensive and produce brine. The energy and waste intensive nature of desalination has negative environmental effects, which accelerate GHG emissions and climate change. In recognition of these challenges, Kenya should increase technical, financial and human capacity investments in desalination technologies to implement cost effective and safe processes that promote sustainable ecosystem management. The processes include prior planning of brine management and dilution before operationalizing desalination plants to prevent pollution, use of renewable energy rather than fossil fuels to run desalination systems to control the resultant greenhouse effect, hybridizing membrane and thermal desalination technologies for better efficiency, expanding the use of desalination technology to offshore areas with saline water to enable universal access to safe water and use of brine waste to recover valuable minerals and energy rather than disposing it to the environment.

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