Increasing Clean Water Access in Kenya Using Reverse Osmosis

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ABSTRACT

In a country of 40 million people, 43% (17 million) of Kenya's population do not have access to clean water (Marshall, 2011). Kenya's climate is varied, but many regions are dry and suffer due to lack of clean and accessible potable water. Average annual precipitation of only 10 inches nationally can also heighten the effects of global warming and increase the danger of droughts on the population (*Kenya Climate*, n.d.). However, improving water filtration, by using systems like reverse osmosis (RO), can help mitigate the water crisis in Kenya. Moreover, Kenya also lacks proper infrastructure for wastewater treatment and transport. RO systems filter unclean water through a semipermeable membrane, removing unhealthy contaminants, leaving pure and drinkable water. This paper will explore the implementation of RO systems on the coasts of Kenya to filter seawater and improve the water resources in Kenya, while accounting for the economic feasibility and potential impacts of this proposal. It is presented that the future installation of optimal RO systems in Kenya will provide its population with improved and more accessible drinking water. These findings could also facilitate the implementation of such projects in other countries.

1. INTRODUCTION

Kenya's current water resources come from five main watersheds with small catchments in areas of the country that have humid climates. Catchments are defined as a land area that collects water from the surface and underground and drains it into streams, rivers and other bodies of water. As seen in **Figure 1**, the watersheds are located in Mt. Elgon, Cherangani Hills, Mau Forest Complex, Aberdare Ranges, and Mt. Kenya, all feeding into major lakes and rivers, such as Lake Victoria, Lake Nakuru, Lake Naivasha, Lake Baringo, Lake Natron, and Lake Turkana. These catchments distribute 75% of Kenya's surface water resources. However, the catchments are unevenly distributed across the country, as they are mostly located in the southwestern parts , which leads to unequal water access across Kenya's population (Mulwa et al., 2021). Despite the western region having access to freshwater, Kenya's rising population, particularly in the east, has led to an unbalanced water supply and demand.

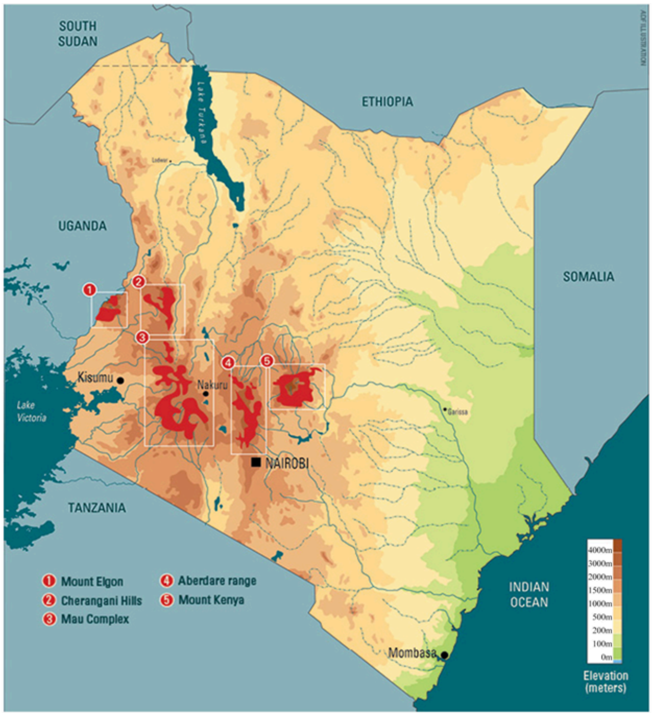


Figure 1: Topographical map depicting Kenya's fresh water supply in which the red shaded regions indicate the five main water catchments. Water catchments are located in the regions above 3000 m in elevation. The blue lines represent the contributing rivers to the water catchments. Image courtesy of (Mulwa et al., 2021)

In addition, the lack of investment in Kenya's water infrastructure has led to inadequate wastewater treatment systems. The improperly treated wastewater is then discharged into rivers, leading to environmental harm like ecosystem degradation and human health issues. A study in 2014 showed that 31.6% of Kenya's population drink from poor water quality sources that are contaminated with fecal matter. From this 31.6%, 7.3% is from unmonitored well water that is not treated, 4.4% is from untreated springs, 1.5% is from tanker trucks or carts with drums, and 18.4% is from surface water (Mulwa et al., 2021). Rural areas are especially limited to substandard water sources compared with urban populations. Notably, 85.7% of the urban population has access to improved water drinking sources that are sufficiently treated compared to only 41.5% of the rural population, which make up around 70.48% of Kenya's total population. (Mulwa et al., 2021). While clean water accessibility exists in urban areas, it is exacerbated in rural populations. Currently, water kiosks and vendors are sources of water with the addition of wells and handpumps, due to limited piped water supplies. The lack of equal water distribution infrastructure has led to increased times to fetch water from those distribution meeting points. For example, in the Kenyan port city of Kisumu, poor households have to spend an average of 112 minutes per day fetching water and around 200 minutes per day during dry seasons and scarce times (*Water Supply and Sanitation in Kenya*, 2024).

The National Environmental Management Authority (NEMA) coordinates environmental management activities and examines their impacts on the environment and resources in Kenya. Currently, Kenya's wastewater treatment does not meet NEMA's standards, threatening and disrupting the population and environment. For instance, in Nairobi, Kenya's capital city, most industrial, agricultural, and municipal wastewater is directly released into the environment, such as lakes or rivers. Pollution in these water bodies contain high levels of pathogens and microorganisms from the discharged wastewater as well as Nairobi's unsafe garbage collection practices. The inadequate sewage disposal points and lack of proper sanitation lead to environmental degradation and harm (Kilingo et al., 2021).

For example, Rivers like the Nairobi River are an important source of water, with one study determining that over 100,000 people use untreated water for daily necessities in the capital city (Kilingo et al., 2021). In the Kibera region, a slum in Nairobi, the region depends on wastewater for farming as there is no other adequate water supply in the area. Discharging such nutrient rich water from agriculture fields can lead to eutrophication, such as algal blooms that remove oxygen from the water and harm water ecosystems (Trotta et al., 2024).

Societal impacts from the lack of access to sufficient clean drinking water around the country is generational and along gender lines. Women and children are forced to travel for water, and children, particularly girls, often miss school for this task (Haushofer et al., 2021). In poor areas, diarrhea and other water borne diseases result from the consumption of unsafe drinking water. Specifically, Kenyan children under the age of five struggle the most, as an estimated 400,000 children die from diarrhea each year due to unsafe and infected drinking water (Haushofer et al., 2021). The Disease Control Priority Project shows that 90% of deaths in Kenya can be avoided with safe and improved hygiene and water (Mulwa et al., 2021).

Additionally, the growing population in Kenya puts further pressure on the water resources of Kenya. With the population rising significantly since 1948, up to 53 million in 2022, (seen in **Figure 2**) the challenge of providing sufficient access to clean water is only intensifying (Mulwa et al., 2021).

