SEAWATER DESALINATION PLANT FOR KARACHI

WATER SUPPLY

Project submitted in partial fulfillment of the requirements for the degree of

BE Civil Engineering

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NATIONAL UNVERSITY OF SCIENCE AND TECHNOLOGY

MILITARY COLLEGE OF ENGINEERING RISALPUR

RISALPUR CAMPUS, PAKISTAN (2020)

This to certify that the

BE Civil Engineering Project entitled

SEAWATER DESALINATION FOR KARACHI WATER SUPPLY

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

DEDICATION

SPECIAL DEDICATION TO OUR BELOVED PARENTS, TEACHERS AND ALL THOSE WHO HAVE CONTRIBUTED IN THIS PROJECT AND FOR ECOURAGEMENT AND BELIEF IN US

ACKNOWLEDGEMENT

In the name of Allah, the entirely merciful, the especially merciful. All praises be to Almighty Allah for his blessings, who enabled us to complete our UG project with utmost dedication and professionalism. I thank everyone who helped me in this project without whom this could not have turned into reality. I am greatly indebted to my dear parents particularly my father Lt Col (Retd) Muhammad Aslam who has been a figure of motivation and guidance all my life. Special thanks to my Mother, Wife, Brother and Sister for their unfaltering love, support and prayers. To those who in some way have contributed in this research, your compassion and effort means a lot to us. I want to pay special tribute to my advisor Lt Col Dr. Irfan Abid for his able guidance and directing us towards our goal in a professional and friendly way.

Capt. Muhammad Umar Aslam (Syndicate Leader)

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LIST OF ABBREVIATIONS

ADB – Asian Development Bank

GDP – Gross Domestic Product

MGD – Million Gallons per Day

PCRWR – Pakistan Council for Research in Water Resources

KWSB – Karachi Water and Sewerage Board

CETP – Combined Effluent Treatment Plant

PC – Planning Commission

PS – Pumping Station

ECNEC – Executive Committee of the National Economic Council

OCL – Osmani and Company Limited

NESPAK – National Engineering Services Pakistan

KB – Kalri Baghar

RCC – Reinforced Cement Concrete

CM – Chief Minister

LG – Local Government

BOD – Biochemical Oxygen Demand

SWRO – Sea Water Reverse Osmosis

RO – Reverse Osmosis

CF – Cartridge Filters

MSF – Multi Stage Flash

MED – Multiple Effect Distillation

ED – Electro Dialysis

RES – Renewable Energy Source

VC – Vapor Compression

PV – Photo-voltaic

kWp – Kilowatt Peak

ABSTRACT

Drinking water is the most essential requirement of living beings. Life on earth relies on use-able water. With increase in population, comes increased water demand. Now a days, water shortage is a global issue which requires to be solved. The best possible solution is to make use of sea water as drinking water through desalination. The water-stressed countries are adopting the desalination technique around the globe to overcome the water issues. Water obtained by desalination far exceeds supplies from the freshwater sources. The advancement in technology has allowed us to make the desalination cost effective using modern techniques. The technological advancements in membranes used in Desalination and the equipment and tools used along with integration of energy-recovery devices to reduce electricity demands, and amalgamation of various Desalination techniques into hybrid designs coupled with use of renewable energy sources has made Desalination efficient and cost effective then it was ever before.

Karachi, being the metropolitan city of Pakistan has experienced significant rise in population as well as water demand. Hub Dam stores the main source of water in Karachi, but it is not enough to mitigate the looming threat of water scarcity. Desalination plant along the Karachi coast is one of the best alternative to satisfy our need for water.

In this paper an endeavor has been made to put forth a brief overview of the efforts that have been made in the past and after understanding the present scenario of Karachi and its environmental conditions, a comparative study between various sites, the analysis of cost related to Desalination as well as various renewable energy technologies which power desalination systems along their economics has been carried out.

CHAPTER 1

INTRODUCTION

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1.1. Overview

The world has always revolved around water as the most important substance on Earth. Pausanias, a geographer, around two centuries ago proclaimed that no civilization can call itself a civilization until its center of gravity was water (Tvedt & Jakobsson, 2006). All civilizations emerged and thrived around water. There has been a never ending venture to carry water to cities from Mohenjo-Daro, an Indus valley community, to the metropolitan cities of today. So basically without water there is no life and water is the ultimate sign of life.

Water is essential for all living beings on this planet. Every organism consumes water. Almost 71% of the Earth's surface is covered by water but not all of it is consumable. Out of this, 96.5% of water is found in the oceans which is not drinkable as it is saline and only 2.5% of it is fresh water from which living organisms fulfill their need for water. This need of freshwater is fulfilled from different sources which are as follows:-

- Glaciers and icecaps (68.7%)
- Groundwater (30.1%)
- Surface/Other freshwater (1.2%) which is further composed of :-
  - Ground Ice and Permafrost (69%)
  - Lakes (20.9%)
  - Atmosphere (3%)

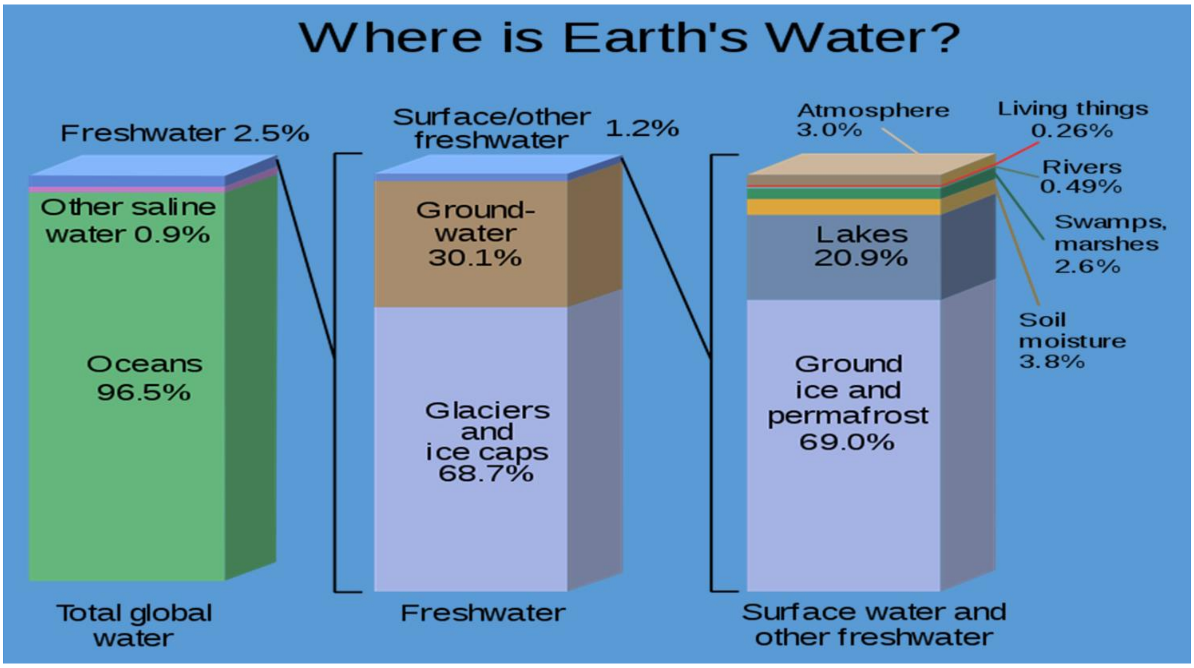


Figure 1.1 Distribution of Earth's water (Gleick, 1993)

The demand of water is increasing at an exponential rate with the rapid growth of population over the past decades or so. This along with the rise in pollution and other environmental hazards have placed immense stress on fresh water resources. This has led to a brisk declination of potable water to an alarming level. "The world is expected to face a 40% shortfall between forecast demand and available supply of water by 2030" (Water Resources Management, 2017). "The lack of fresh water resources to meet the water demand affects every continent and is one of the largest global risks in terms of potential impact over the next decade" (World Economic Forum, 2019).

1.2. Reasons of Water Scarcity

The main reasons causing water scarcity at a global level are:-

- **Population Growth**

With the sharp increase in population the demand for water has multiplied exponentially. This has not only burdened the existing fresh water resources but has also led to a rapid depletion of this asset leading towards water scarcity.

- **Spatial Distribution of Water**

The global fresh water is irregularly dispersed over different regions of the planet. Some areas lack fresh water and are barren and arid while others have lakes, glaciers and other fresh water sources.

1.3. Water Scarcity in Pakistan

Pakistan is one of the most water-scarce countries in the world with less than 1,000 cubic meters of water per person per year (Asian Development Bank, 2013). Most of the country is suffering from lack of supply of fresh water for drinking, cleaning and washing purposes. The country has also been put under stress by its neighbour as the major rivers that run into Pakistan are now being controlled by India. This has not only become a serious concern for authorities but forced our think tanks to raise matters in the United Nations and look for solutions. Moreover lack of storage reservoirs, outdated irrigation systems, pollution caused by industrial and domestic waste has led to a great wastage and loss of our fresh water sources.

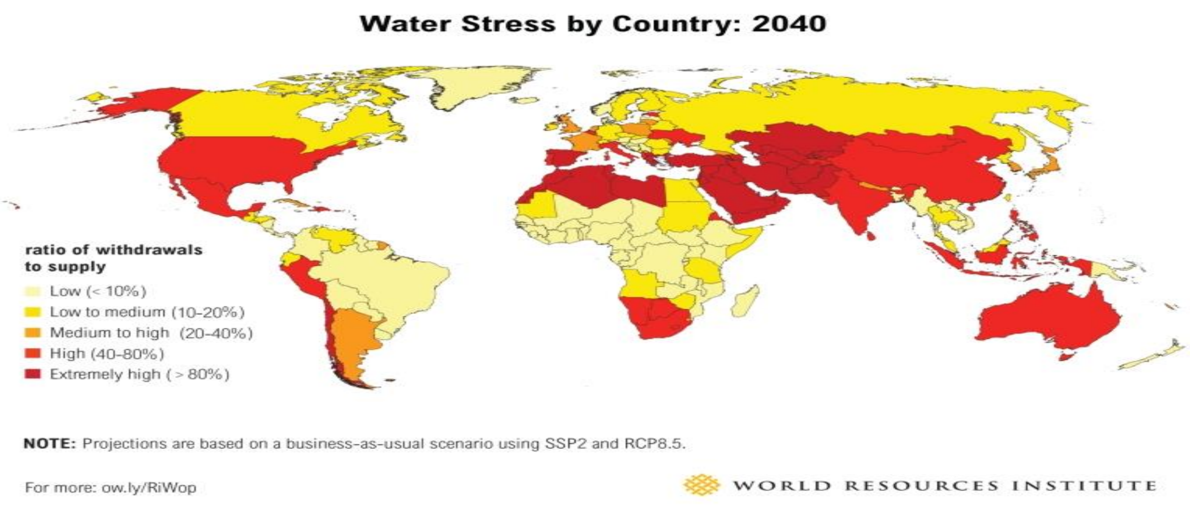


Figure 1.2 Water Stress by Country (Reig, Maddocks, & Young, 2015)

1.4. Water Scarcity in Karachi

Karachi is Pakistan's chief industrial and financial hub and plays a major role in Pakistan's economy. It is the largest and most populous city of Pakistan and is located along the Southern coastline of Pakistan in Sindh province alongside Arabian Sea. The 'City of Lights' is the worst hit city when it comes to population and climate change. This has resulted in extreme water shortage in different areas of Karachi.

1.5. Remedy

Fresh water resources are on the decline globally and this is now a known fact that the ice caps are melting and the world is going to face a serious water emergency in a few decades. Different countries in the world have worked out various plans to defeat this water issue. One of them is to use more than 95% of the Earth's Water which is saline and convert it into potable water through process of Desalination. This technology was very expensive and costly during its introduction in the second half of 20th century but today due to technological advancements and scientific research many countries have transformed it into a reality and made it sustainable and feasible and they have used it to solve this predicament of water shortage.

1.6. Problem Statement

Pakistan is suffering from an acute shortage of fresh water and with the increasing population and depletion of fresh water sources Pakistan needs an alternative. Karachi is the most severely hit city suffering from a serious declination in availability of drinking water. Karachi being the hub of economic and industrial activity of Pakistan needs to quench its ever increasing thirst with water. Moreover, the available fresh water sources are also being polluted due to dumping of industrial waste and the small number of available sources of fresh water are themselves becoming slowly and gradually unsafe for drinking.

1.7. **<u>Objectives.</u>** The major objectives of this research are:-

- Understand the present condition of fresh water sources of Karachi and study the relationship between population of Karachi and demand of drinking water.
- Identify probable sites of Desalination and analyze them keeping in mind the safety of natural ecological system of Karachi.
- The study of various energy systems suitable for Desalination in Karachi keeping in view the environment and climatic conditions.
- Carry out cost analysis of Desalination plant and propose a most cost effective model based on successful desalination technologies used in the past.

1.8. **<u>Scope.</u>** The scope of our study is:-

- Study the existing water resource management and water supply in Karachi.
- Keeping in view the impurities in Karachi sea water and other site parameters, recommend a possible site for Desalination Plant.
- Carry out Cost Analysis of Desalination Plant.
- Study the energy systems based on their efficacy and efficiency.

1.9. Limitations.

- Lack of standard gauging criteria for different energy sources
- Negligible research carried out on long term dependency on desalination Projects in water scarce regions of Pakistan.
- Limited research on use of Hybrid technologies for Desalination Projects in Pakistan for lowering power consumption.
- Availability of land is limited due to uncontrolled expansion of Karachi coupled with settling of communities along the coast.

CHAPTER 2

LITERATURE REVIEW

CHAPTER 2
LITERATURE REVIEW

2.1. Overview

This chapters contains a review of the scholarly text referred during the study. An in-depth review of the information and data available enabled to understand the issue of water scarcity in Karachi in the larger context and also gave a brief overview of the distribution of water sources of Karachi as well as the process of Desalination. It also helped to understand the cost and energy related aspects of a desalination plant that can be implemented to mitigate issues of elevated financial burden in constructing and maintaining a desalination plant as well as keeping it efficient and environment friendly.

2.2. Karachi and its Existing Water Resource Management

2.2.1. Karachi, the City of Lights

Karachi, the city of lights, is located on the coast of Arabian Sea in the extreme south of Pakistan and lies between 24° 56' 46.4" north latitude and 67° 0' 20.2" east latitude. The total area of Karachi is approximately 3530 kms. It inhabits approximately 20 million people (2017 census) which is expected to be increased exponentially. It is among the most populous metropolitan cities of the world. The population of Karachi is increasing rapidly, partly due to the migration of rural population to the urban areas for better livelihood opportunities resulting in urban sprawl and an increase in the number of housing schemes in the outskirts of the city. This additional increase in the population has put undue pressure on all available utilities and resources, including water resources, of the city. Resultantly, the abstraction of groundwater has increased.

2.2.2. Economic hub

Housing almost 60 per cent of the industries in the country, it is recognized as the industrial and financial center of Pakistan. Its significance in Pakistan‘s economy can be depicted through its 15-20 percent contribution to the national Gross Domestic Product (GDP). Due to the international buyers‘ demand, export-based industries need to comply with stringent environmental standards. Compliance with international and national standards not only promotes enterprise efficiency and supports competitiveness in international trade but also protects workers and consumers‘ health and safety. This in turn leads to more sustainable socio-economic development of the country. To achieve this, policy statements indicating specific regulations, rigorous implementation and stakeholders‘ participation is necessary. One of the main components of environmental compliance is water and its management, therefore data regarding it is crucial for effective policy making. This report regarding the water situation of Karachi is based on data compilation from different sources.

2.2.3. Rivers of Karachi

The city is divided by two non-perennial river streams namely Rivers Lyari and Malir. The River Malir flows from the east towards the south and center, and the River Lyari flows from north to the southwest. The main tributaries of the River Lyari are Gujjar nullah and Orangi nullah while Thaddo and Chakalo are the main tributaries of the River Malir. The Karachi Harbour is a sheltered bay to the southwest of the city, protected from storms by the Sandspit Beach, the Manora Island and the Oyster Rocks

2.2.4. Water Resources

The water supply of Karachi is dependent on surface water and groundwater sources. Surface water sources include Lake Haleji, Lake Keenjhar and Hub Dam while groundwater source includes Dumlottee fields well. However, the water supply from these wells is negligible, providing only 2 to 5 (MGD) of water after the rainy season while remaining dry for the rest of the year. Capacity of different water resources are shown in Figure 2-1. Moreover, the quality of groundwater in most of the parts is saline due to over extraction and sea-water intrusion. Pakistan Council for Research in Water Resources (PCRWR) reports that 86 per cent of the water sources (surface water and groundwater) are contaminated with Coliform and are considered unsafe for drinking.

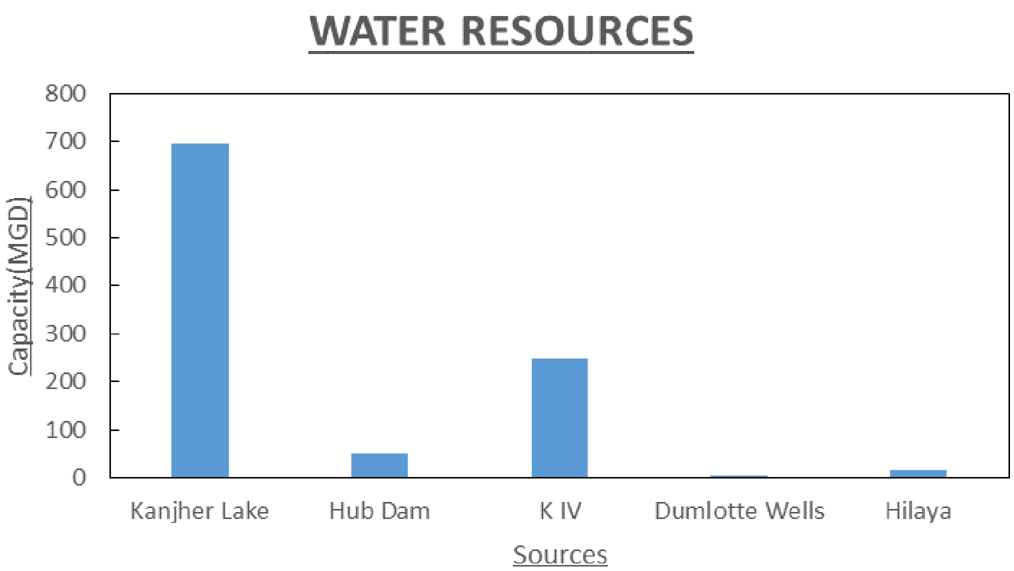


Figure 2.1 Capacity of Water Resources of Karachi

2.2.5. Water Demand And Short Fall

The Water supply provided by Karachi Water and Sewerage Board (KWSB) is approximately 695 MGD against a demand of 1200 MGD out of which 30 MGD are supplied to the Steel Mills and Port Qasim before the water reaches the Dhabeji pumping station leaving Karachi with 665 MGD resulting in a shortfall of 535 MGD. Unfortunately, an estimated 35 per cent (232 MGD) in the supplied water is lost during transmission thus decreasing the water availability to a mere 433 MGD. There is no metering for retail customers and only 25 percent of commercial and industrial customers have a metered supply.