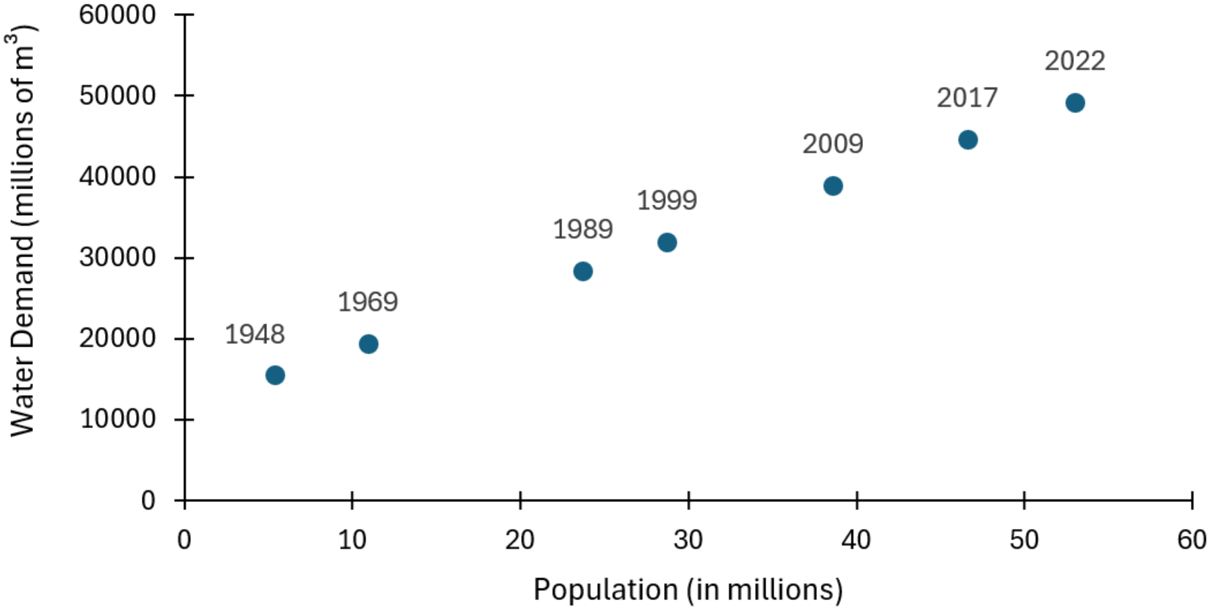


Figure 2: Population growth in relation to the total water demand across Kenya. The graph shows the population at a specific year (shown in the data label) against the water demand (in 10^6 m^3). In addition to the increasing population, the water that is being used is polluted.

This paper outlines drinking water challenges in Kenya and how the incorporation of reverse osmosis (RO) systems in coastal areas of Kenya could contribute to a more reliable water scarcity solution in the nation. The paper will provide an overview of the RO treatment process, discuss maximizing efficiency while lowering costs, address the legal, environmental and economic policies to apply RO in Kenya, and examine the optimal places to install these treatment systems. Additionally, it will be argued why RO is the suitable choice in comparison to other treatment methods.

2. REVERSE OSMOSIS FILTRATION

Reverse osmosis (RO), which utilizes a semipermeable membrane to remove contaminants from water, is a dependable way to provide clean water using seawater. RO is based on the process of osmosis, where less concentrated solutions migrate to more concentrated solutions. A high pressure pump applies pressure to the more contaminated side of the membrane and forces the water through the semipermeable membrane, filtering out contaminants and leaving essentially pure water.

RO desalination has been increasingly deployed due to its simple and reliable operations and maintenance. Since RO membranes were discovered in 1748 and first utilized in 1949 (Olszak, 2020), the design of the RO system has been optimized, allowing for thriving international supply chains of components, such as pre-filters, pumps and cleaning chemicals. Additionally, the system can be easily scaled due to the modular elements that can work in parallel or in series. The desalination process is a stepwise process that includes the feedwater intake system, pretreatment, the reverse osmosis desalination separation system, post-treatment, and concentrate management.

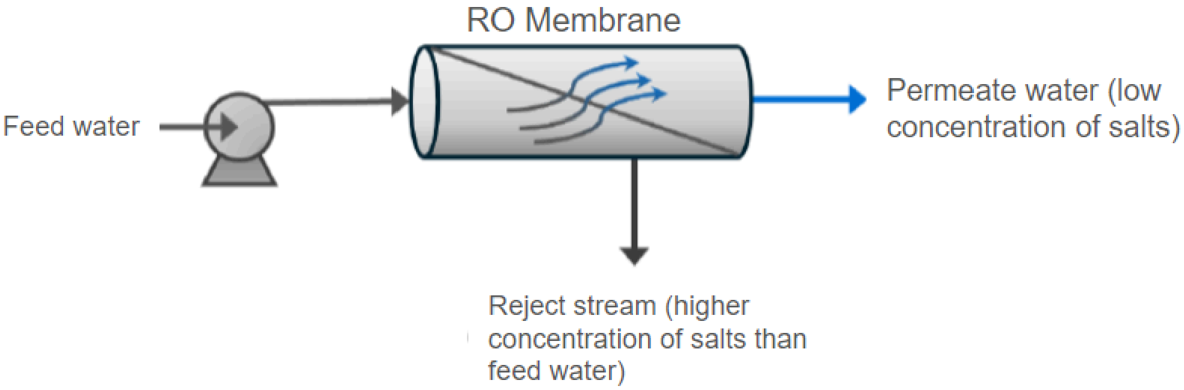


Figure 3: Simplified schematic of the reverse osmosis process, displaying the feedwater traveling through the RO membrane where contaminated water is filtered to create permeate water, and water containing salts and contaminants is rejected as brine (*The Basics of Reverse Osmosis*, n.d.).

2.1. PRETREATMENT

Pretreating feedwater is crucial in ensuring that the RO system will function properly, not be damaged, and last as long as possible. Even though many of these contaminants cannot be seen by the human eye and are harmless when consumed by humans, they can still block the RO membrane surface and damage the other parts of the system. Contaminants include colloidal matter (clay, dirt, etc.), organic matter, inorganic compounds, and microorganisms. Bacterial microorganisms are one of the most common fouling contributors because the membranes cannot tolerate hash chemical cleaning, resulting in microorganisms surviving and multiplying.

Additionally, scaling occurs when concentrated inorganic compounds exceed their solubility limits, precipitating on the membrane's surface and lowering its removal efficiency. The most common example of this is calcium carbonate, which is present in seawater, as it is the main material that makes up shells and rocks in oceans. When temperature increases, the solubility of CO_2 present water decreases, causing the formation of insoluble calcium carbonate (Neils, n.d.).The combination of foulants on the membrane surface can cause back pressure, or pressure applied to create a hydraulic flow, damaging an RO's membrane (The Basics of Reverse Osmosis, n.d.). Fortunately, there are methods to prevent fouling.

Common pretreatment methods to prevent fouling include granular activated carbon (GAC), multi-media filters (MMF), microfiltration (MF), scale inhibitors, and sodium bisulfite. Firstly, GAC filters can remove organic contaminants as well as residual disinfectants like chlorine from the feed water. A chemical reaction involving the transfer of electrons from the GAC surface to the chlorines creates a chlorine ion that no longer oxidizes and harms the membrane. Moreover, multi-media filters can prevent organic fouling. These filters contain 5 layers: a larger layer of anthracite coal on the top, followed by sand, two layers of garnet, and a layer of gravel at the bottom. Larger, lighter media is at the top, and heavier, smaller media is at the bottom to remove contaminants of decreasing size as the water flows through the filter (see **Figure 4**). Standard MMF filters can remove particulates down to 15-20 microns. Comparatively, a human hair is 50 microns. These types of filtration systems are an important pretreatment step to ensure that the RO system functions efficiently by reducing the fouling potential of the RO system (*The Basics of Reverse Osmosis*, n.d.).