2.2.6. Wastewater

Unsegregated industrial and municipal wastewater is gathered through pipes and uncovered channels and drained through rivers and nullahs (streams) into the Lyari and Malir rivers, and finally disposed off to the nearest coastal belt through the 232 km network of Main nullah and 1000 km network of town drains. There are three sewer districts in Karachi city, namely TP-1, TP-2 and TP-3. A system of six large scale and 16 smaller scale pumping stations convey the generated sewage directly or indirectly to one of three sewage treatment plants. Out of the 151.5 MGD of installed capacity of wastewater treatment only 55 MGD of wastewater is treated and one of the treatment plants is not functional. There is one Combined Effluent Treatment Plant (CETP) installed at Korangi Industrial Area, capable of treating wastewater generated from tanneries in Korangi Industrial Area and domestic sewage from KWSB Pumping Station-II (PS-II). However, it treats approximately 20,000 m^3, much lower than its designed capacity. The reason is that the CETP was designed for tanneries waste however, it is also a recipient of effluents from 280 other industries which compromises its performance. In essence, Karachi produces around 475 MGD of wastewater daily, out of which 420 MGD of wastewater remains untreated and severely contaminates the surface and groundwater sources. Recent studies suggest that population will grow by 30 per cent from 2017 to 2030. This will translate in an increased water demand which will in turn put pressure on the already scarce water resources. Moreover, water supply pipelines and sewerage pipelines are corroded and often lie parallel to each other causing cross-contamination. Resultantly, majority of Karachi does not receive safe and clean water. Climate change also poses a threat to the water security of Karachi in the form of variable river flows due to change in rainfall pattern and rising of sea levels at the rate of 1.1 mm/year putting population residing by the water bodies at increased risk. Variation in rainfall patterns will also affect the Hub dam, which is rain-fed, thereby decreasing or increasing the supply to Karachi. Industrial and agriculture sector is also predicted to be severely affected by the reduced water availability in the future. The situation of water in Karachi will continue to worsen if immediate steps are not taken to ameliorate the crisis. This report recommends mitigation, preventive and compensatory measures that can be adopted to alleviate the water and wastewater predicament.

2.2.7. <u>Future Projects</u>

- **<u>K-IV project</u>**

The K-IV project was conceived in 2002. Its initial survey cost was Rs 33million in 2005. Osmani & Co Ltd was awarded the project's consultancy contract to prepare its design and feasibility report. The feasibility study was completed in 2007. It finalized Route 8 out of the total nine routes suggested. The project was divided into three phases. Phase-I was to provide 260 millions of gallons per day of water to Karachi. Phase-II was also supposed to provide 260 MGD while Phase-III 130 MGD. The authorities had planned to provide a total of 650 MGD water through this project. The initial cost of the project's Phase-I was Rs25 billion. In 2011, the PC-I was prepared and the project was approved by ECNEC in 2014. When the government plans to build something it has to create a Planning Commission Proforma. These are the PC-Is and PC-IIs. The federal and provincial governments had decided to share the project's 50-50. In 2016, the Sindh government asked the Frontier Works Organisation to work on the project. However, work on the project was stopped in August 2018 due to a fault in its design. In 2019, the Sindh government nominated National Engineering Services of Pakistan as the third party to review the K-IV design prepared by the OCL. It also ordered an inquiry into delay in the project's completion in 2018. In the inquiry report, Sindh Government Secretary Aijaz Mahesar said, "The consultant lacks expertise and the project of planned badly". The report said the choice of Route 8 for the project was incorrect, as three other routes were more feasible for its execution. Last year, the NESPAK also submitted its Design Review Report, categorically stating that the selected design was not feasible for the project's execution. In Oct 2019, the Sindh government constituted a technical committee to find a way forward in the light of NESPAK's Design Review Report. The committee was headed by the Sindh Local Government Secretary Roshan Ali Shaikh. Sheikh then formed a sub-committee to review the NESPAK report. Members of both the committees held six meetings with OCL and NESPAK officials. During the meetings, some heated discussions took place between members of the OCL and NESPAK officials, as neither of the two sides was ready to withdraw from its view point. However, these meetings did not yield any result and the fate of K-IV is still hanging in the balance.

- **<u>Haleji Lake</u>**

Sindh Chief Minister Syed Murad Ali Shah decided to start a water supply project to provide the people of Karachi with an additional 65 MGD by reviving the KB (Kalri Baghar) Feeder's lower canal through the Haleji Lake at a cost of Rs6 billion. The rehabilitation of the Haleji Lake, the construction of the RCC (reinforced cement concrete) lined canal and conduit from the Haleji Lake to the Gharo Pumping Station will be undertaken. The province's chief executive took these decisions in a meeting that he chaired at the CM House on Saturday to review the progress of the projects that have been planned to provide additional water to the metropolitan city. Local Government has said that there has been no progress on the Haleji Lake rehabilitation project since 2000. They added that the project's scope included the construction of the RCC lined canal and conduit from the Haleji Lake to the Gharo Pumping Station, and the remodeling of the reservoir branch. He informed the meeting that a new 65mgd pumping house will be equipped with mechanical and electrical pumping machines at Gharo, a 72-inch-diameter mild steel pipe will be laid from Gharo to the high point, and a transmission line will be laid to convey the 65mgd water from the high point to the Pipri filer plant. The chief executive said the 65mgd water will be provided to the water-deficient areas of the metropolitan city, and this will benefit a population of some 1.2 million. He also reviewed the upgrade of the Dhabeji Pumping Station at a cost of Rs1.23 billion. The LG minister briefed the meeting on the rehabilitation of the existing electrical and mechanical machines of the second, third and fourth phases. He stressed the need of rehabilitating the K-II and K-III pumping houses because they have completed their lives. The chief executive was told that 65 per cent of the work has been completed, following which the CM directed the LG minister to get the work swiftly completed so that its benefits can be passed on to the people of the city. The chief minister also directed the Karachi Water & Sewerage Board (KWSB) to propose a project for the rehabilitation of the canal coming from Hub to provide 100mgd water to District West. He said the canal is completely defective, so half of the total water goes to waste. He added that with its rehabilitation 50mgd water going to waste will be made available for the people of District West.

2.3. Impurities in Karachi Sea Water

2.3.1. Overview

Water pollution has developed itself to be one of the biggest and main issues worldwide due to its serious impacts on health and environment. The world has put a serious concern and hence spending a handsome amount of money to overcome and reduce this danger of contamination of large water bodies like seas and oceans. Researchers have been reporting and warning time and again regarding the impacts of continuous output of untreated effluent and municipal waste water on the marine environment.

Municipal and industrial untreated sewage discharges are two main factors contributing in seaside aquatic contamination. Unprocessed sewage effluent of more than 6000 manufacturing entities dispersed in six mega business estates other than that of 300 MGD domestic and industrial untreated water which is quitted into sea through two major rivers i.e. Layari River and Malir River. Manora channel receives all the discharge of Layari river while Malir river junctions itself with sea at the Ghizri creek found on Southeastern part of coastal belt. Manufacturing entities pouring their waste into sea through these rivers are generally fabric industries , laundry related factories , dyes and colors companies ,medical and medicines units, malleable industry , metallurgy factories , diet and drinks companies, oils and greases , automobile units are the main sources of flooding the Malir and Liyari river with sewage water and effluent. According to a careful estimate BOD weight of fifteen thousand tons/day is additionally put into sea by these manufacturing units other than nonliving contaminants.

2.3.2. <u>Sampling</u>

Karachi coast was divided into three main zonal areas for sampling as shown in Figure 2.2 which are:-

- Southeast coastal area
- Northwest coastal area
- Manora channel.

<u>Figure 2.2 Water Demand of Karachi</u>

2.3.3. Impurities found in different belts and areas

Stream Name	Parameters			
	pH	Electric conductivity (mS/cm)	Turbidity (NTU)	Fecal Coliform per 100 ml
Layari river	7.9 ± 0.199	2.49 ± 0.19	65 ± 1.2	4900,000 ± 50
Malir river	7.3 ± 0.1	4.7 ± 0.2	68 ± 1	610,000 ± 50

Table 2.1 Characteristics of Layari and Malir River water

Sampling sites (coordinates)	Characteristics							
	High Tide				Low Tide			
	pH	E.C. mS/cm	Turbidity (NTU)	Fecal Coliform per 100 ml	pH	E.C. mS/cm	Turbidity (NTU)	Fecal Coliform per 100 ml
Marina plaza N 25-49-19, E 66-00-47	8.2 ± 0.1	50.7 ± 2.2	22.0 ± 1.1	182 ± 10	8.1± 0.1	50.6± 1.4	50.0± 2.7	341 ± 10
Casino N 25-48-44, E 68-02-39	8.1 ± 0.1	50.0 ± 2.8	34.0 ± 1.6	256 ± 12	8.1 ± 0.1	50.4± 1.7	54.5± 2.4	432 ± 14
Naval jetty N 25-46-24, E 68-04-36	8.1± 0.1	49.7 ± 2.1	29.0 ± 1.3	387 ± 14	8.0 ± 0.1	50.4± 1.4	55.0± 2.3	521± 17
Marina club N 25-46-24, E 68-04-36	8.1 ± 0.1	47.6 ± 1.4	24.0 ± 1.2	398 ± 12	8.0 ± 0.1	46.6± 1.5	58.5± 2.2	421 ± 16
Ghizri area N 25-44-24, E68-04-38	8.0 ± 0.1	47.4 ± 1.2	58.7 ± 2.8	489 ± 16	7.8 ± 0.1	40.6± 1.1	69.7± 2.2	850 ± 25
Ibrahim Haideri fish harbour N 25-48-04 E 68-09-38	8.0 ± 0.1	49 ± 1.3	68.5 ± 2.6	678 ± 20	7.8 ± 0.1	46.5± 1.4	92.5± 2.7	895 ± 23

Table 2.2 Characteristics of Manora Channel

Sampling sites (coordinates)	Characteristics							
	High Tide				Low Tide			
	pH	E.C. (mS/cm)	Turbidity (NTU)	Fecal Coliform (per 100 ml)	pH	E.C. (mS/cm)	Turbidity (NTU)	Fecal Coliform (per 100 ml)
Manora sea side ***N 25-46-27, E 67-57-13***	8.1 ± 0.2	50.2 ± 1.5	1.9 ± 0.3	200 ± 13	8.1± 0.2	50 ± 1.4	4.2 ± 0.5	204 ± 14
Hawke's Bay ***24°52'00" N, 66°51'51" E***	8.1 ± 0.1	50.1 ± 1.2	1.7 ± 0.1	150 ± 12	8.0± 0.2	50.1± 1.4	3.0 ± 0.2	120± 16
Sandspit ***N 25-48-14, E 67-54-22***	8.1 ± 0.2	50.6 ± 1.4	2.0 ± 0.2	175 ± 12	8.0± 0.1	51.0± 1.3	2.3± 0.2	143 ± 7
Kakka pir ***N 25-48-54, E 67-52-54***	8.1 ± 0.1	50.6 ± 1.6	2.1 ± 0.1	165 ± 4	8.0± 0.2	50.7± 1.3	2.1± 0.3	147 ± 12
Buleji ***N 25-48-03, E 67-51-42***	8.2 ± 0.2	51.0 ± 1.4	2.2 ± 0.2	123 ± 8	8.1± 0.1	50.7± 1.2	1.6± 0.2	159 ± 10
Cape Mount ***24°49'35.2" N, 66°39'52" E***	8.1 ± 0.1	52.2 ± 1.3	1.9 ± 0.2	125 ± 7	8.1± 0.2	52.7± 1.4	1.6± 0.2	100 ± 5
Sunehri beach ***N 25-51-53, E 67-46-47***	8.1± 0.2	51.7 ± 1.3	1.1 ± 0.1	115 ± 10	8.1± 0.2	51.8± 1.2	1.3± 0.2	95 ± 6

Table 2.3 Characteristics of North West Coastal Water

Comparison of these two tables shows that pollution level in the North West coast is far below than in the Manora channel. It reveals that North West coast is not much polluted and industrialized in term of water contamination. Waste water of small villages on Northwest coast is mostly exhausted into backwaters of Manora channel and inflow of residential wastewater and industrial waste into the northwest coastal water is minimum. (A. MASHIATULLAH, 2009)

2.4. <u>Desalination</u>

The world's population is increasing and multiplying and this has put a lot of burden on our fresh water sources. Only 2.5% of the water is drinkable and the rest is mostly ocean water which is salty and is not consumable. To access that water you need to take that salt out and this sea and ocean water can be reliably converted to drinking water through a process known as Sea Water Reverse Osmosis Desalination (SWRO).

The procedure begins by pulling out water using wells in the sea positioned on the coast or by constructing an intake structure located in the sea. Osmosis is a naturally occurring process in which a liquid such as water spontaneously passes through a membrane. The membrane or semi permeable barrier allows some molecules such as water through while other molecules such as majority of the salts are unable to easily pass through the membrane structure. The flow of liquid through such a membrane occurs naturally to even out the salt concentrations between the two solutions i.e. the liquid flows from the less concentrated solutions such as fresh water to more concentrated solution such as seawater. When the direction of liquid flow is reversed, it's called reverse osmosis. By pressurizing the concentrated solution, in this case seawater, we are able to force water molecules in the reverse direction from the salty seawater side through the membranes to the fresh water side. (Voutchkov, Desalination Engineering: Operation and Maintenance, 2014)

There are several stages that the seawater goes through on its way to becoming clean drinking water. Seawater flows via gravity or pump through a tunnel to the plant. Band screens remove coarse solids from the seawater before it is pumped into the plant. Disc filters clean the seawater further before ultrafiltration membranes remove very tiny particles including bacteria and viruses. (Voutchkov, Desalination Engineering: Planning and Design, 2012)

Now it is time to remove the salt from the filtered seawater by reverse osmosis. At the heart of the reverse osmosis process are the membranes. Each membrane has three layers i.e. a support backing, the porous support and the thin barrier layer (0.2 micron thickness) through which water can pass easily while the majority of dissolved salt molecules and any remaining impurities cannot pass. When a reverse osmosis unit has made these membrane sheets; they are folded, stacked and glued in such a way that when pressure is applied to the incoming seawater, the fresh water molecules can move through the membrane barrier layer leaving the salt molecules behind. Spaces between the membranes allow room for the incoming seawater and outgoing desalinated water to flow easily. A tube at the end of the membrane sheet collects the desalinated water that is produced. However the final reverse osmosis unit is not flat. The many layers of membranes and spaces are rolled around the central tube creating a cylindrical shape which is called a spiral wound unit. In this form a very large membrane area can be packaged into a small sized unit. These spiral wound units are loaded into a white fiber glass tube called a pressure vessel. (Voutchkov, Desalination Engineering: Planning and Design, 2012)

For reverse osmosis to work, the filtered seawater is brought up to a very high pressure using high pressure pumps. The pressurized seawater is then fed through a bank of pressure vessels. The majority of the dissolved salt molecules cannot pass through the membranes and are rejected. As a result the feed water becomes enriched in salts as the pure water is removed progressively by each of these spiral wound units in the pressure vessel. The rejected seawater is now called saline concentrate liquid and is largely indistinguishable from seawater except from its higher salt content. The saline concentrate liquid which still contains most of the pressure supplied by the high pressure pumps leaves the rear of the pressure vessels and is directed to an energy recovery device. Here about half of the new incoming filtered seawater is pressurized by the transfer of energy from the outgoing saline concentrate liquid. The pressurized seawater leaving the energy recovery device has its pressure boosted by a small booster pump so that it is at the same pressure as the seawater leaving high pressure pump. The boost is necessary as some pressure has been lost as the stream travels through the Reverse Osmosis system. This transfer of energy recovers nearly all of the energy originally put in by the high pressure pumps decreasing the plants overall energy requirements by approximately 40% and further reducing its environmental footprint. The energy recovery devices significantly reduce the Plant’s operating costs. (Voutchkov, Desalination Engineering: Operation and Maintenance, 2014)

Meanwhile the desalinated water which is passed through the membrane surface flows along the pure water channel and into the centered tube for collection. This water then passes through a second set of pressure vessels containing more spiral wound units to remove more salts. (Voutchkov, Desalination Engineering: Operation and Maintenance, 2014)

This desalinated water is then piped to the post treatment area and is treated with lime, chlorine and fluoride which improves the taste and makes the water safe for distribution and drinking. Through the reverse osmosis process, for every liter of seawater reaching the plant, about half of the clean drinking water is produced. An innovative and sustainable design of a Desalination plant can reduce the carbon footprint and ensure it remains operational during its life span.

2.5. Cost

2.5.1. Cost Analysis

It is a mechanism used to evaluate and estimate the cost of a certain project and then based on the benefits associated with it the feasibility of the project is considered.

2.5.2. Types of Costs

- **Capital Cost**

  It consists of all the costs required to develop and construct the infrastructure. It further consists of two types of costs:-

  – **Material Cost**

    It includes the cost of material procurement required for the project.

  – **Installation Cost**

    It includes all the cost required for construction of the structure and the installation and development of the project other than the cost of materials.

- **Recurring Cost**

  It is cost that happens to occur repetitively over the lifetime of a project. It is further divided into two types:-

– **<u>Operational Cost</u>**

It is the cost required to operate the project over a period of time i.e. weekly, monthly, annually etc. It is required for functioning of a project.

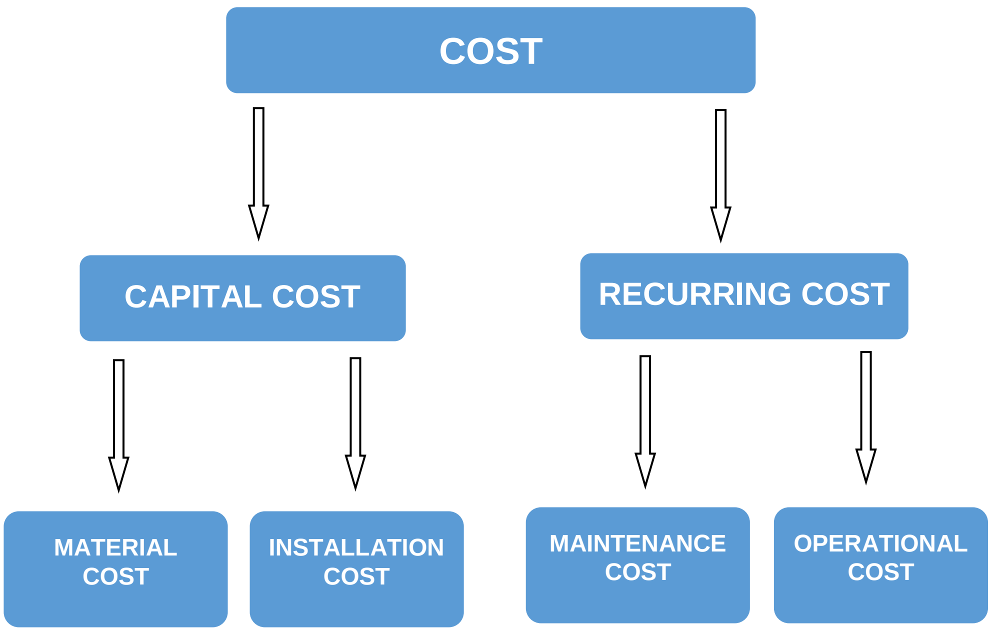
– **<u>Maintenance Cost</u>**

It is the cost that is incurred to maintain and keep the project in a good functional and working condition.

2.5.3. <u>Cost Flow Chart</u>

The breakdown of these costs is shown in Figure 2.3 for better understanding of the different types of costs associated with any project undertaken.

<u>COST FLOW CHART</u>



<u>Figure 2.3 Cost Flow Chart</u>

Figure 2.4 shows the breakdown of construction cost of a typical Seawater Reverse Osmosis Desalination Plant. (Voutchkov, 2010)

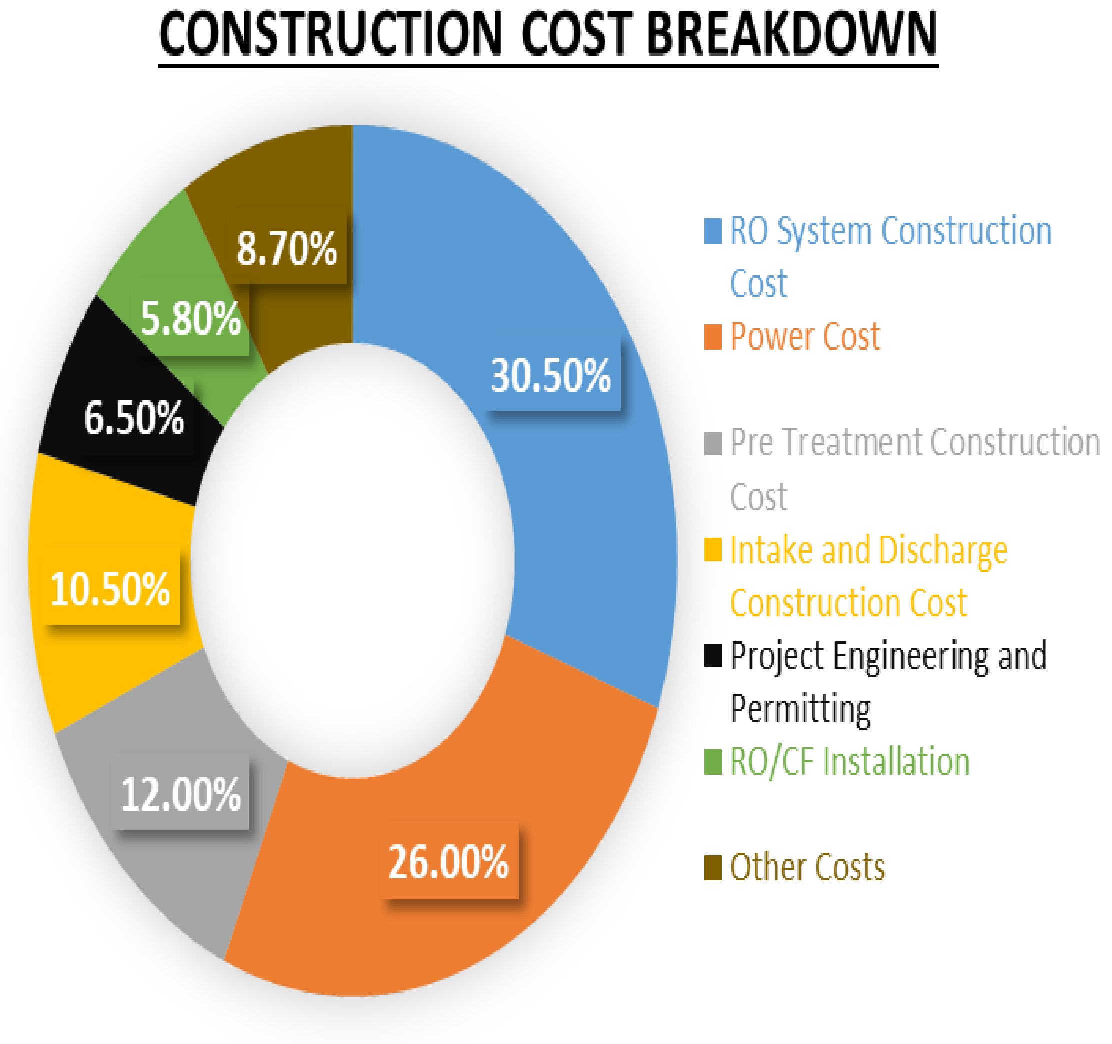


Figure 2.4 Construction Cost Breakdown

The breakdown of O&M cost of a typical Seawater Desalination Plant has also been given by (Voutchkov, 2010) which is shown in Figure 2.5.

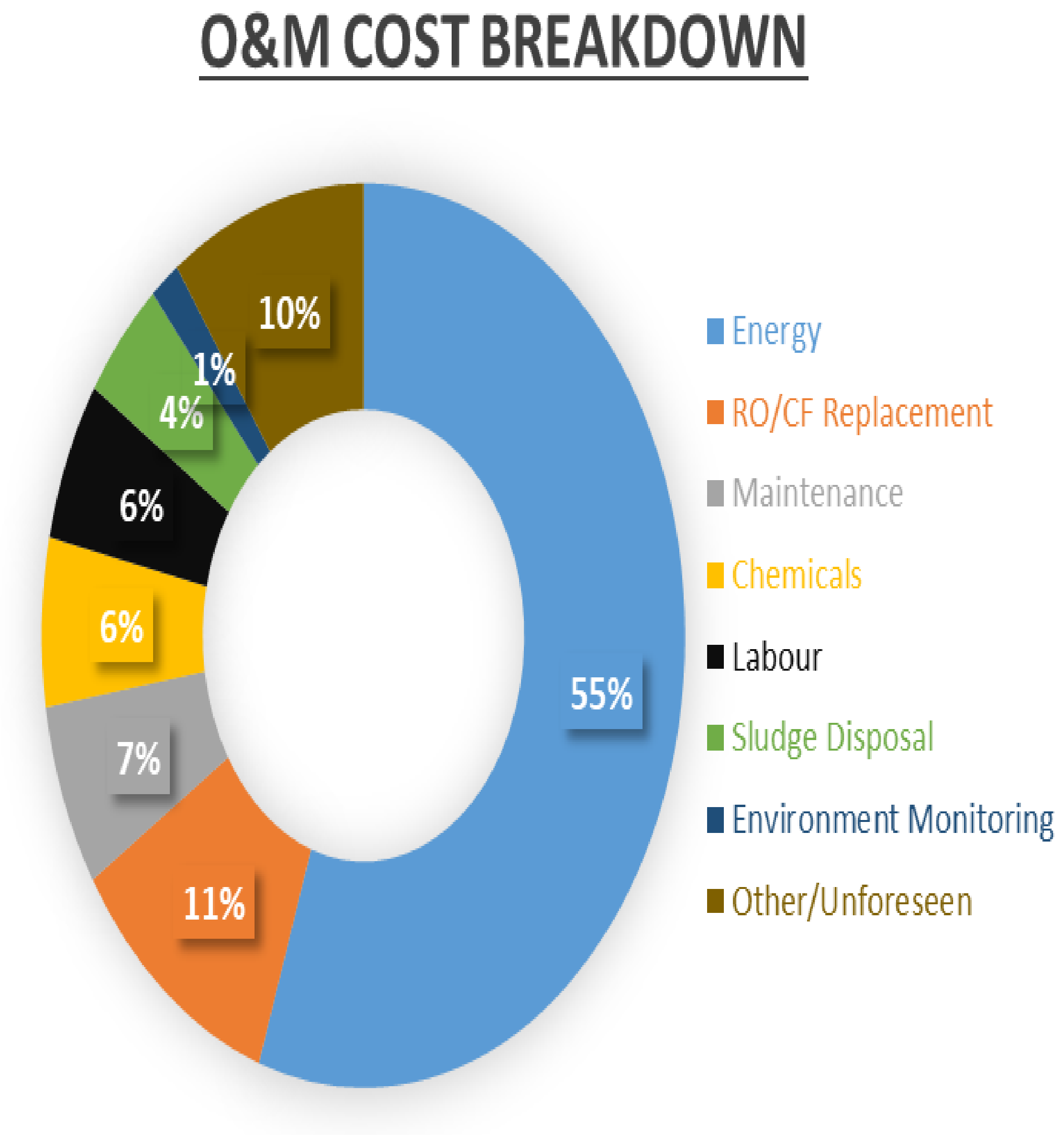


Figure 2.5 O&M Cost Breakdown

2.5.4. To carry out the Cost Analysis of a Desalination Project various case studies have been studied and analyzed to draw results and extract data. The analysis carried out is detailed in the Analysis Chapter of the document.

2.6. Renewable Energy Powered Desalination Systems.

2.6.1. Overview.

Sustainable development is related to energy resources and their utilization to achieve the optimum results. Making use of the energy resources, by increasing the efficiency of energy resources to attain sustainable development, play a pivotal role. A vast array of benefits can be achieved by properly utilizing the energy resources to their full potential. The paper focuses on the work of significant importance done in the recent years worldwide and quality efforts done on using renewable energy as a source to overcome energy issues in the field of Desalination with emphasis on economy and technology used. A comparative study has been undertaken keeping in view different renewable energy powered desalination systems and their cost effectiveness. The real challenge in analyzing these systems is the optimum economic design and also the feasibility of combined plants in remote locations. A very high capital cost is required for renewable energy powered plants including solar and wind energies. Economic feasibility of desalination is directly related to amount of salt concentration in the feed water. With emphasis being on reduced energy consumption and lower cost of water produced, RO process has gained the preference over other process in terms of overall optimum economic design and lower costs. Also, RO is environment friendly, consumes less energy resources and has almost negligible greenhouse effect. (Eltawil, Zhengming, & Yuan, 2008)

2.6.2. <u>Types.</u> Desalination processes are categorized into following main types:

- Thermal process
  - Multi stage flash process (MSF)
  - MED process (Multiple Effect Distillation)
- Membrane
  - Reverse Osmosis process (RO)
  - Electro dialysis process (ED)

Commonly used are:-

- Reverse Osmosis process (RO)
- Multi Stage Flash process (MSF)
- Multi Effect Distillation (MED)

Commonly used energy sources are as follows:-

- Sunlight
- Geothermal heat
- Wind
- Fossil Fuels

2.6.3. Renewable Energy Coupling To Desalinating Technologies

Solar, wind, photovoltaic, thermal and geothermal are the types of renewable energy sources used with desalination plants. Renewable energy source (RES) powered desalination plants fall into two types. The first type includes distillation processes powered by heat produced by the renewable energy systems, while the second type membrane and distillation processes powered by mechanical and electrical energy produced by RES. (Eltawil, Zhengming, & Yuan, 2008)

A large number of (RES)-desalination systems have been tested and analyzed in the frame of underway research for ingenious desalination processes. Detailed analysis of available and operable water resources and water needs have been carried out in the framework of research programs taking into account current and future trends of economic development and environmental and socioeconomic factors. Moreover, the market opportunity for RES desalination in different regions has been looked upon, basing on the scarcity of water in the region and also the RES growth opportunity with the view to analyze the economically competitive options for RES-powered desalination. RES offers vast array of different RES options and assist in lesser reliance on external energy sources costing a lot more. High energy is required for sea water desalination. Therefore, consumption of fossil fuels and its impact on environment are important factors to be taken care of. The possible future fluctuations in prices of fossil fuels make the RES powered desalination systems more important and significant.

Possible combinations of RES in the different desalination processes are shown in Table 2.4 and Figure 2.6. Figure 2.6 shows the possible combination of water desalination process and RES based on the type of energy requirement. It shows different types of RES available, the energy form in which they are converted and their coupling with different types of desalination techniques. The biggest challenge affecting the employment of renewable energy is the intermittency and low intensity of energy sources. Wave, tidal, solar and wind energies for example are highly intermittent and weather dependent. There are methods that can be utilized to minimize and eliminate these issues such as usage of batteries, connection to grids, thermal storage, or mixing different renewable energy sources. Coupling of various RES unit and different desalination are possible with their inherent pros and cons. Every combination poses different challenges in the way of achieving the optimum design keeping in view the efficient, cost effective system. (Mohammad Ali Abdelkareema, 2017)

Renewable Technologies	Desalination Technologies				
	MSF	**MED**	**VC**	**RO**	**ED**
Solar thermal	●	●	●	●	●
Solar PV			●	●	●
Wind			●	●	●
Geothermal	●	●	●	●	●

Table 2.4 Combination Technologies of RES and Desalination Methods

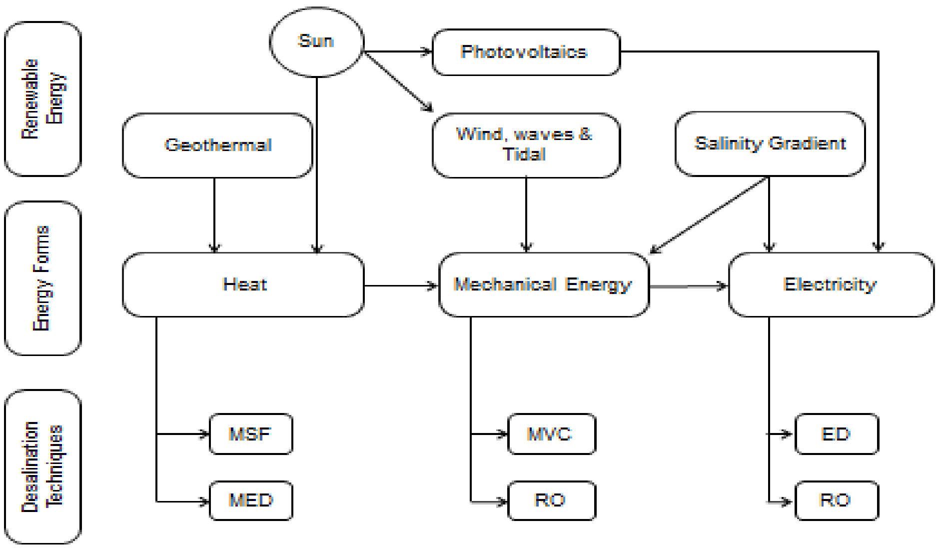


Figure 2.6 Possible Applications of Renewable Energy Sources in the Different Desalination Techniques

Developing RES powered desalination plant to meet the water requirement requires various considerations. Figure 2.7 illustrates the various factors which are considered for developing a basic algorithm to develop RES powered desalination plant. Water demand is identified to estimate the Desalination Plant capacity and its energy requirement to design the Desalination unit. Further, the technology database provides the basis for estimation of energy requirements, installed capacity and energy production respectively, to design the RES unit. Integration of Desalination unit and RES unit results in a RES powered Desalination unit.

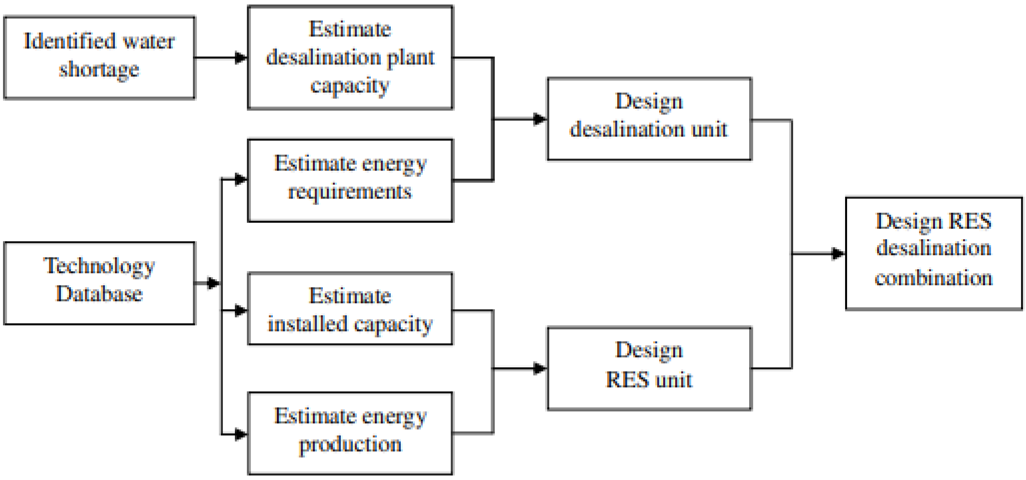


Figure 2.7 Algorithm for the design of the appropriate RES/desalination plant

Table 2.5 shows the inherent pros and cons of different RES unit and desalination unit combinations with their respective degree of suitability for a particular criterion.

Criterion	Solar thermal energy	Photovoltaic	Wind energy	Geothermal energy
Suitability for powering desalination plants	Well suited for desalination plants requiring thermal power (3)	Well suited for desalination plants requiring electrical power (3)	Well suited for desalination plants requiring electrical power (3)	Well suited for desalination plants requiring thermal power (3)
Site requirements and resources availability	Typically good match with need for desalination (3)	Typically good match with need for desalination (3)	Resources is location-depend ent (2)	Resources is limited to certain location (1)
Continuity of power output	Output is intermittent (energy storage required) (1)	Output is intermittent (energy storage required) (1)	Output is intermittent (energy storage required) (1)	Continuous power output (3)
Predictability of power output	Output is relatively unpredictable (2)	Output is relatively unpredictable (2)	Output is very unpredictable/ fluctuates (1)	Output is predictable (3)

Note: 3 = excellent compliance with criterion; 2 = good compliance with criterion; 1 = poor compliance with criterion.