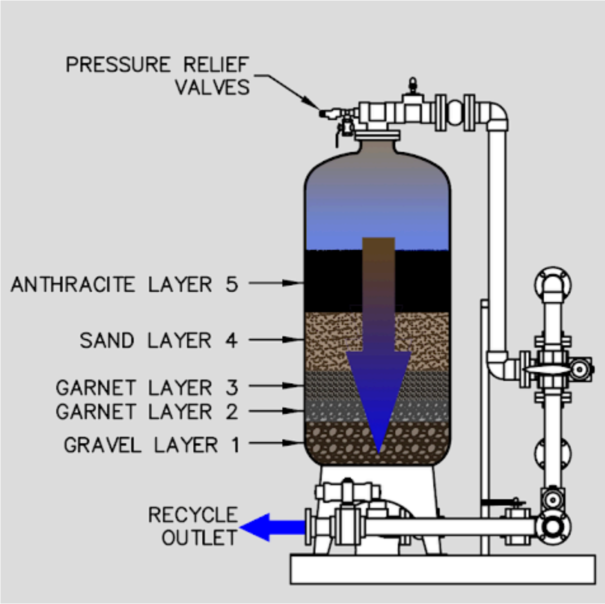


Figure 4: Multi-media filter (MMF) where water enters at the top, passing through multiple sediment layers. The top layer is typically filled with a large layer of anthracite coal, with sand as the next layer. There are then two garnet layers, followed by the last layer of gravel, removing contaminants 15-20 microns in size. Larger particulates in the water are filtered out, with water released through the recycle outlet (*Multi-Media Filters (MMF)*, 2017).

Microfiltration (MF) membranes are also efficient in removing colloidal and bacterial matter between 0.1-1 microns, as seen in **Figure 5**. The hollow fiber MF membrane is the most utilized, where pumps draw water outside the fibers and clean water collects in the fibers. Microfiltration membranes have a recovery rate greater than 90%. MF membranes are preferred as a first step in the pretreatment process over membranes with smaller pores as they can remove larger particles and bacteria, which reduces fouling for the RO membranes by reducing the buildup of these bigger contaminants.

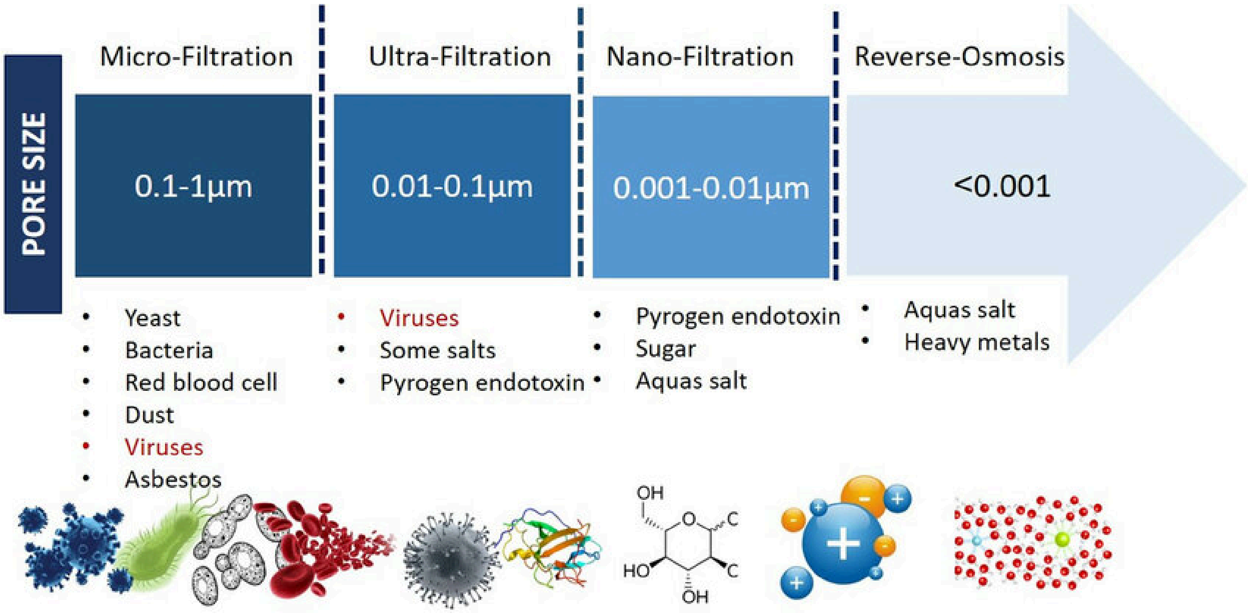


Figure 5: Feedwater filled with contaminants passes through the four membranes of different pore size. Contaminants are filtered out in descending size (*What Is Membrane Filtration?*, n.d.).

To mitigate scaling by increasing the solubility of inorganic compounds, antiscalants, which are also known as scale inhibitors, are added. Solubility of an inorganic compound is determined by the maximum amount a solute can dissolve in a solvent (like water). Antiscalants are chemicals that are added to increase the solubility of inorganic compounds, interfering with scale formation and mineral growth. This allows for a higher recovery rate. Water softening also prevents scaling, where ions in contaminated water exchange the scale forming ions, like calcium, with non-scale forming ions, reducing compound build up on the membrane (*Water Formed Scale*, n.d.). Additionally, pretreating water with sodium bisulfite can reduce the chlorine that is present in seawater, as chlorine can damage the membrane when added before being processed through the RO system (*The Basics of Reverse Osmosis*, n.d.). Chlorine originates from dissociated salts, such as sodium chloride, causing the chloride ions to become an elemental chloride gas (*Chloride and Salinity*, 2011).

2.2. RO PROCESS

In the RO treatment system, feedwater from surface water or seawater is pumped to the plant. The water is then pretreated, removing the suspended solids, organics, and microorganisms to prevent fouling, including inorganic scaling. After the pretreatment processes, desalination occurs, where the water flows through an RO membrane that rejects inorganics, heavy metals, small organics, viruses and bacteria.

The rate that water flows in a RO system (product water flux (J_w)) is determined by the difference between the applied pressure (ΔP) and the osmotic pressure ($\Delta\pi$). The product water flux can be shown through the expression

$$J_w = L_P(\Delta P - \sigma\Delta\pi) \qquad (1)$$

where L_p is the permeability of the membrane and σ is the reflection coefficient (generated osmotic force) (Cohen et al., 2017).

Most RO systems use membrane channels in a cross flow operation (i.e., water across the membrane instead of into the filter) to reduce the concentration of foulant buildup on the membrane. Concentration in the discharge stream increases as it flows downstream along the membrane channel. For example, if the recovery of seawater in an RO system is 45%, 55% of the processed feed volume will be discharged with a salt concentration of a factor of 1.55 above the raw feedwater (Cohen et al., 2017).

Membrane elements are normally multiple membrane sheets arranged to form flow channels where pressurized feed water flows. These elements are inside of pressure vessels, allowing up to a maximum pressure of 1200 psi. To avoid wasting energy on increasing pressure for the discharge stream, energy recovery devices (ERDs), such as pressure boosters, can be incorporated into RO systems . These can reduce the energy consumption of RO systems, a large factor in implementing RO systems in certain locations (Cohen et al., 2017). Cleaning is a crucial process to maintain efficiency in RO systems. The use of low and high pH cleaners to address scaling and colloidal or organic matter build up on the membranes will ensure better efficiency and proper function.