Table 2.5 Evaluation of Renewable Energy Technologies (Eltawil, Zhengming, & Yuan, 2008)

2.6.4. RES Powered Desalination Processes

- **Wind Driven Water Desalination**

Remote locations with likely availability of wind energy resources such as flat open areas with natural wind availability can employ wind energy systems to operate seawater desalination for drinkable water production. The main purpose of such systems is that cost of water production is curtailed to a minimum cost as compared to providing water through increased distances or by using other cost inefficient to power means such as fossil fuels. There are a number of possible wind desalination combinations. Firstly, grid system connectivity with desalination system as well as with wind turbines. Here, the cost of fuel as well as the optimal design sizes of desalination system and wind turbine is of significance. Secondly, the direct integration of desalination system and wind turbine system pose certain challenges. In this case, the sporadicity of power source (wind) affects the functionality of desalination plant. Efficiency of different components of the desalination plant equipment and the shelf life are adversely affected by the intermittency of power source (wind). Hence, back-up systems, such as batteries, diesel generators, or flywheels might be integrated into the system. The main area of focus is to develop a self-sufficient system incorporating the desalination plant and wind turbine such that the continuous power supply, cost effectiveness and overall system efficiency is enhanced. Regarding desalinations, there are different technology options, e.g. electro-dialysis or vapor compression. However, due to very low energy requirement in reverse osmosis technology, it is the mostly adopted option. Figure 2.8 shows diagram of RO desalination plant wind/ energy recovery. (Eltawil, Zhengming, & Yuan, 2008)

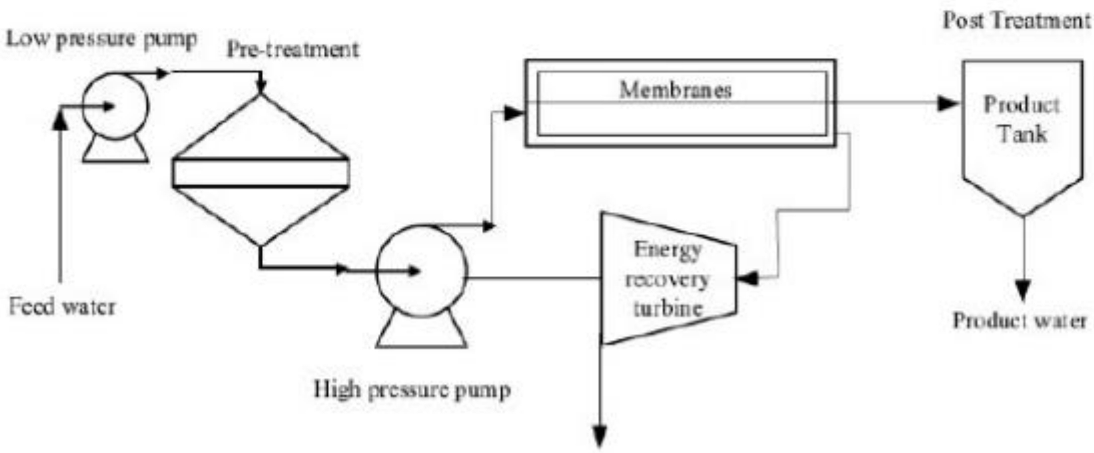


Figure 2.8 Diagram of RO Desalination Plant Wind/ Energy Recovery (Eltawil, Zhengming, & Yuan, 2008)

Research about the integration of a reverse osmosis unit and wind energy source operated by means of a shaft power has been done at Canary Islands Technological Institute—projects AERODESA I and AERODESA II. The system coupling directly the shaft power production of a windmill with the high pressure pump; 13 l/min can be maintained for wind speed of 5 m/s. Modeling and experimental tests results of one of such system installed at the ITC, Gran Canarias, Spain is presented. The capacity range of this plant is 192–72 m^3 /day. (Mohammad Ali Abdelkareema, 2017)

- **Photo-voltaic (PV) Driven RO Desalination Plant**

Due to the substantial reduction in the cost of solar energy, technological advancement in the field and a growing support from governments globally, solar PV has now become a very efficient and workable mean to produce electricity economically and also without any environmental hazards. It has now become a very effective mean from where it was 15 years ago. Figure 2.9 shows the exponential rise in global solar PV installations and associated plummeting costs of the technology. Solar PV works on the principle of using the sunlight directly for conversion into electric power very economically and effectively. Karachi city receives a very high radiation of sunlight which also remains continuous all-round the year. So PV solar can effectively use the advantage to meet the energy requirements for desalination system in Karachi. (Abdullah Kaya, 2019)

The most commonly used PV operated membrane process is reverse osmosis process. The process explained above and from technical viewpoint, RO as well as photovoltaic processes are practicable and being applied commercially now. The efficacy and practicability of PV powered RO system has been tested and established successfully in terms of its quality, efficiency and cost effectiveness. However, this system incurs high initial cost and requires PV cells which may sometimes become a consideration while weighing its feasibility for smaller projects of lesser water demand Figure 2.10 shows diagram of PV-powered reverse-osmosis (PV-RO) system to desalinate seawater. The system is operated from seawater, since the rate of production of freshwater varies throughout the day according to the available solar power. Initial testing of the system, with the modest solar resource available in the UK, provided freshwater at approximately 1.5 m 3 /day. Nearer to the equator and with a PV array of only 2.4 kWp, a software model of the system predicts production of over 3 m^3 /day throughout the year. (Enas R Shouman, 2015)

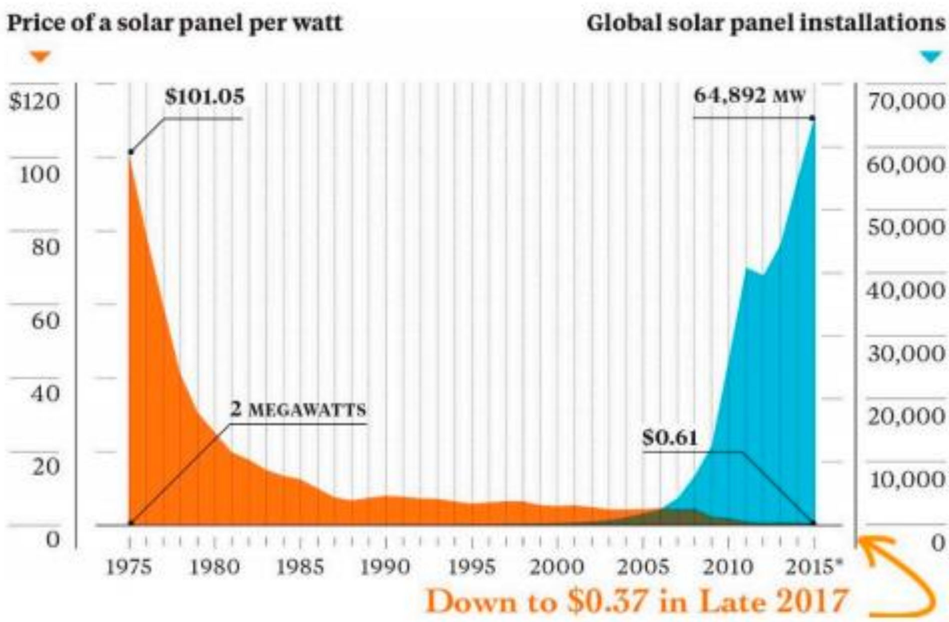


Figure 2.9 Global Solar Photovoltaic (PV) Installation (MW) and Investment Cost-$/watt (Abdullah Kaya, 2019)

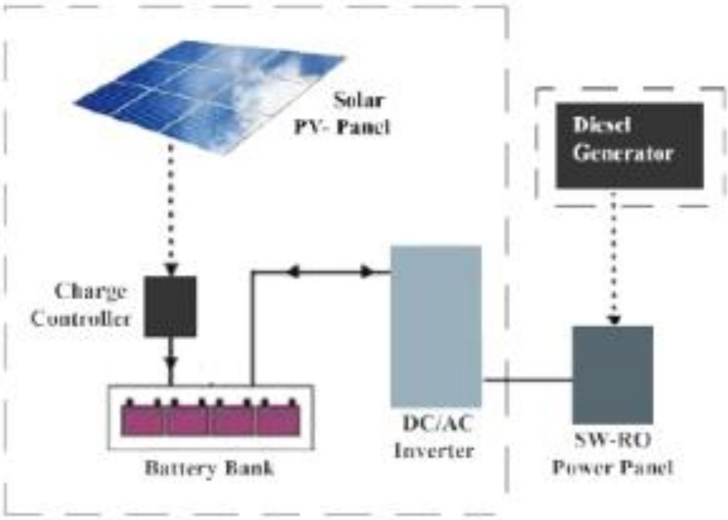


Figure 2.10 A Schematic for the SW-RO Desalination Plant with PV and Diesel Power Option (Enas R Shouman, 2015)

CHAPTER 3

METHODOLOGY

CHAPTER 3
METHODOLOGY

3.1. Overview

This chapter aims at clearly defining a methodology, ways & means to conduct the study and the techniques being used to obtain the results that is expected to be gained at the end. The methodology devised will allow for smooth and efficient conduct of research and help to achieve desired outcomes.

SWRO Desalination projects are actively being taken by many developed countries like USA, Saudi Arabia, Egypt, UAE, Israel, UK etc. They have proved to be very successful towards the achievement of reducing water stress on existing water resources in these countries. However, Pakistan is not making use of this technology amid already increasing water shortage. If the situation remains the same, the short fall may be doubled in next decade.

Nexus to above, this research was carried out to promote the concept of Desalination technology in Pakistan. The broad philosophical underpinning of the research method was largely quantitative. The analysis was based on the data collected, collated and processed after surveying various books, research papers, articles, case studies etc. The complete research was conducted smoothly in which a major contribution was provided by the Water and Power Development Authority (WAPDA) House Lahore (Hydel Resource Management) by their timely responses and provision of relevant data whenever approached.

3.2. Research Methodology

Based on the problem statement, the research was focused on finding the most efficient and cost effective solution for installation of a SWRO Desalination Plant in Karachi to alleviate the ever increasing burden on the depleting water sources of the city. Flow Chart of Research Methodology is shown in Figure 3.1

The data on the existing water resources of Karachi was extracted from different sources and was used to draw the demand and the deficiency of potable water in Karachi. Then it was understood that the existing water resources will not be sufficient to sustain Karachi in the long term and hence Desalination of Seawater came up as the best possible solution.

Various sources were then consulted to gather information on the water quality parameters of different rivers of Karachi to understand the level of Desalination required and which will be the most cost effective and energy efficient in the long term use.

To carry out the cost analysis, case studies of the most successful and energy efficient Desalination Plants in United States were consulted and analyzed to best suit our requirements. The energy demand of the project was also catered for and data was collected from different sources of energy being used in the modern world and the various technologies utilized and they were analyzed and studied to suit the requirements of Karachi as per its topography, ecology and population distribution.

Site Analysis was then carried out in detail to locate the construction site of the Desalination plant. This analysis was done keeping in mind the effects of the plant on the flora and fauna of the area but also to draw maximum output with least utilization of energy and minimum costs.

Figure 3.1 Flow Chart of Research Methodology

CHAPTER 4

ANALYSIS OF COST AND ENERGY

CHAPTER 4
ANALYSIS OF COST AND ENERGY

4.1. General

The study aimed at collecting and analyzing the data related to the cost and energy of SWRO Desalination Plant. As there is an acute shortage of water and stress of natural resources of water in Karachi, this study focused to eliminate this shortage by adding cost-effective and energy efficient Seawater Desalination Plant.

4.2. Analysis of Cost

Karachi being the economic hub of Pakistan, contributes in major part of the country's GDP. It is the financial capital of Pakistan and capital city of Sindh. Karachi is admired for its financial potential and its location with a seaport. Urbanization and population growth is ascending every passing year thus increasing the demand of daily needs. Figure 4.1 shows the expected population rise in near future which is calculated using method of Geometric growth rate of population.

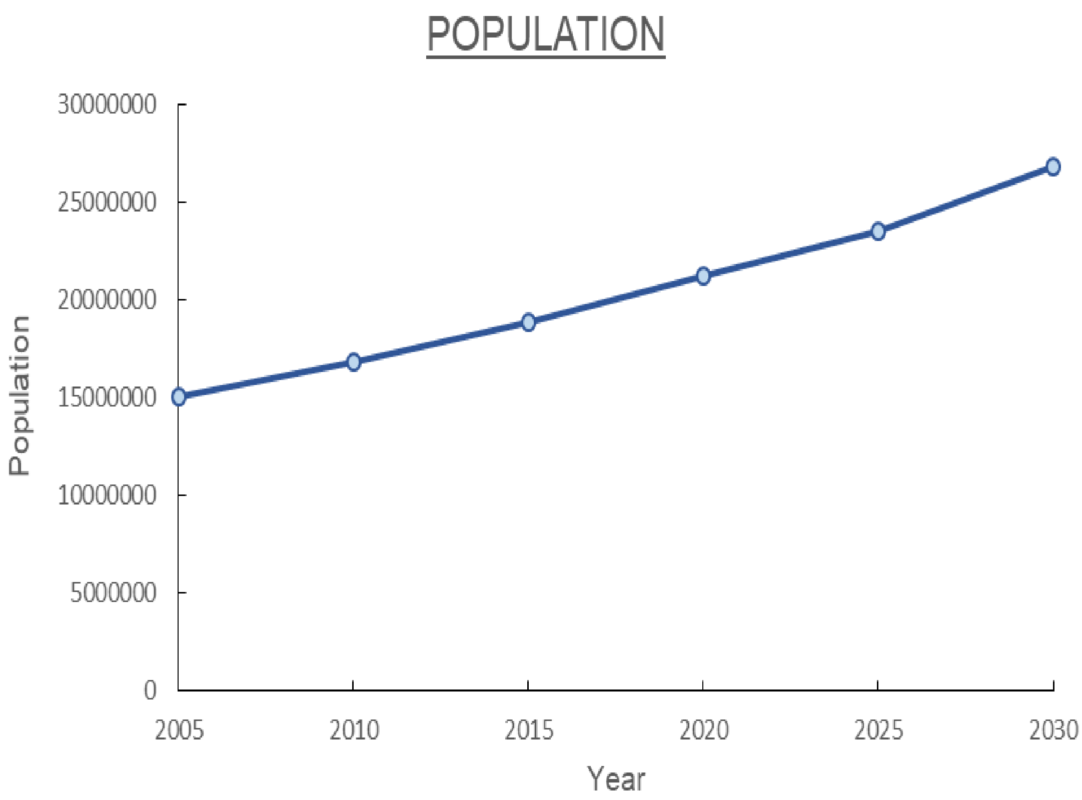


Figure 4.1 Estimated Population of Karachi

Water been an imperative asset plays a vital role in progress of any country. Karachi is running out of water and will be amongst the water scarce cities of the world, if measures are not taken to overcome the grave issues. Water demand of Karachi over the next few decades has been shown in Figure 4.2

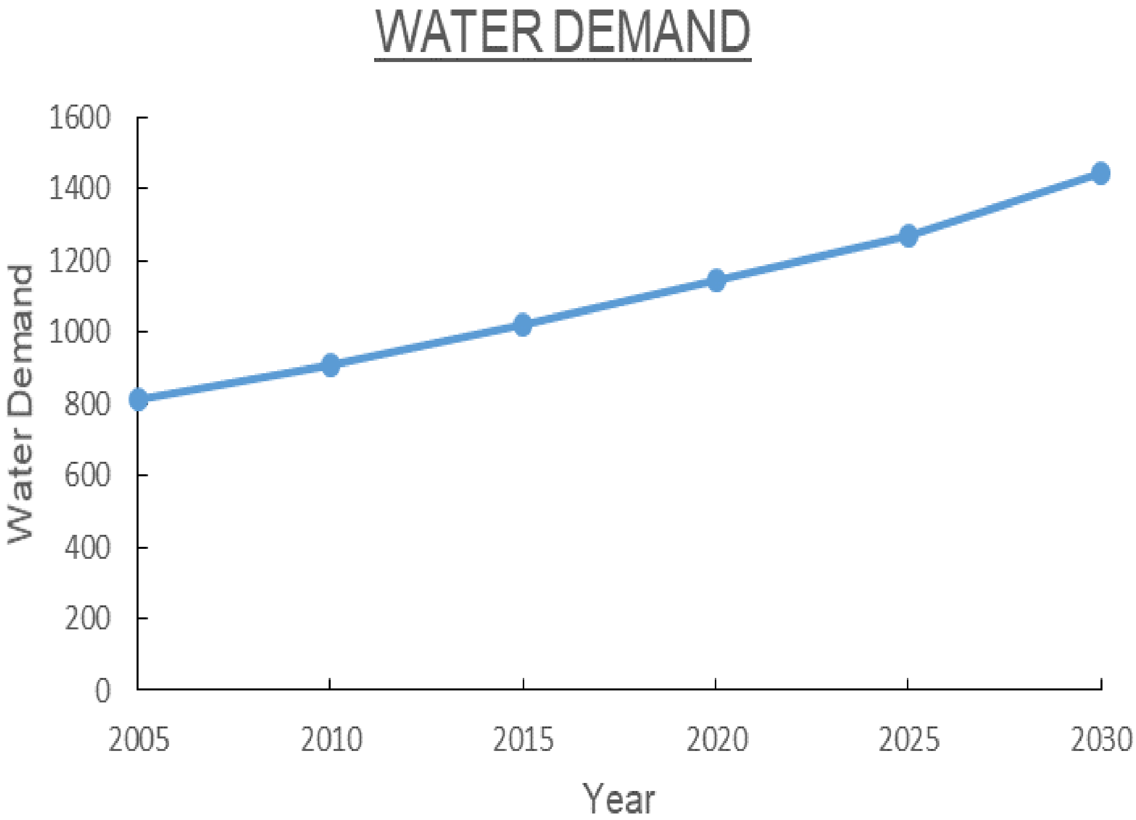


Figure 4.2 Water Demand of Karachi

Depleting water resources gives us an alarming situation to overcome water management issues else it will have a negative impact on the future water requirement of city. The city is already facing a water shortage of 535 MGD and the predicted water shortage has also been highlighted in Figure 4.3.

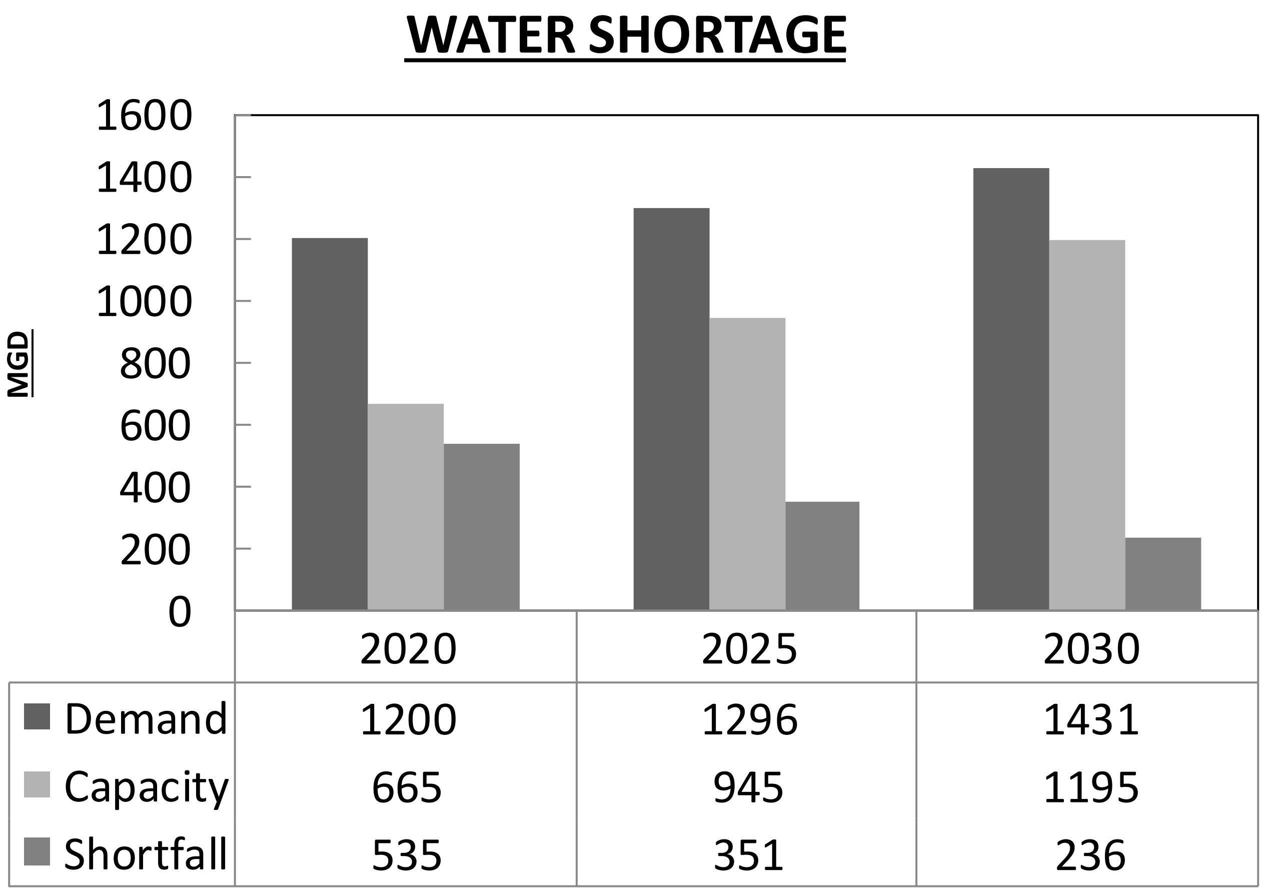


Figure 4. 3 Water Shortage of Karachi

The cost of a Desalination Plant is affected by a variety of factors which directly affect the functioning and operation of the plant. In this study we have gone through various operational Desalination Plants and have analyzed them to suit our needs and demands. An effort has been made to figure out the most financially sound and feasible Plant for the city of Karachi.

4.2.1. Capacity Analysis

- **Capital and O&M Cost vs Capacity**

Capital Costs and Operational Costs of various SWRO desalination projects undertaken in United States of America were studied (Voutchkov, 2010). They were used to develop a comparison between their costs and capacity which is shown in Figure 4.4. This will give us an understanding of the impact of various capacities on cost and the role they play in determining capital costs and operational costs. As it can be seen in Figure 4.4, the capital cost of desalination plants with smaller capacity is exponentially high as compared to plants of larger capacity. Also, operational cost is pretty much the same for different plants as all of them use membranes for Reverse Osmosis and their maintenance and operational cost does not vary much. It is important to note here that Tampa Bay Desalination plant uses simple but rigorous pretreatment techniques of Sedimentation, Coagulation and Flocculation which has a comparatively higher maintenance cost whereas Carlsbad Desalination Plant uses Nano filtration pretreatment which is energy efficient and it not only removes hardness, turbidity and microorganisms but it also removes some portion of salts which are dissolved in water thereby reducing the pressure required for operation and hence maintenance is comparatively cheaper (Carlsbad Desalination Plant, 2017; Hilal, Al-Zoub, Darwish, Mohammad, & Arabi, 2004). This plant has accrued several awards for efficiency of energy and design (Tampa Bay Sea Water Desalination, 2019)

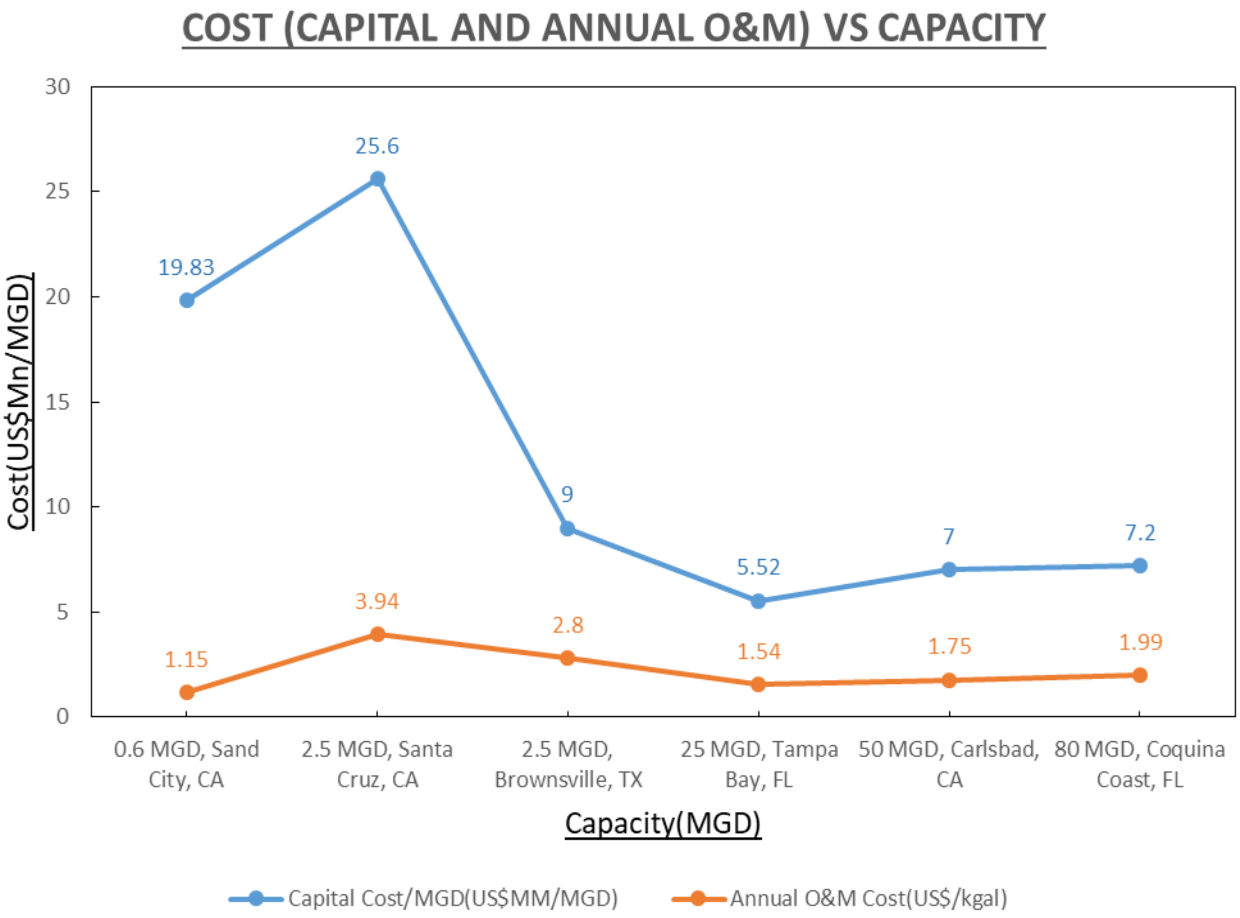


Figure 4.4 Cost vs Capacity

- **Total Cost vs Capacity**

The relationship of total cost, which includes Capital Cost plus 30 years O&M per MG, and Capacity of different SWRO desalination plants in the United States is shown in Figure 4.5. It again becomes clear that cost of plants with capacity less than 25 MGD is significantly higher than the plants with capacity equal to our greater than 25 MGD.

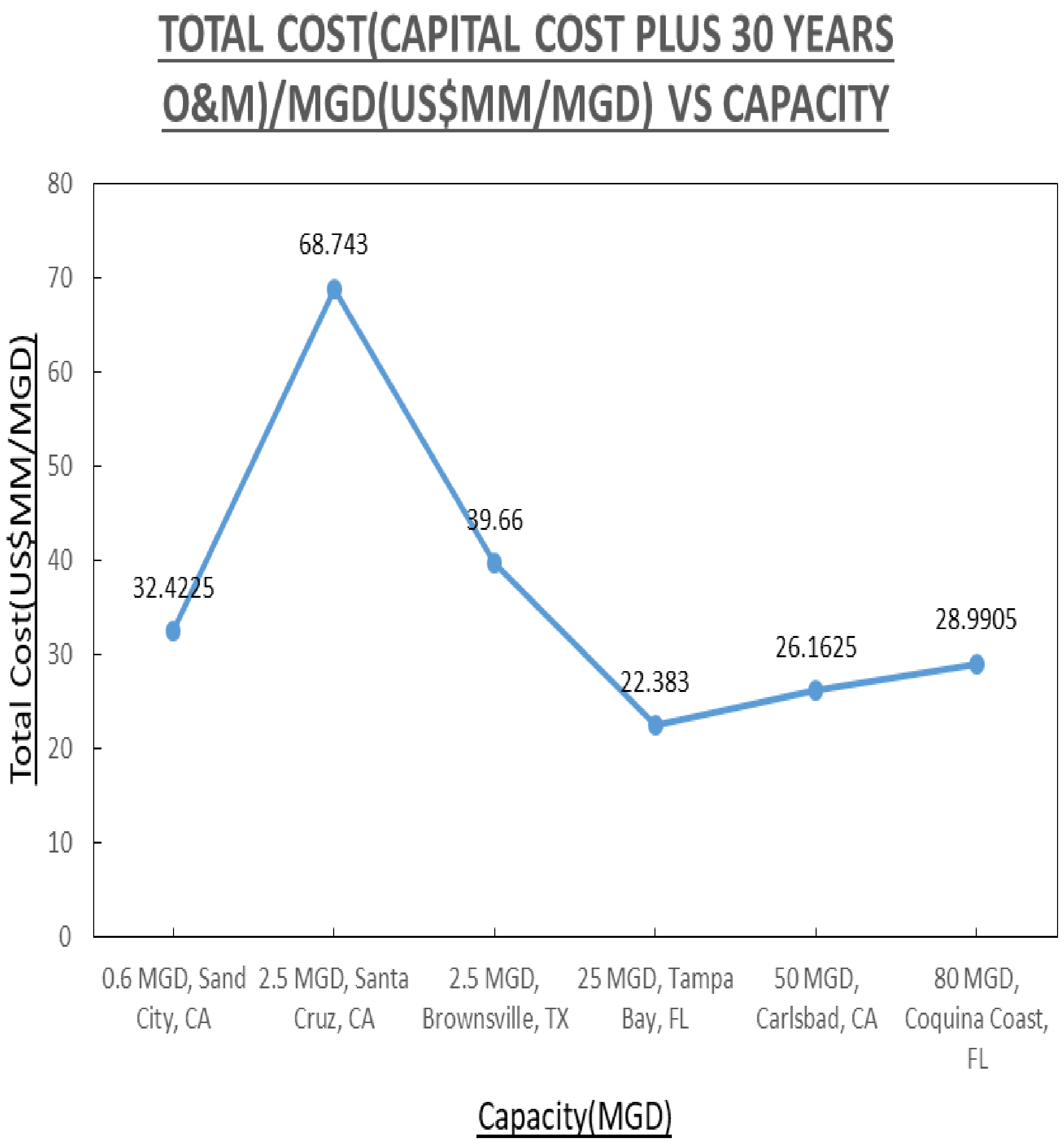


Figure 4.5 Total Cost vs Capacity

- **Most Feasibile Capacity**

As it can be seen from the above analysis that desalination plant with a capacity greater than or equal to 25 MGD is the most feasible option but keeping in view the requirement of drinking water in Karachi, it is imperative to undergo a project of a larger capacity. So we will choose the capacity of 80MGD for our plant and will take forward Desalination plant in Coquina Coast, Florida as case study for cost analysis.

4.2.2. Quality of Water

Figure 4.6 and Figure 4.7 were formulated to study the relationship between Capital Cost and Operational Cost with the quality of product obtained. Figure 4.6 shows that there is more or less a gradual rise in Capital cost based on the level of impurities present in the product while Figure 4.7 shows that the Operational Cost shows a sudden inclination in slope from water ‘Good for Drinking’ to water ‘Excellent for Drinking’. Moreover water ‘Good for Drinking’ fulfills our requirements of the level of product we want to obtain as it is suitable for all types of communities including healthy as well as sick who are in hospitals or at home. So we will move forward with these costs.

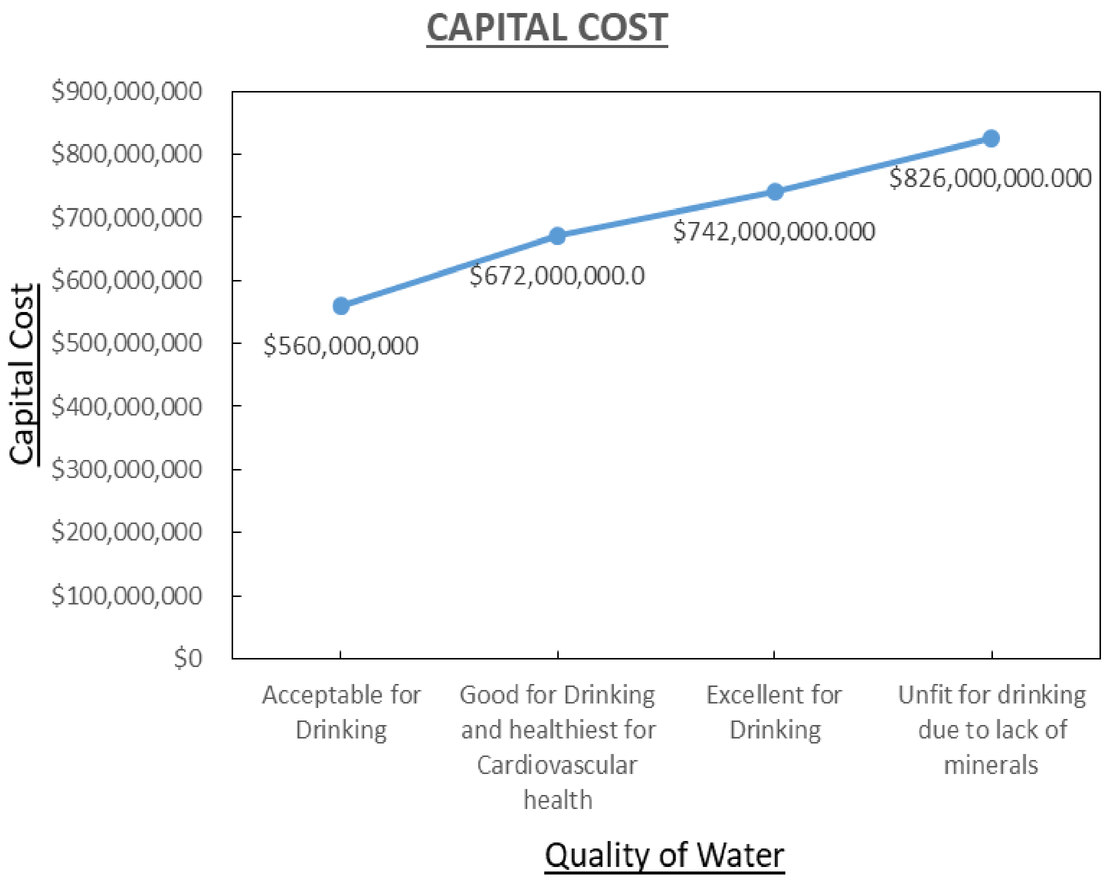


Figure 4.6 Capital Cost vs Quality of Water

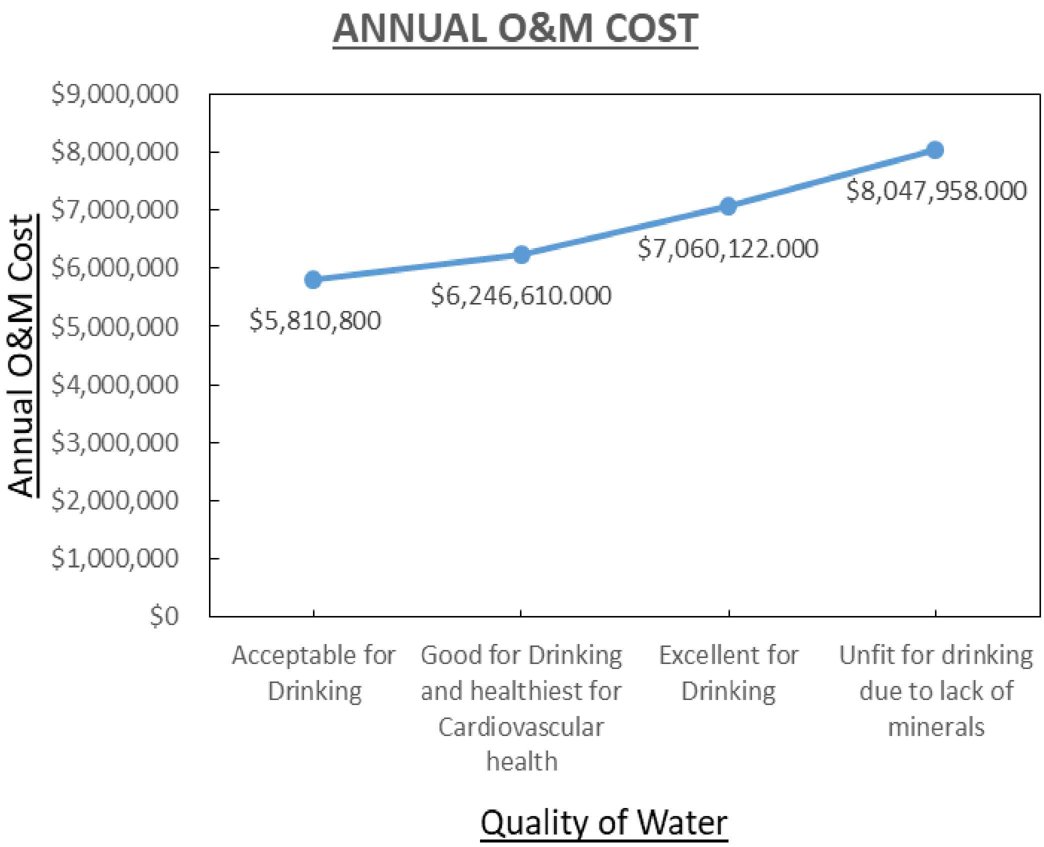


Figure 4.7 Annual O&M Cost vs Quality of Water

4.2.3. Annual increase in Cost with Devaluation of Rupee

Percentage annual Rupee devaluation over the past 20 years was evaluated which came out to be 7.97% (Trading Economics-Pakistan Rupee, 2020). It was used to plot Figure 4.8 to depict the variation in cost of Project during the next 30 years of project life. It takes approximately 2 years for the plant to construct from start to finish so the capital cost has been used for 2 years and have plotted it as per the devaluation of Rupee (Head, 2017). The life of a well-designed and maintained desalination plant is about 25 to 30 years (Watereuse Association Desalination Committee, 2011). So considering the life of our Desalination plant as 30 years, Figure 4.8 has been plotted to show the variation in O&M cost over a period of next 30 years.