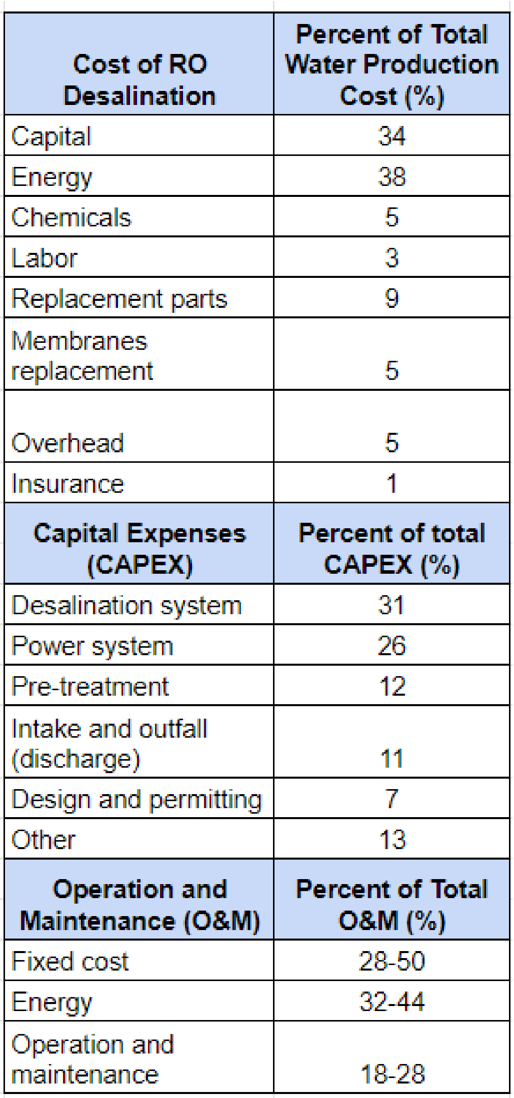
After the desalination process, rejected water is discharged, while the admitted water is then post-treated, removing micropollutants. Water is remineralized to add flavor, and the treated water is disinfected to remove bacteria and viruses that can be present in the distribution system. However, in a place like Kenya, a place without proper wastewater infrastructure, the brine discharge from the rejected water is still a large factor that needs to be addressed. However, the brine can be discharged through outfall systems, which are pipelines that release highly concentrated brine from desalinated water into the ocean.This system disperses the concentration in a manner that lowers the impact of the increased saline water and ensures that environmental considerations, like the salinity tolerance of the ocean organisms, toxicity levels, long-term growth in the water's salinity levels, and effluent water quality are respected. Since inland discharge makes the disposal process of brine much harder, having RO systems along the coast would ensure a better discharge process that reduces the environmental degradation and harmful wastewater impacts on inland bodies of water (Cohen et al., 2017). Ultimately, RO can be used to desalinate water, which is the removal of salts and other contaminants from water. Since the membranes can filter out over 99% of the dissolved ions that are present in seawater, the filtered water is potable and is an immensely available resource (Cohen et al., 2017).

2.3. COST OF DESALINATION RO SYSTEMS

An important factor in implementing desalination RO systems is the cost. The cost to produce water through RO desalination plants includes total energy consumption, equipment, membrane replacements, residual concentrate (discharge/brine), management, labor and maintenance. These costs vary due to location, plant size, quality of the source, and the local electrical energy cost.

In traditional RO desalination plants, energy and capital costs) account for the majority of the costs along with operation and maintenance costs (seen in **Table 1)**. The total energy consumption for a seawater RO desalination plant includes the desalination stage and discharge stage, which consumes 67% of the energy, the RO feed pre-treatment (13%), the intake (7%), and the post treatment (13%). RO systems are energy intensive, but the cost of desalination via RO is not as high as other alternative water sources as seen in **Figure 6** (Cohen et al., 2017).

Table 1: Capital expenses (CAPEX) of RO systems and Operation and Maintenance costs (O&M)



Cost of RO Desalination	Percent of Total Water Production Cost (%)
Capital	34
Energy	38
Chemicals	5
Labor	3
Replacement parts	9
Membranes replacement	5
Overhead	5
Insurance	1
Capital Expenses (CAPEX)	**Percent of total CAPEX (%)**
Desalination system	31
Power system	26
Pre-treatment	12
Intake and outfall (discharge)	11
Design and permitting	7
Other	13
Operation and Maintenance (O&M)	**Percent of Total O&M (%)**
Fixed cost	28-50
Energy	32-44
Operation and maintenance	18-28

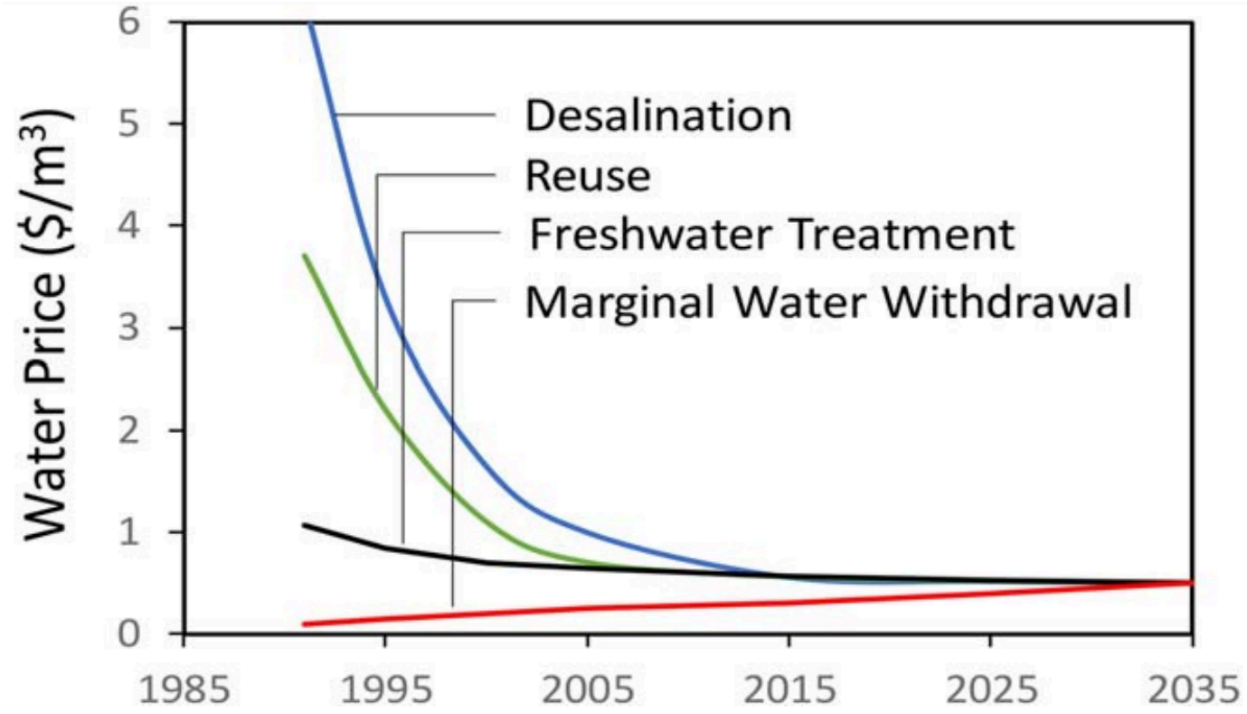


Figure 6: Seawater RO desalination (blue) costs over time compared to wastewater reuse (green), freshwater treatment (black), and marginal water withdrawal (red).