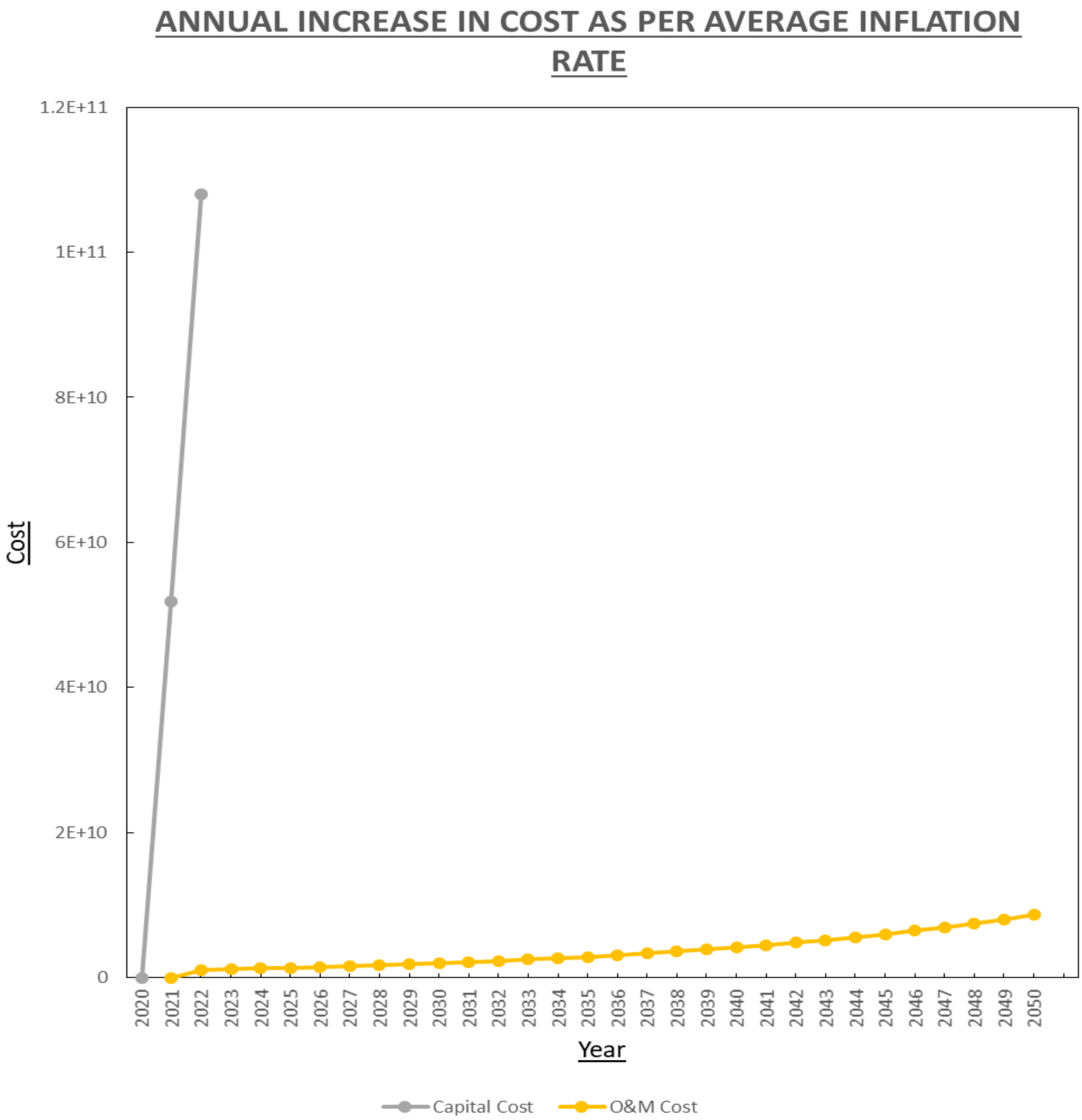


Figure 4.8 Annual Increase in Cost as per Average Inflation Rate

4.2.4. Final Breakdown of Cost.

The final calculation and distribution of Construction cost and O&M cost for year 2022 (1st year of Plant's Operation) is shown in Figure 4.9 and Figure 4.10 respectively by using data from Figure 2.4 and Figure 2.5.

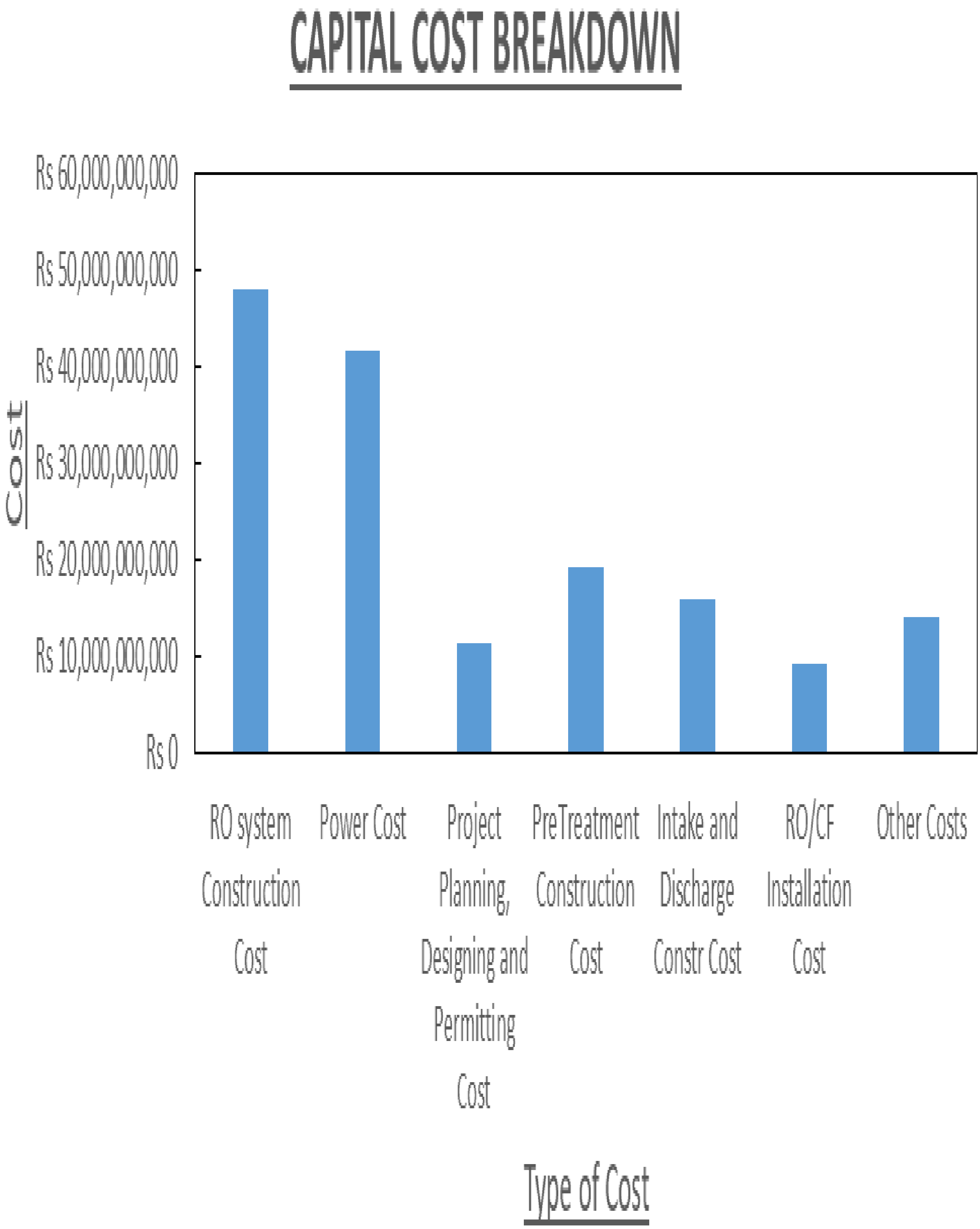


Figure 4.9 Construction Cost Breakdown

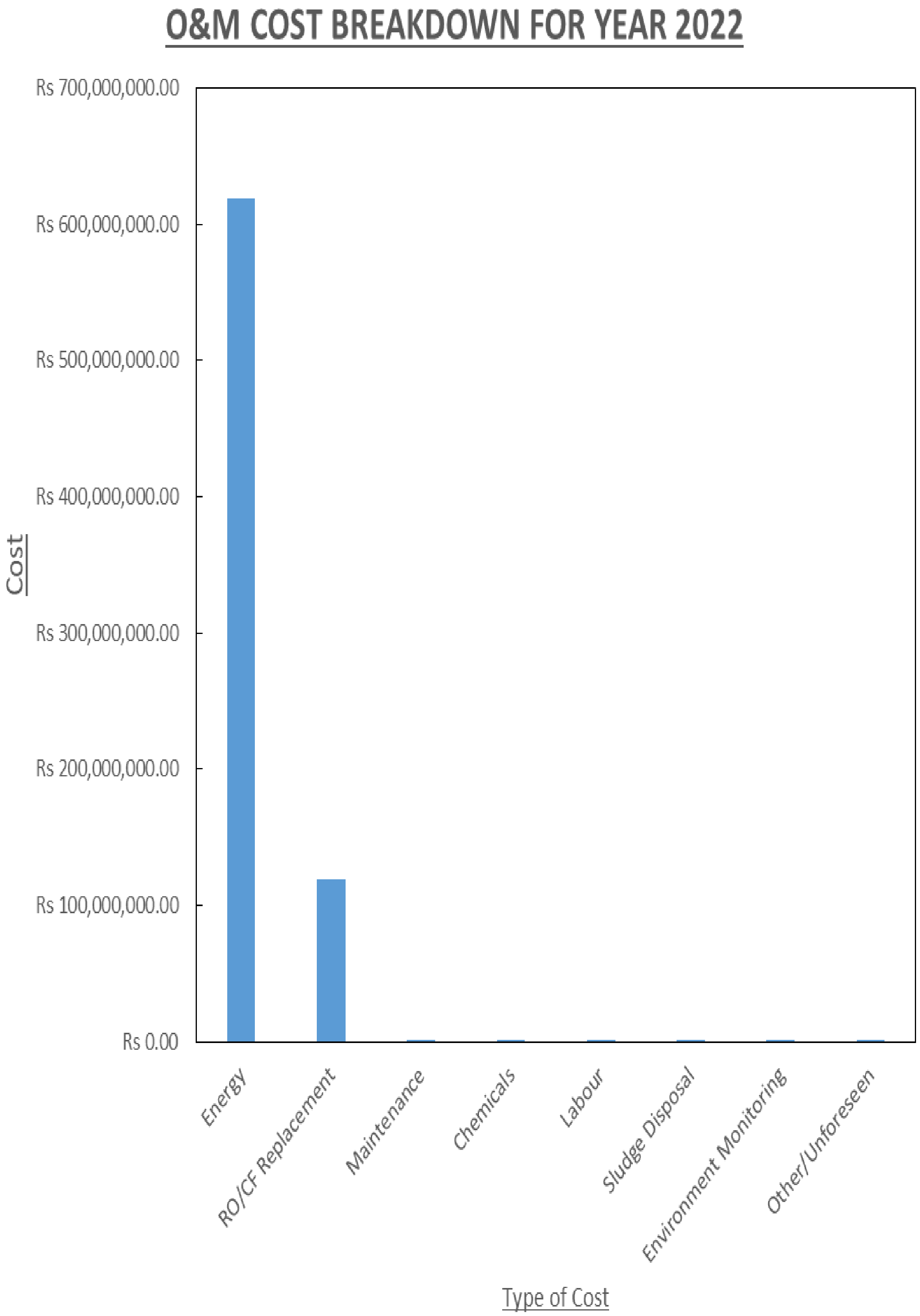


Figure 4.10 O&M Cost Breakdown

4.3. Analysis of Renewable Energy Powered Desalination System

The global shift on the use of renewable energy powered desalination system appears to be a reasonable and more realistic approach in light of the emerging energy and water scarcity problem. In light of the emerging challenges, the dependence on renewable energy powered desalination systems is bound to increase manifolds in near future. In this document, different desalination systems have been studied, keeping in view the economically feasible, efficient desalination system coupled with a RES.

4.3.1. Combination of RES and Desalination Methods

Different desalination methods like RO, Distillation process, ED are being effectively used for desalination of sea water, globally. In order to make these methods cost effective, use of RES is extensively being carried out with these desalination methods. Research and studies are ongoing to analyze and test different combinations of desalination methods and RES for the optimum design configuration resulting in efficient cost effective water treatment of sea water. Table 2.4 provides all the possible combinations that can be integrated for renewable energy powered desalination plant. Figure 2.6 further illustrates the mechanism of transmission of energy from source till its conversion to power respective desalination method. Different combinations have their inherent pros and cons, which need to be analyzed and tested before the application of respective combination. Table 2.5, shows the suitability of various desalination methods with different RES. A thorough assessment of all the viable combinations has been carried out to meet the water shortage issue in Karachi with emphasis on its cost effectiveness and quality of product water.

4.3.2. Renewable Energy Powered Desalination System

Karachi is very humid and high temperature region with traditionally less rainfall throughout the year. Hence, development of a renewable energy powered desalination plant is done to meet the rising water demands of the metropolitan city. Different renewable energy powered desalination systems have been analyzed and assessed to establish a system which meets the water scarcity issue efficiently with emphasis on cost effectiveness and quality of water treated. In section 2.6.4, wind and PV powered desalination systems have been studied to develop a cost effective and efficient system for Karachi water supply issue. Wind powered desalination system is the most economical system with good efficiency but due to high intermittency and dependency on weather, it requires backup source to perform efficiently to meet the requirement. In case of PV driven RO system, there is continuous and a good amount of strong solar energy available around the year to provide better power source as a primary energy source to power the RO unit and reduce the intermittency and weather dependency of the plant. It is evident from Figure 4.11 that solar energy is the cheapest form of energy available naturally, which paves its way for selection as the most favorable option. Also, Figure 2.9 shows the reduction of solar panel price to $0.17/Watt and an increase in the installation of the global solar panels. The trends show a further decrement in the solar energy cost in the future thereby, enhancing its significance further. Figure 4.12, shows the cost analysis of different RES powered desalination systems. Wind RO costs $0.9/cubic meter and PV-RO cost 2.2$/cubic meter but due to availability of continuous solar energy around the year in Karachi and reduction trend in solar energy cost, PV-RO leads the Wind-RO as a preferable option. Figure 4.13 illustrates the global usage of

PV-RO as modern renewable powered desalination system. One of the probable plant site in Cape Mount has a power plant in the near vicinity which can provide a constant electric source to the desalination system as a backup for any energy intermittency.