RO has become cheaper over time, leveling itself with many other water treatment methods used to purify and supply water for people. However, due to the purity of the water that RO produces, it is the better option to implement in places like Kenya, which struggles with water that is adequately clean and accessible.

The minimum energy consumption for RO systems with an efficient pumping system is 3.2 kWh/m^3 (Kilowatt hours per cubic meter). With an efficient ERD (energy recovery device), the energy consumption can be as low as 1.6 kWh/m^3 (Cohen et al., 2017). To put this into perspective, average 1000 ft^2 homes in the world use around 32 kWh per day (*How Many KWH Does a House Use on Average Per Day?*, 2023).

2.4. IMPROVEMENTS TO THE DESALINATION RO SYSTEM

RO system designs improve over time, lowering the cost and energy consumption of these systems, which are the biggest factors limiting the application of RO globally. For example, more effective energy recovery processes and improving membrane element designs could reduce the energy consumption and costs while also improving the system efficiency (Okampo & Nwulu, 2020).

Methods of plant fault detection are also emerging to reduce maintenance costs due to plant malfunctions. Additionally, self-adapted pretreatment solutions are being employed to lower the pretreatment costs of chemical additives and reduce the number of membrane cleanings (Okampo & Nwulu, 2020).

However, even with these improvements, the energy consumption, and therefore cost, is still high. Incorporating renewable energy sources like wind and solar power can cut down the energy costs of RO systems (Okampo & Nwulu, 2020). Wind and solar power can be optimally scheduled with time of use, the demand of water, and the consideration of carbon emissions to lower the energy costs compared to if traditional energy sources, such as fossil fuels were used. This design would be also powered by the power grid as a backup to the load demand of the RO desalination unit or when wind and solar energy sources are not available.

On the other hand, when there is excess energy from the high output of the wind and solar energy sources, this excess energy can be given back to the electrical grid. This relationship creates a balanced, energy efficient system, keeping energy costs down by utilizing renewable energy sources and reducing the risk of providing sufficient energy to keep the treatment system operational. Additionally, the maximum transferable power from both the importation and exportation of energy from the power grid is assumed to be equal as shown in the following expression:

$$(GP_i)^{max} = (GP_e)^{max} \qquad (2)$$

GP_i^{max} is maximum energy from the grid to the design, and GP_e^{max} is the maximum energy from the design back to the grid. This means that the most energy that the grid could “give” to the design is the same as the most amount of energy that the design could “give” back to the design, highlighting the balance in the energy efficient design between the grid and the design. The cost of the grid power depends on the energy price and the difference between the energy given to the design from the grid and the energy given back to the grid from the design. Therefore, since the cost of purchasing energy from the grid and selling energy back to the grid is equal, the potential costs of getting energy from the grid to keep up the energy of the RO desalination system is compensated when the system's excess energy is sold back to the grid, or at least reduced (Okampo & Nwulu, 2020).These costs can be expressed as:

(3)

This equation represents the imported energy, where CGP (Cost of Grid Power) is the total annual cost of transferable grid power and P(t) is the hourly price. The exported energy is given by:

$$CGP_e(t) = GP_e(t) \times P(t) \qquad (4)$$

The total cost can then be expressed as:

$$CGP = \Sigma(CGP_i(t)\ x\ P(t)\ -\ GP_e(t)\ x\ P(t)) \qquad (5)$$

in which the total annual cost of transferable grid power equals the sum of the grid power given to the system times the hourly rate subtracted by the grid power given back to the grid times the hourly rate of the grid power (Okampo & Nwulu, 2020).

3. IMPLEMENTATION IN KENYA

3.1. WATER TRANSPORTATION

Currently, Kenya’s water infrastructure uses mostly surface water and groundwater from the drainage basins, as seen in **Figure 1**. However, the water distribution is uneven across the catchment areas. For example, the Athi drainage system from Athi River has the lowest water availability, and Nairobi receives its water from two main drainage systems: the Kikuyu springs and the Ruiru Dam located in the Athi River Basin (*Water Supply and Sanitation in Kenya*, 2024). Only the Tana and Lake Victoria Basins have extra water availability, while all other basins face deficits.

Currently, however, Kenya has many water pipelines along the coastal regions of Kenya, such as the Mzima, Baricho, Marere and Tiwi. For example, the Likoni pipeline provides water for the coastal regions and cities like Klifi and Mombasa. These pipelines are maintained by the Coast Water Works Development Agency (CWWDA), who ensures that leaks and bursts are detected and managed to eliminate the waste of precious water resources.

Ultimately, Kenya has a sufficient pipe system and water transportation systems to allow for the access of water from coastal RO systems to reach populations in cities and rural areas. However, the implementation of RO systems could require additional pipelines, as there is going to be more water that needs to be transported on top of the existing water, meaning that the pipelines might not have the capacity to carry the amount of water that is produced from the RO systems.

3.2. IMPLEMENTATION POLICIES

3.2.1. CHANGING LAWS AND POLICIES

Kenya, which is dealing with water scarcity all across the country, hasmany different laws which attempt to mitigate and manage their water challenges. In 2010, Kenya passed a constitution stating that every person has the right to “goods and services of reasonable quantity” as well as the right to “the protection of their health, safety and economic interests” (*The Constitution of Kenya, 2010*, 2010). In Article 62, the constitution also states that all water catchments and bodies of water are held by the national government for the people. This means that all citizens of Kenya have the right to clean water access, and laws and policies don’t play a factor in whether or not RO water will be accessible to individuals in Kenya.

On the policies related to implementing RO in Kenya at the county level, the Water Works Development Authority is responsible for developing, maintaining, and managing national public waterworks. They also provide technical services and capacity building to county governments and Water Service Providers (WSPs), which are providers responsible for serving water to their respective areas (*The Constitution of Kenya, 2010*, 2010).

3.2.2. ENVIRONMENTAL POLICIES

When installing large scale projects, the environmental factor always plays a large role in the decision to implement the project. In terms of this RO system, an environmental impact assessment (EIA) is conducted to assess the environmental impact of a certain project. It examines the positives and negatives of the project in relation to the population and the property on which it is conducted. An EIA aims to minimize the negatives in a project while maximizing the positives to ensure a safe and managed implementation of a project. EIAs are conducted during the initial stages of the development of the project, and the assessment decides whether or not the project should be implemented, modified, or rejected. The EIA also considers effects on the population and economy.

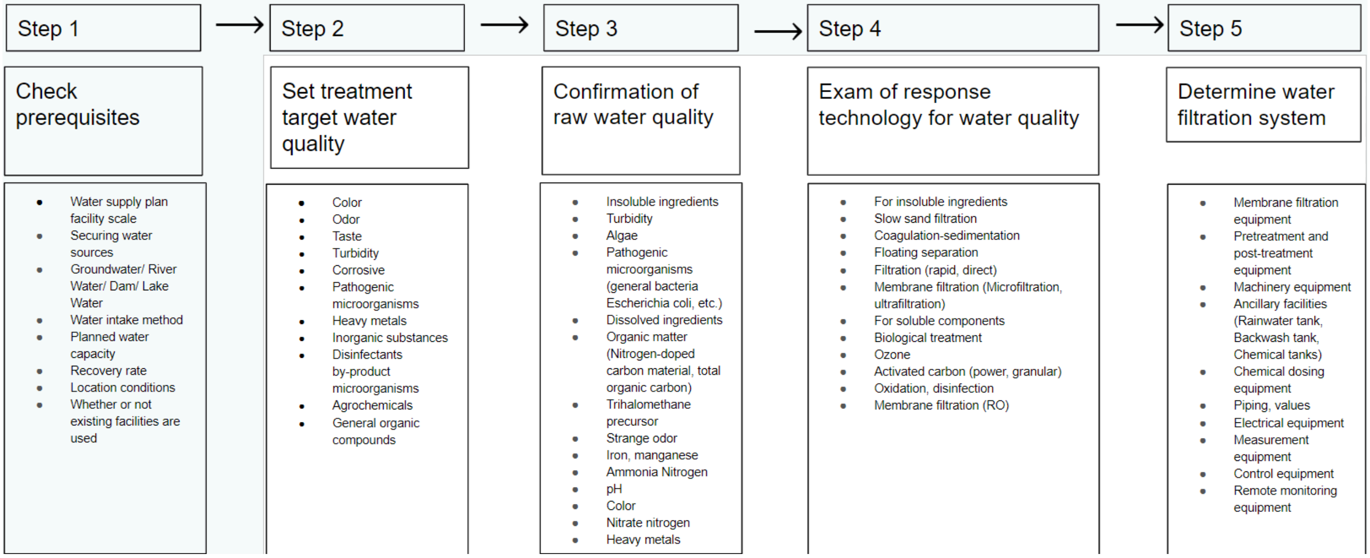
For this particular project about implementing an RO system in coastal areas of Kenya, the impact on water and water sources (the ocean, in this case) in Kenya will be heavily considered, as well as the drainage and wastewater impacts. The EIA process includes submitting a project, and if a study is required due to its likelihood of having an environmental impact, it will undergo a complex process.

First, a Terms of Reference is created for the project, in addition to the gathering of baseline information about the project based on thorough research. The Terms of Reference and baseline information are filled out in a study report, which is then reviewed by the National Environment Management Authority who decides whether the project is approved or not.

The project can then be implemented, where it is monitored and audited. In addition to the EIA, the Water Services Regulatory Board also has a statutory mandate under Section 72 of the Water Act in 2016, which essentially monitors and reviews the regulation of water services to ensure that they are efficient, affordable, effective, and equitable specifically for membrane technology filtration solutions. This includes determining the national standard for the provision of water services, setting and managing water service providers licenses, monitoring the design, constructing, operating, implementing facilities and water strategies for the water provider, and ensuring that the works meet the prescribed standards.

The overall selection procedure of a new water treatment system selection is detailed in **Figure 7** (*Environment Impact Assessment (EIA)*, 2022).

Table 2: Steps of water treatment selection procedure. Examines characteristics of water being treated and the treatment system being implemented to determine if a treatment system is adequate ((*Guideline on the Use of Membrane Technology in Water Treatment*, 2024).



Step 1	Step 2	Step 3	Step 4	Step 5
Check prerequisites	Set treatment target water quality	Confirmation of raw water quality	Exam of response technology for water quality	Determine water filtration system
• Water supply plan facility scale • Securing water sources • Groundwater/ River Water/ Dam/ Lake Water • Water intake method • Planned water capacity • Recovery rate • Location conditions • Whether or not existing facilities are used	• Color • Odor • Taste • Turbidity • Corrosive • Pathogenic microorganisms • Heavy metals • Inorganic substances • Disinfectants by-product microorganisms • Agrochemicals • General organic compounds	• Insoluble ingredients • Turbidity • Algae • Pathogenic microorganisms (general bacteria Escherichia coli, etc.) • Dissolved ingredients • Organic matter (Nitrogen-doped carbon material, total organic carbon) • Trihalomethane precursor • Strange odor • Iron, manganese • Ammonia Nitrogen • pH • Color • Nitrate nitrogen • Heavy metals	• For insoluble ingredients • Slow sand filtration • Coagulation-sedimentation • Floating separation • Filtration (rapid, direct) • Membrane filtration (Microfiltration, ultrafiltration) • For soluble components • Biological treatment • Ozone • Activated carbon (power, granular) • Oxidation, disinfection • Membrane filtration (RO)	• Membrane filtration equipment • Pretreatment and post-treatment equipment • Machinery equipment • Ancillary facilities (Rainwater tank, Backwash tank, Chemical tanks) • Chemical dosing equipment • Piping, values • Electrical equipment • Measurement equipment • Control equipment • Remote monitoring equipment

Kenya’s Community Land Act of 2016 states in Article 35 that natural resources found in community land shall be used and managed sustainability, are beneficial to whole communities, including future generations, and are based on equitable sharing and acquisition. The Public Health Act of 1986 addresses sanitation and hygiene as well as the general health and safety of populations, stating that no person or institution should cause conditions that are liable to human health, such as discharged wastewater(*Environmental Management and Coordination (Water Quality) Regulations,* 2006). In this case, implementing an RO system will have many environmental issues, such as the resulting brine and wastewater and its potential harmful effects on the surrounding environment, as well as the land use and energy consumption. However, with efficient RO systems, efficiently managed wastewater techniques, and renewable energy uses, these impacts can be mitigated, and therefore, should be approved by the Authority and pass the EIA examination.

3.2.3. ECONOMIC POLICIES

There are many economic factors to be considered in the implementation of RO systems. Typically, a 50 million gallon per day seawater desalination plant ranges from around $300 million to over $1 billion, depending on the circumstances of the location in which it is built (Gunnar, 2024). Coastal areas of Kenya will cost somewhere on the higher end due to the lack of existing infrastructure and the need for the additional renewable energy systems, water transportation, and brine and wastewater treatment. Currently, the Gross Domestic Product (GDP) of Kenya is $113.4 billion USD, which is much higher than surrounding countries in East Africa, such as Tanzania or Uganda, which are $75.73 billion USD and $45.57 billion USD, respectively. (Serajuddin & Maeda, n.d.) The GDP being higher in Kenya than other countries increases the feasibility of the implementation of RO in this country compared to other surrounding countries.

Before the COVID-19 pandemic, Kenya's economy was growing with an average growth of 4.8% per year from 2015-2019 (*The World Bank in Kenya*, 2024). Kenya's growth level falls into the lower middle class income level, where the gross national income is between $1,136 and $44,46 per capita 5 (*The World Bank in Kenya*, 2024), but the COVID-19 pandemic heavily worsened the situation. The stop of international trade, transportation, tourism, and urban services worsened their economy.

In 2021, Kenya bounced back with their GDP growing by 7.5%. However, the effects of the COVID-19 pandemic, two consecutive years of drought, a tight monetary policy, and the depreciation of currency still affect the country's economy (*The World Bank in Kenya*, 2024). The government of Kenya has set a target of $12.9 billion USD in order for universal access to water, sanitation, and hygiene services (WASH) by 2030 across the country. However, the national budget of Kenya spent on water infrastructure and supply is only $5.6 billion USD, meaning that $7 billion is needed for Kenya to reach their goal.