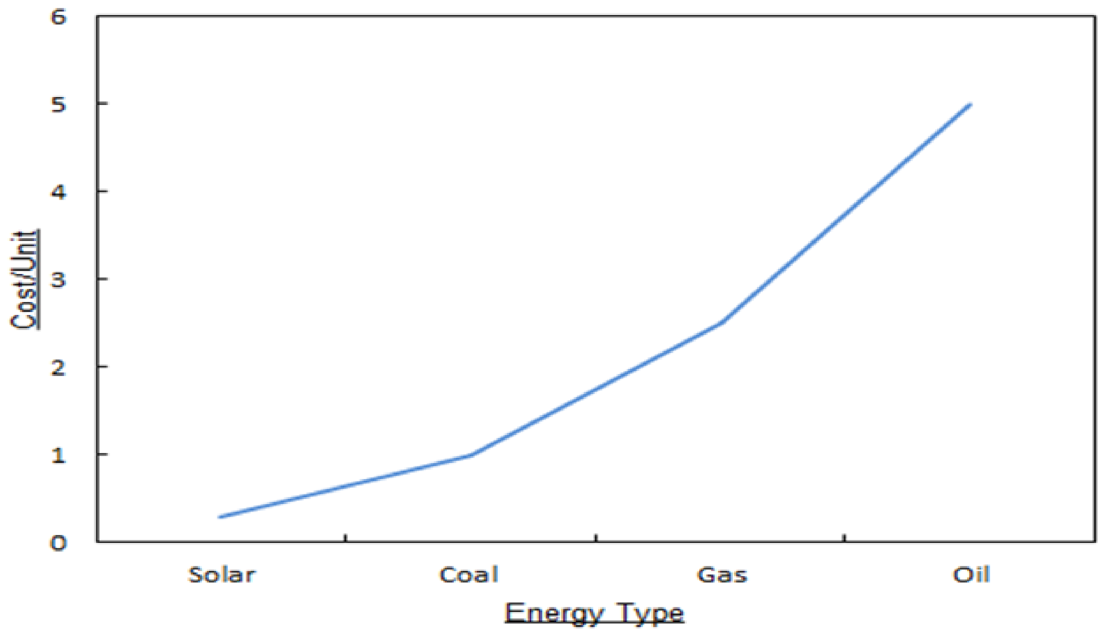


Figure 4.11 Primary Energy Cost

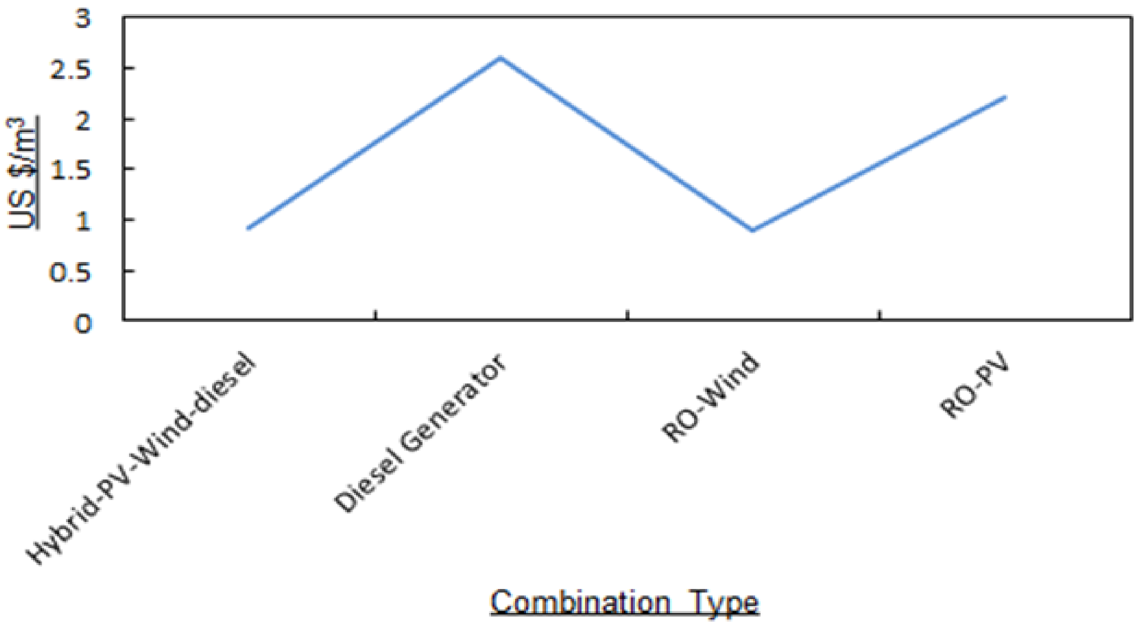


Figure 4.12 Worldwide usage of Different Desalination Techniques

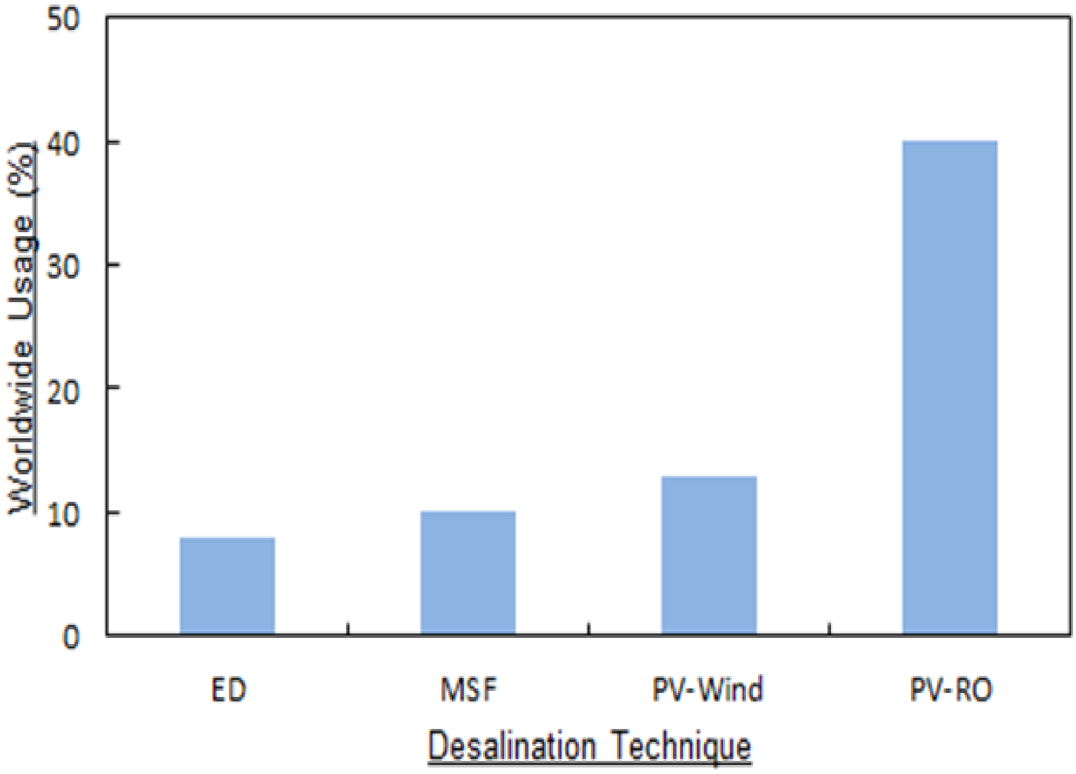


Figure 4.13 Cost Analysis of Different Combination Types

CHAPTER 5

SITE ANALYSIS

CHAPTER 5
SITE ANALYSIS

5.1. Karachi Coast

Karachi coast is the boundry between Indus Delta and northern part of Arabian Sea. It has the total length of 100 km extending from Gharro creek in the east and Hub River in the west. Karachi coast is sub-divided into eastern coast (Gharro creek to Hawkes Bay) and western coast (Hawkes Bay to Hub River). Depth varies from point to point due to rocky and sandy bed.

Eastern coast has mangrove species which plays vital role in maintaining ecological system in the sea whereas western coast is free from it. Aquatic life will be hugely affected by installing desalination plant in mangrove areas. Water quality varies along Karachi coast i.e. eastern part has poor water quality as compared to western part due to Malir and Lyari river outlet. Location of mangrove areas along Karachi coast are as shown below in Figure 5.1.

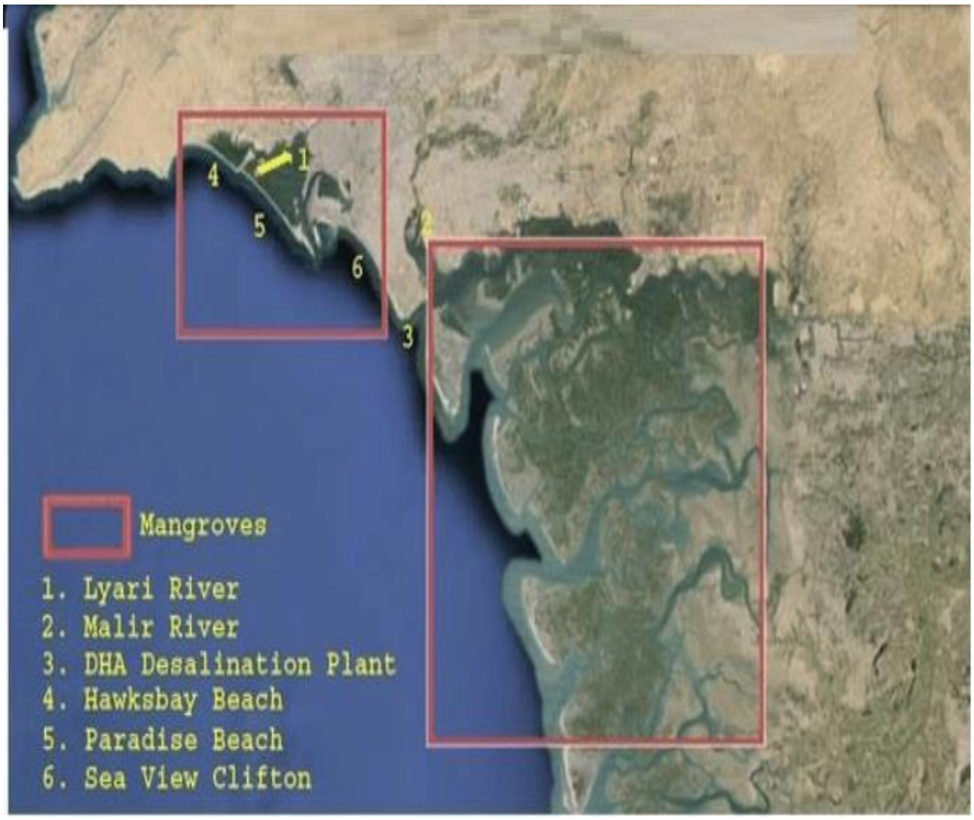


Figure 5.1 Karachi Coast (researchgate.net)

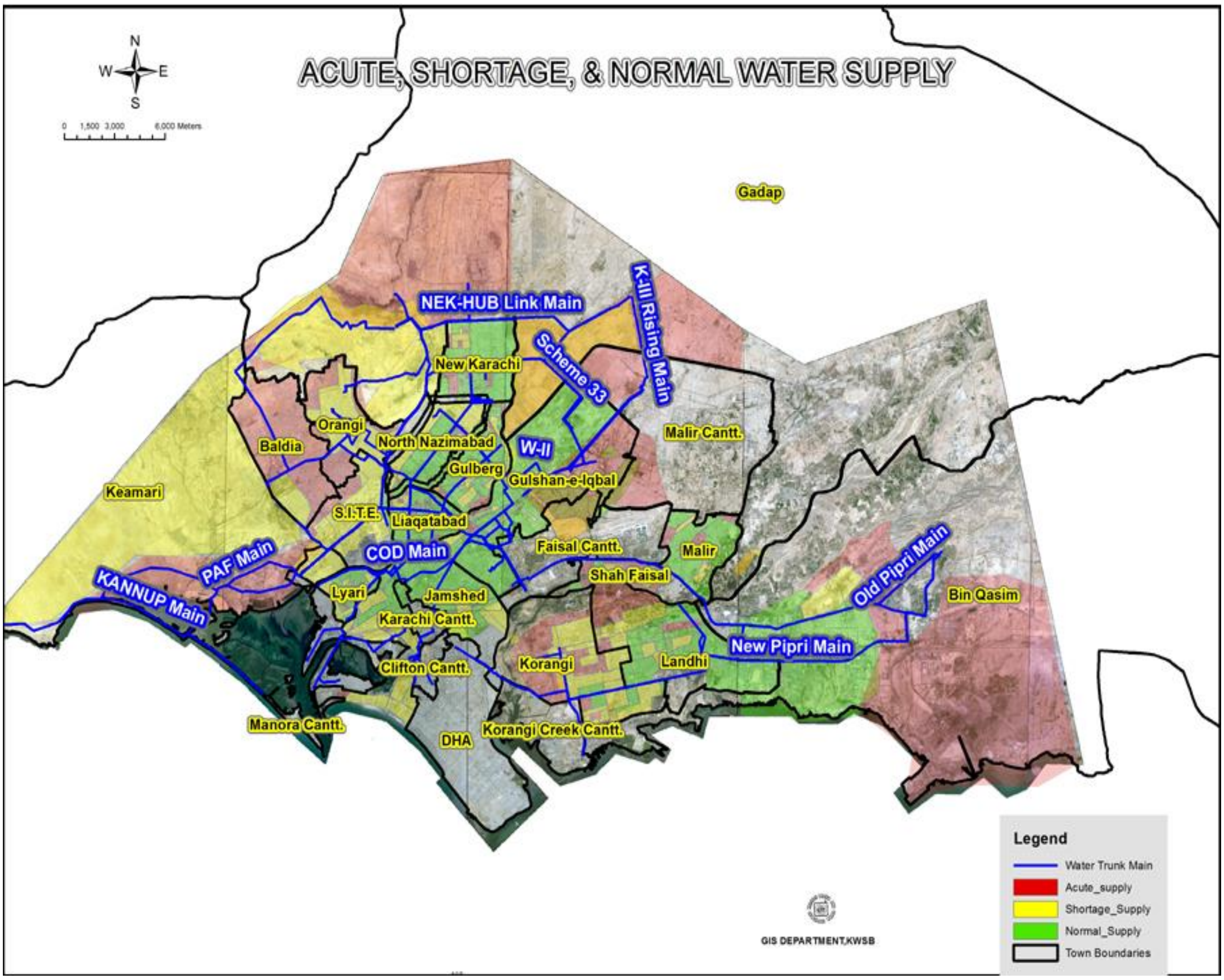


Figure 5. 2 Karachi Water Supply System (KWSB)

5.2. Study Area

Study area for this research is Western part of Karachi coast i.e. from Hawkes-Bay to Hub River. In this study, we will estimate best possible sites for desalination plant along western coast with minimum effect on surrounding environment.

5.3. Site Selection Parameters

Site selection for desalination plant is the primary step to reduce the significant passive effect on surrounding ecological system. Desalination plant site must meet some technical, economical and environmental parameters to make the project technically feasible, economically viable and environment friendly. Following are the parameters which needs to be fulfilled before finalizing site for desalination plant:-

- **Mangrove Areas**

Mangroves are salt tolerant bush type trees which grows in inter-tidal zones of tropical and subtropical areas, river deltas and along the coast. Mangroves serve the ecosystem and maintain balanced aquatic life. They avoid erosion of land. Their survival is of extreme importance and should not be affected by the discharge of brine from desalination plant. Desalination plant must be installed in the area where there are no mangrove species.

- **Road Network**

Access to the site is of prime importance. Road network must be available to ease the material transport during construction phase. Transportation linkage between the plant site and residential areas must be there to facilitate the users and workers of plant.

- **Reclaim Areas**

Site selected for plant must be available and there should be no reclaim areas for smooth execution. Along the Karachi coast there are many reclaim areas on eastern part as compared to western part.

- **Water Quality**

Quality of water must be as per desalination plant required standards. Karachi waste water is discharged into sea via Malir and Lyari Rivers. The outlet of these rivers are in the eastern part of Karachi coast. Therefore, water quality in eastern part is not suitable due to its high degree pollution. Whereas, western part of Karachi coast has good water quality.

- **Coastal depth**

Coastal depth plays vital role in discharge of brine to the sea. Areas with steep slope are best suitable as compared to gentle slope. Steep slopes disperses brine into the sea easily and no pumping action required for the disposal of brine solution. Karachi coast has gentle slope in some areas whereas a sudden depth of 3 m is measured at some areas. Western part of Karachi coast has steep slopes as compared to eastern part.

- **Brine Discharge**

Brine is the by-product of desalination plant, which is saline in nature. It has adverse effect on aquatic life. Brine must be discharged in to sea in a way that it disperses easily and no accumulation along the coastline is occurring. For effective brine discharge we must select area with steep slope.

- **Power Supply**

Desalination plant has to be sited where access to power supply source is easy. The selected site should make the project economical and not expensive by adding up expenditure of laying power lines from power source.

- **Connection to Public Water Supply System**

The desalinated water needs to be supplied to the public for their daily use. For this, we have to select a site which is near to the public water supply system.

- **Away from Public Areas**

Desalination plant should be sited away from public areas because of heavy noises produced during its functioning.

5.4. Suitable Sites

Figure 5.3 shows the various sites that have been identified for Desalination plant. Each site will now be analyzed in detail.

Figure 5.3 Suitable sites for Desalination

5.5. Site Description

- **Hawkes Bay**

Hawkes bay is located at 30 km south-west of Karachi with an easy access due to availability of road network. General lat-long of the area is 24°52’00” N, 66°51’51” E (Figure 5.4). This area of Karachi coast is rich in mangrove species which is important for aquatic life. Hawkes bay is part of sandpit beaches which is used as picnic spot by human beings. It also nests green sea turtle and olive ridley sea turtle during winter months. The area has uniform slope and main water trunks passing near-by. The major drawback of this area for installation of desalination plant is that the quality of sea water is not good due to presence of heavy metals concentration like iron and nickel etc.

Figure 5.4 Hawkes Bay

- **Rehman Goth**

Rehman Goth is located at 24°50’49” N, 66°49’05” E lat-long near french beach with easy access via road network (Figure 5.5). Rehman Goth is in the neighbourhood of Kemari town, Karachi. This area is old-fishing village with fishing as their main economic activity. Due to presence of Karachi Nuclear Power Complex in the near vicinity, the water quality is bad. Also, availability of area for desalination plant is difficult due to security concerns of Karachi Nuclear Power Complex. Rehman Goth hosts mangrove species too. The area has uniform slope and main water trunks passing near-by.

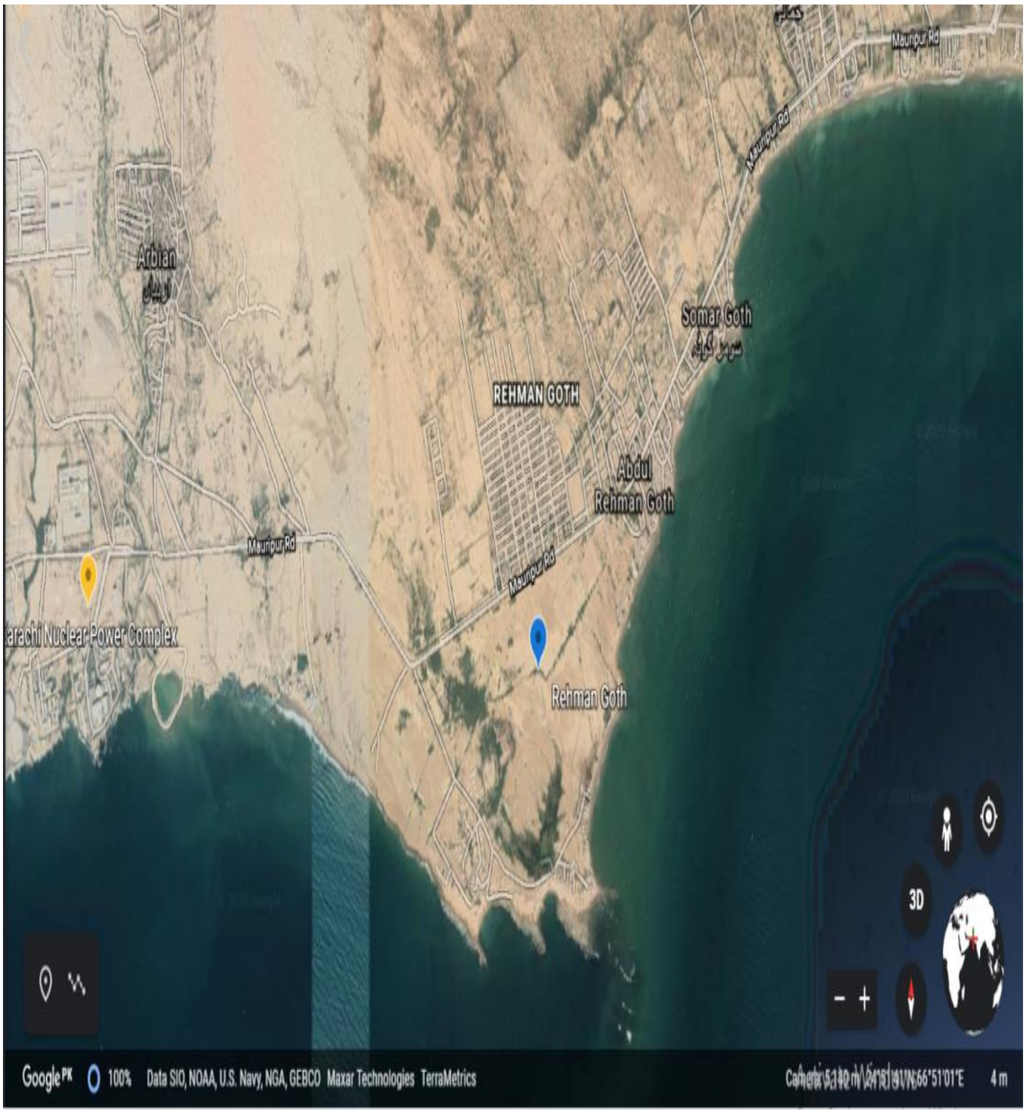


Figure 5.5 Rehman Goth

- **Goth Jumma**

Goth Jumma is located at 24.85° N, 66.74° E lat-long in Karachi, Pakistan (Figure 5.6). Road network is available for easy approach. This area has steep slope, good quality sea water for desalination plant and no mangrove species. This site has no nearby power source. The availability of land for desalination plant at this site is doubtful due to presence of Karachi Nuclear Power Complex, but if land is being made available, it is the best site for desalination plant. The processed water can be made available for use by connecting it to nearby main water trunk.