Since 2000, the Kenyan government has significantly increased the economic spending on water (*Water, Sanitation and Hygiene Finance*, n.d.). The National Water Master Plan in Kenya, which was released in 2014, invested about $14 billion in the water supply over the next 30 years to around 2030 (*Climate Action in the Water Sector in Kenya- Sector Roadmap*, 2022). Therefore, an investment in energy efficient and low wastewater producing filtration systems could prove to be worth it in the long run to start to bridge this gap by meeting the water access needs and lowering the long term costs of water sanitation and filtration services through the efficiency of RO desalination systems.

3.3. SENSIBLE LOCATIONS TO IMPLEMENT RO

Many coastal areas of Kenya are facing major water shortages, such as Mombasa, Kwale, and Kilifi counties, located on the eastern coast of Kenya. With about one million consumers living in Mombasa County, for example, their water supply deficit is up to 152 million liters per day (*Coast Counties Grapple with Water Shortage*, 2016). Since Mombasa depends on the piped water supply from its neighboring counties like Klifi, Kwale, and Taita-Taveta, Mombasa only receives around 48 million liters of water per day when the demand of water is up to 200 million liters per day (*Coast Counties Grapple with Water Shortage*, 2016).

Therefore, desalination plants would be significantly beneficial in Mombasa county. Implementing an RO system that would desalinate around 100 million liters of seawater per day would be sufficient enough to mitigate this water deficit and provide clean water to the population in Mombasa. This would also take stress off of neighboring counties. The convenient location of these counties (shown in **Figure 7**), next to the Indian Ocean and surrounding canals would allow for these RO systems to desalinate the abundant supply of seawater while keeping the costs of transporting the ocean water lower. The installation of an RO desalination system in this area would be a good start to mitigate the water crisis in Kenya and improve water quality and access for the population along the coast of Kenya.

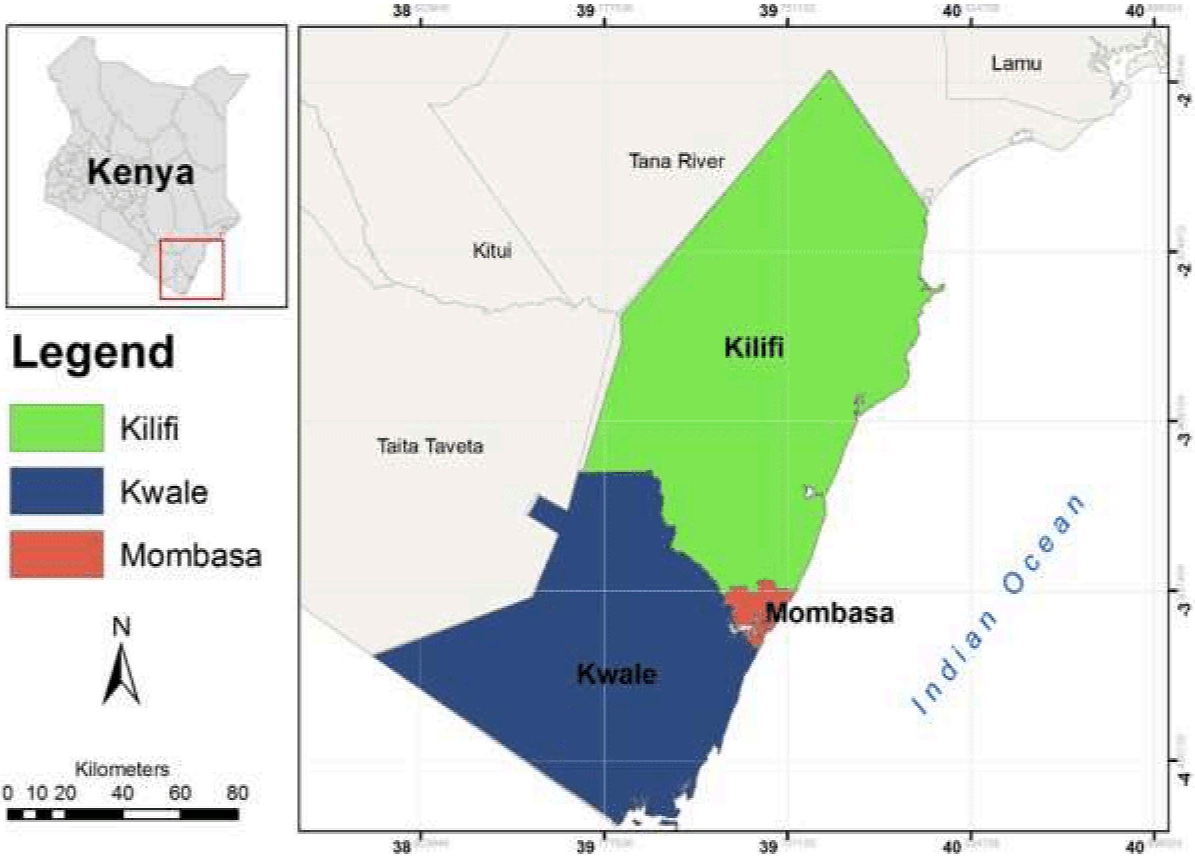


Figure 7: Mombasa (red), Kwale (blue), and Kilifi (green) counties bordering the Indian Ocean, located in the southeastern part of Kenya (Ogega, 2016).

3.4. PERSONNEL REQUIRED TO IMPLEMENT

The design of these systems will require engineers, technicians, quality control managers, technicians, and project managers in order to successfully account for every factor that these complex filtration systems require. These factors include determining flow rates and operating conditions in order to satisfy the demand of water and the operating hours. The membrane module will also need to be determined, depending on the usage and turbidity of the water, where either external or internal pressurized membranes are chosen.

Additionally, the maintenance of physically and chemically cleaning the system is extremely important to the RO systems, particularly the membranes, pipes, and water tanks through which water flows.

Constant monitoring and control equipment and personnel are also required to ensure that the plant is maintaining its production and efficiency. Finally, the power supply equipment and management is important to ensure that the system has the necessary power to function (*Guideline on the Use of Membrane Technology in Water Treatment*, 2024). Ultimately, there are many factors that need to be maintained in order for RO systems to properly function, requiring lots of skilled personnel with the necessary knowledge. However, the investment of these personnel will be advantageous, as these RO desalination systems will heavily support Kenya in the fight against water scarcity as the efficient production of the abundant water source of the ocean will enable this to happen.

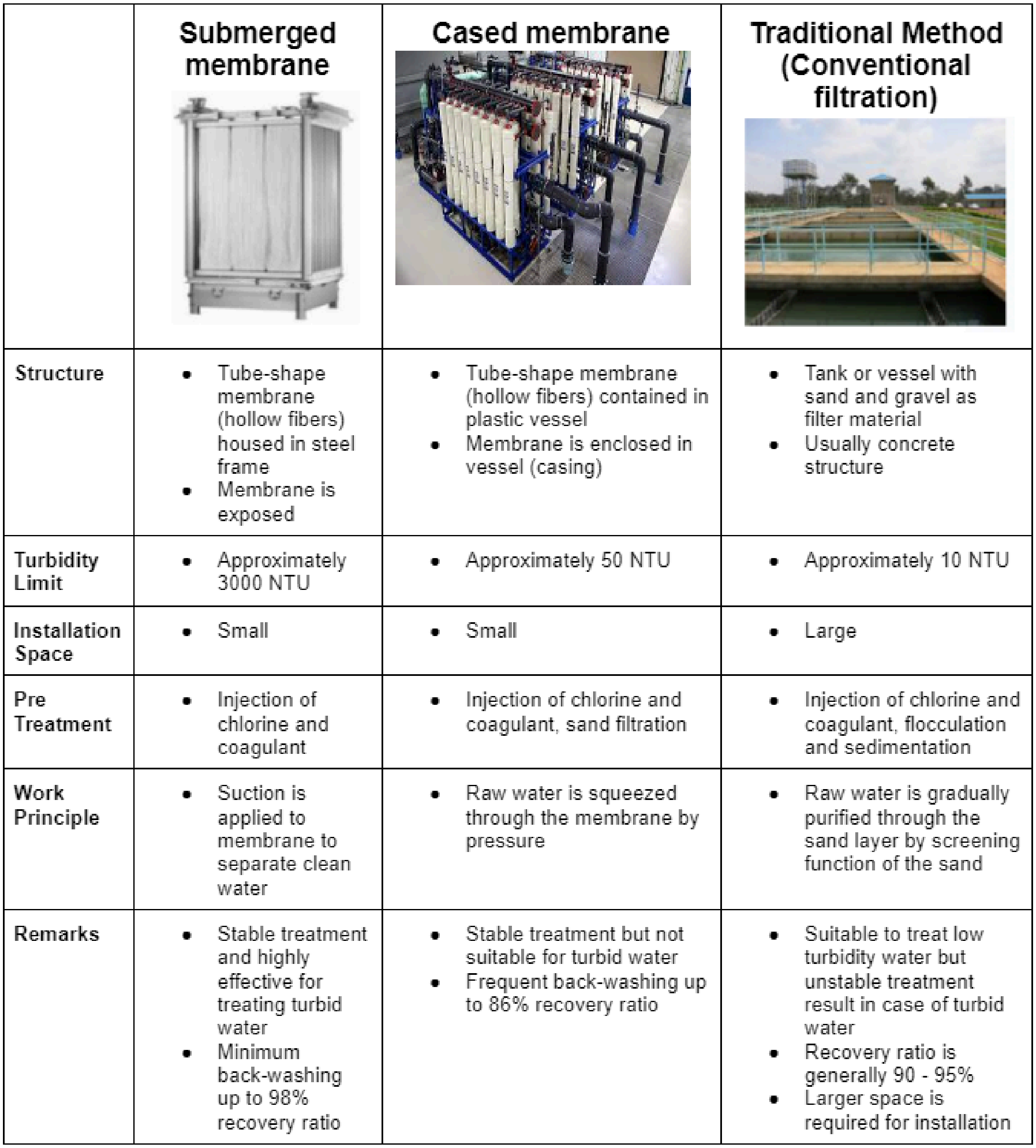
3.5. ALTERNATIVES

There are many alternatives to RO desalination systems that are less expensive and easier to maintain. Conventional water treatment systems include large pools of raw water being filtered through sand and gravel, effectively removing organic and inorganic material in addition to pre treatment using coagulant, flocculation, and sedimentation (*Guideline on the Use of Membrane Technology in Water Treatment*, 2024). Additionally, coagulants can be added to water by causing suspended particles to clump together, which is known as flocculation, and can be removed via settling. Other treatment methods involve adjusting the pH to an optimal level to minimize corrosion and ensure the water is not too basic or acidic (*Guideline on the Use of Membrane Technology in Water Treatment*, 2024).

These methods are much lower in costs than RO systems. For example, the chlorination method can be as low as $0.13 per 1,000 gallon (Raudales et al., 2017), whereas RO systems can cost around $10 per gallon (*How Much Does Seawater Desalination Cost per Gallon?*, 2024). The cost to install large scale raw water treatment systems such as sedimentation or chlorination range between $975,000 to $3 million (*How Much Does an Industrial Water Treatment System Cost?*, n.d.). On the other hand, the costs of RO systems are much higher, and very large systems can range between $300 million to over $1 billion.

However, RO desalination has been proven to outperform these conventional water treatment systems and are more versatile in terms of the water that can be sourced. **Table 3** compares membrane technology to conventional filtration methods, outlining the significant benefits that membrane technology has over these filtration methods.

Table 3: Comparison of membrane filtration technology to traditional filtration methods in Kenya in structure, turbidity limit, installation space, pre-treatment, work principle and remarks ((*Guideline on the Use of Membrane Technology in Water Treatment*, 2024).



	Submerged membrane	Cased membrane	Traditional Method (Conventional filtration)
Structure	• Tube-shape membrane (hollow fibers) housed in steel frame • Membrane is exposed	• Tube-shape membrane (hollow fibers) contained in plastic vessel • Membrane is enclosed in vessel (casing)	• Tank or vessel with sand and gravel as filter material • Usually concrete structure
Turbidity Limit	• Approximately 3000 NTU	• Approximately 50 NTU	• Approximately 10 NTU
Installation Space	• Small	• Small	• Large
Pre Treatment	• Injection of chlorine and coagulant	• Injection of chlorine and coagulant, sand filtration	• Injection of chlorine and coagulant, flocculation and sedimentation
Work Principle	• Suction is applied to membrane to separate clean water	• Raw water is squeezed through the membrane by pressure	• Raw water is gradually purified through the sand layer by screening function of the sand
Remarks	• Stable treatment and highly effective for treating turbid water • Minimum back-washing up to 98% recovery ratio	• Stable treatment but not suitable for turbid water • Frequent back-washing up to 86% recovery ratio	• Suitable to treat low turbidity water but unstable treatment result in case of turbid water • Recovery ratio is generally 90 - 95% • Larger space is required for installation

The table outlines the features that membrane technology offers compared to a conventional filtration method of a large concrete sediment filtration with the chemical pretreatment. Membrane technology, like RO, have higher turbidity limits than conventional filtration systems, meaning that they can filter more water sources, especially water that is lower in quality (e.g., 10 NTU to 3000 NTU). Membrane technology also involves less space, as the conventional sediment filtration requires a larger area due to its slower filtration process requiring water to travel through gravel and sand layers with the force of gravity instead of water being pumped at high pressure. Therefore, less water can be filtered at a time using a traditional treatment system (*Guideline on the Use of Membrane Technology in Water Treatment*, 2024).

4. CONCLUSION:

Accessing clean water and safe drinking water is a major problem faced by almost half of Kenya's increasing population due to the growing environmental problems and inadequate infrastructure and practices. However, implementing an RO system on the coast of Kenya to filter seawater can improve this crisis, which uses a semipermeable membrane that filters out contaminants and salt present in water. The high energy costs of RO systems will be addressed by incorporating renewable energy sources which are abundant off the coast of Kenya, optimizing the energy and lowering the total costs. Currently, Kenya has sufficient water transportation infrastructure to transport water from water sources to coastal cities. However, implementing new systems will require the expansion of current pipelines to maintain the additional water that is being distributed.

The feasibility of implementing these systems will be complex, as the multitude of legal, environmental, and economic policies to implement large scale projects require addressing miniscule details and implications. Kenya's GDP is not high, but their economy is developed enough to start addressing the water crisis through RO. Coastal cities of Mombasa, Kwale, and Klifi face the most significant water shortages, unable to keep up with the demand of water. However, the location of these cities on the coast of Kenya would allow Kenya to implement RO systems to sustain the demand of these cities and provide clean, accessible water. Ultimately, an improved RO system would greatly benefit coastal cities of Kenya to start mitigating the major water shortages in the country and reduce unsafe consumption.

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