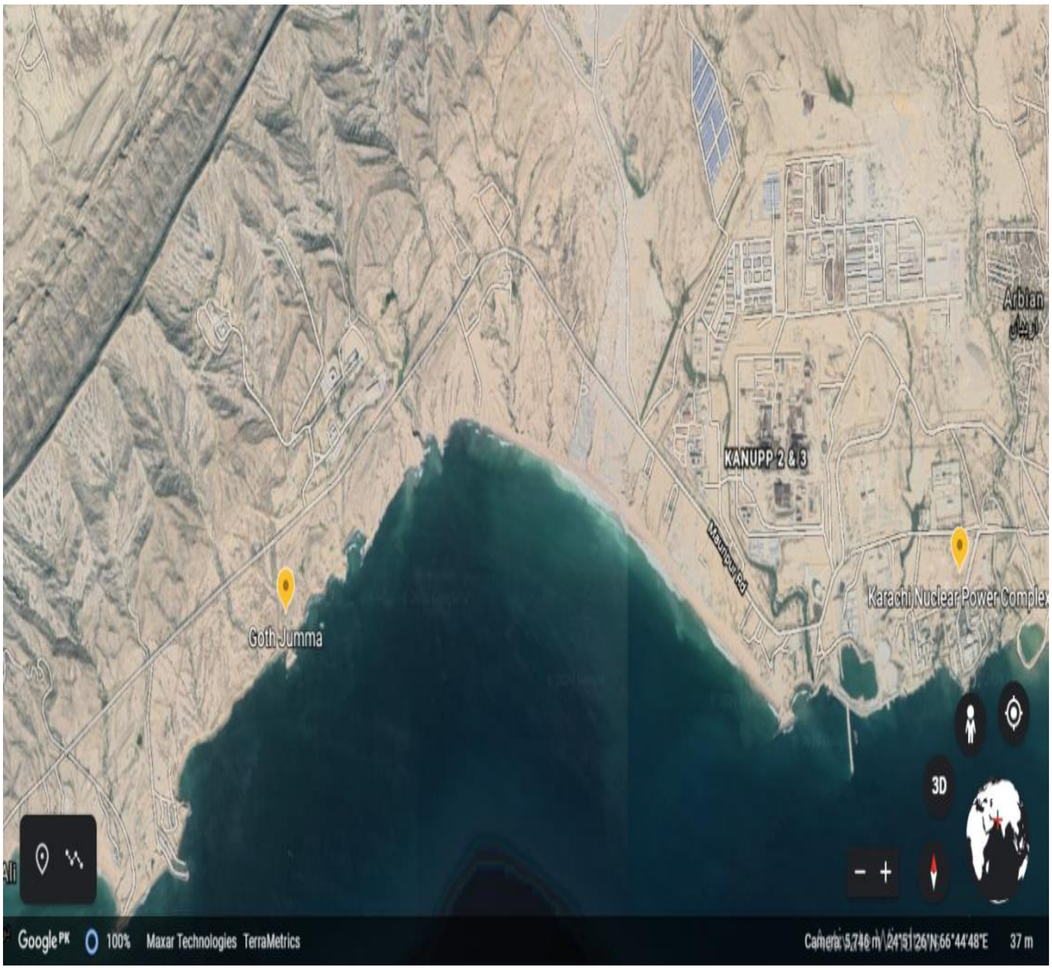


Figure 5.6 Goth Jumma

- **Cape Mount**

Cape mount is basically a beach located at 24°49'35.2" N, 66°39'52" E lat-long (Figure 5.7). This area was used by general public for picnic but recently it has been closed by Karachi Nuclear Power complex. This area is far away from public residency. Geological studies confirms that cape mount has steep slope with sea water quality as per required desalination plant standards. No mangrove species are seen in this part of Karachi coast. It is considered as a habitat for endangered whale, dolphin and turtle species but due to steep slope, the brine discharge will not affect them heavily. Access to this place via road is available. Power for functioning of desalination plant can be made available from nearby Hub Power station. The distribution of processed water can be made by connecting it to nearby main water trunk i.e near KANNUP.

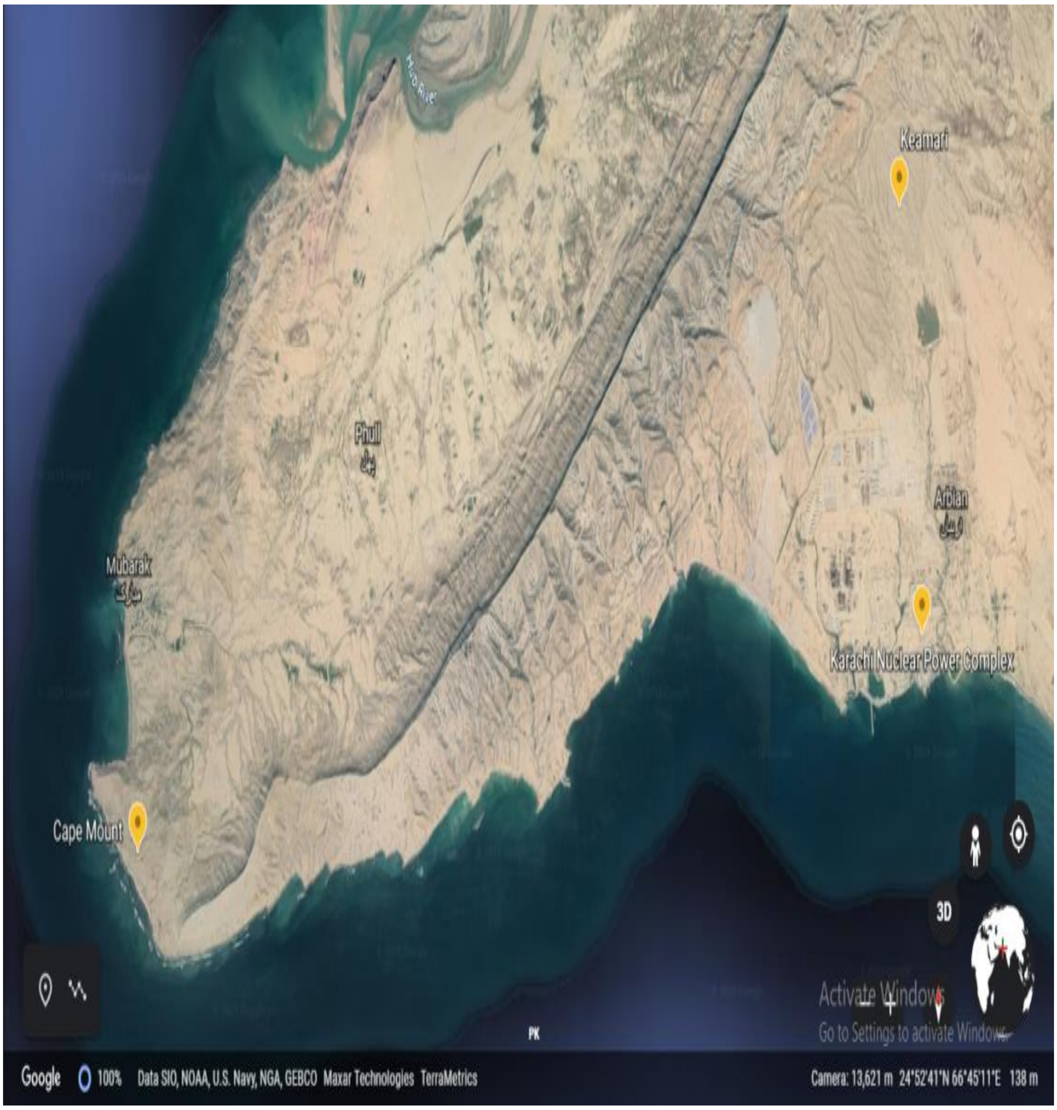


Figure 5.7 Cape Mount

- **Goth Manjar**

Goth Manjar is at the boundry between Sindh and Balochistan province (Figure 5.8). It is situated at 24.88° N, 66.69° E lat-long. This area has the nearest power source i.e. Hub power station. The slope is generally steep and has good water quality. This area is mainly used by locals for fishing as it is the only source of their livelihood. There is no nearby water distribution lines through which desalinated water can be made available for consumers. Road access is available.

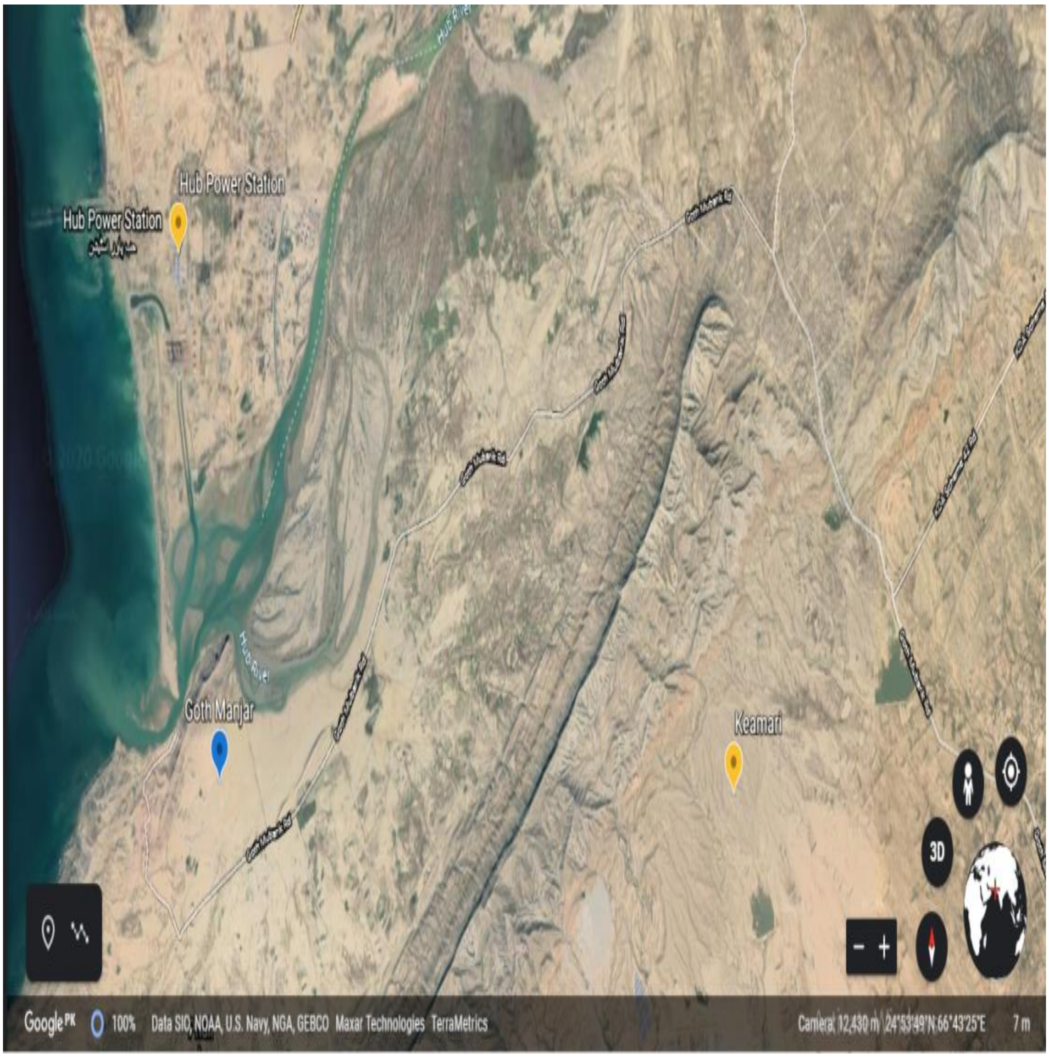


Figure 5.8 Goth Manjar

5.6. Site Ranking Based on Site Parameters

After observing, processing, analyzing and evaluating the required parameters, keeping in view the economical aspect, of the sites for desalination plant, sites have been prioritized in Table 5.1. In addition to aforementioned data, sites have been ranked after studying the effects on aquatic life, availability of land, water quality and nearby power source.

Site Name	Parameters/Factors									Priori-ty
	No Mangrove Areas	No Reclaim Areas	Road Network	Coastal Depth (Steep)	Coast-line	Sea Water Qualit-y	Brine Discharg-e to Sea	Connection to Public Water Supply System	Away from Public Areas	
Hawkes Bay	✖	✖	✔	✖	✔	✖	✖	✔	✖	5
Rehman Goth	✖	✖	✔	✖	✔	✖	✖	✔	✖	4
Goth Jumma	✔	✖	✔	✔	✔	✔	✖	✔	✔	3
Cape Mount	✔	✔	✔	✔	✔	✔	✔	✔	✔	1
Goth Manjar	✔	✔	✔	✔	✔	✔	✔	✔	✖	2

NOTE: Eastern coast has mangrove species and reclaim areas. Also, water quality is not suitable for desalination plant. Therefore, eastern coast is not considered during study.

Table 5.1 Site Ranking

CHAPTER 6

CONCLUSIONS & RECOMMENDATIONS

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

6.1. Overview

The research was conducted with the aim to study the feasibility of a Desalination Plant in Karachi. Although many projects are existing at international level and are functioning successfully but there have been very few cost effective and efficient projects in Pakistan. This study acts as a facilitator and a stepping stone for upcoming projects on SWRO Desalination in Pakistan in general and Karachi in particular, where the study should be taken a step further. This study was conducted in the face of limitations and challenges, the most prominent being that the research related to this topic is very limited in Pakistan. This would however provide some insight to future researchers who intend to continue the endeavor in this field since Pakistan's literature related to SWRO Desalination is in its embryonic stages.

6.2. Conclusions and Recommendations

The water requirement is increasing day by day and available water resources are not sufficient to fulfill the water requirement of Karachi. Shortage of water is already adding up with few upcoming projects which are in the pipeline. K-IV which was a hope for the city, it could have reduced the water shortage by 250 MGD for next 50 years. It was due to complete this year but the construction and management flaws have put the project on hold. Political will and management flaws has already jeopardized its future with no future hope to overcome the rising water issues which will affect the local population and industrial sector of the city.

As our population increases so does the demand for water. Our drying climate means we need to find other sources of water now and in the future. When proper conservation of natural water resources is practiced water reuse has been applied and water deficit still remains. SWRO can now offer a sustainable alternative. With good stewardship it can provide life sustaining water for coastal communities. Desalted water supplies which are not susceptible to drought and other natural disasters can provide clean and safe potable water supply.

This study, after analyzing the water demand and shortfall and its projection over the next few decades plus after carrying out comprehensive analysis of successful and operational Desalination Plants in the world, recommended 80 MGD as the most cost effective capacity of SWRO Desalination Plant and it also recommended the quality of water that will suffice our need and will not be a financial burden. It also inculcates the inflation rate and Rupee devaluation for an accurate assessment. Finally a detailed breakdown of Capital and Operational Cost was put forward.

Energy sources and RES were thoroughly taken into account and analyzed and it was concluded that PV powered Desalination Plant will be the most cost effective and efficiently functioning Plant keeping in mind the weather and climatic conditions. To counter any intermittency, Cape Mount has a power plant in the near vicinity which can provide a constant electric source to the SWRO Desalination Plant.

A detailed and comprehensive site analysis was carried out and five probable sites were thoroughly competed keeping in view the site selection parameters. This led to the final recommendation of Cape Mount as the most feasible site.

It is worth mentioning that along with investment in the sector of Desalination and Research and Development water recycling should be increased by employing treatment facilities to treat brackish water and water dumped with industrial waste. Moreover, awareness should be created for efficient water use and strict water disciplinary measures and conservation measures are required to be put in place. IT is also need of the hour to make strict policies and implement them to ensure that all industries install a treatment plant to treat their waste thereby saving existing water resources.

If water conservation is practiced and proper rules and regulations are implemented along with investment in Desalination sector, our problem of water scarcity and lack of potable water will be history.

BIBLIOGRAPHY

A. MASHIATULLAH, R. M. (2009). PHYSICO - CHEMICAL AND BIOLOGICAL WATER QUALITY OF KARACHI COASTAL WATER. *The Nucleus*.

Abdullah Kaya, M. E. (2019). A Levelized Cost Analysis for Solar-Energy-Powered. *Sustainability*.

Asian Development Bank. (2013). *Asian Development Outlook (ADO) 2013: Asia's Energy Challenge.* Manila, Phillipines: Asian Development Bank.

Carlsbad Desalination Plant. (2017). Retrieved from Carlsbad Desal Plant: www.carlsbaddesal.com

Eltawil, M. A., Zhengming, Z., & Yuan, L. (2008). RENEWABLE ENERGY POWERED DESALINATION SYSTEMS:. *Twelfth International Water Technology Conference, IWTC12 2008, Alexandria, Egyp*, 36.

Enas R Shouman, S. M. (2015). Economics of Renewable Energy for Water Desalination in Developing Countries. *International Journal of Economics & Management Sciences*.

Gleick, P. H. (1993). *Water in Crisis: A Guide to the World's Fresh Water Resources.* Oxford University Press.

Head, T. (2017, October). *Cape Town water crisis: Why desalination can't provide water overnight*. Retrieved from The South African: https://www.thesouthafrican.com/news/cape-town-water-crisis-desalination-issues/

Hilal, Al-Zoub, Darwish, Mohammad, & Arabi, A. (2004). A comprehensive review of nanofiltration membranes:Treatment, pretreatment, modelling, and atomic force microscopy. *Desalination: The International Journal of the Science and Technology of Desalting and Water Purification* , 281-308.

Mohammad Ali Abdelkareema, M. E. (2017). Recent progress in the use of renewable energy sources to power water. *Desalination*.

Reig, P., Maddocks, A., & Young, R. S. (2015, August 26). Ranking the World's Most Water-Stressed Countries in 2040. Washington, DC, United States of America: World Resources Institute.

Tampa Bay Sea Water Desalination. (2019). Retrieved from Tampa Bay Water: https://www.tampabaywater.org/tampa-bay-seawater-desalination

Tariq, e. a. (2016). Physico-Chemical Profile Of Malir river And Chinna Creek. *Procedia Environmental Sciences*, 514 -524.

Trading Economics-Pakistan Rupee. (2020, March). Retrieved from Trading Economics: https://tradingeconomics.com/pakistan/currency

Tvedt, T., & Jakobsson, E. (2006). *A History of Water: series I: Vol. I: Water Control and River Biographies.* I.B Tauris.

Voutchkov, N. (2010). *Slide Serve.* Retrieved from Slideserve.com: https://www.slideserve.com/kendis/nikolay-voutchkov-pe-bcee

Voutchkov, N. (2012). *Desalination Engineering: Planning and Design.*

Voutchkov, N. (2014). *Desalination Engineering: Operation and Maintenance.*

Water Resources Management. (2017). Retrieved from The World Bank: worldbank.org/en/topic/waterresourcesmanagement#1

Watereuse Association Desalination Committee. (2011). *Overview of Desalination Plant Intake Alternatives.* Watereuse Association.

World Economic Forum. (2019). *The Global Risks Report.* Geneva: World Economic Forum.