

إقرار

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Environmental Impacts of Brine Disposal to the Sea

Case Study: Deir El-Balah SWRO Plant

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Environmental Impact of Brine Disposal to the Sea

Case Study: Deir El-Balah SWRO Plant

الأثر البيئي للمحلول الملحي الخارج من محطة تحلية دير
البلح على البحر

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نتيجة الحكم على أطروحة ماجستير

بناءً على موافقة شئون البحث العلمي والدراسات العليا بالجامعة الإسلامية بغزة على تشكيل لجنة الحكم على أطروحة الباحث/ حسن أحمد حسن الطويل لنيل درجة الماجستير في كلية الهندسة قسم الهندسة المدنية - البنى التحتية وموضوعها:

الأثر البيئي للمحلول الملحي الخارج من محطة التحلية في دير البلح على البحر

Environmental Impacts Of Brine Disposal To The Sea Case Study:- Deir El-Balah SWRO Plant

وبعد المناقشة العلنية التي تمت اليوم الأحد 13 ربيع الأول 1436هـ، الموافق 2014/01/04م الساعة العاشرة صباحاً بمبنى القدس، اجتمعت لجنة الحكم على الأطروحة والمكونة من:

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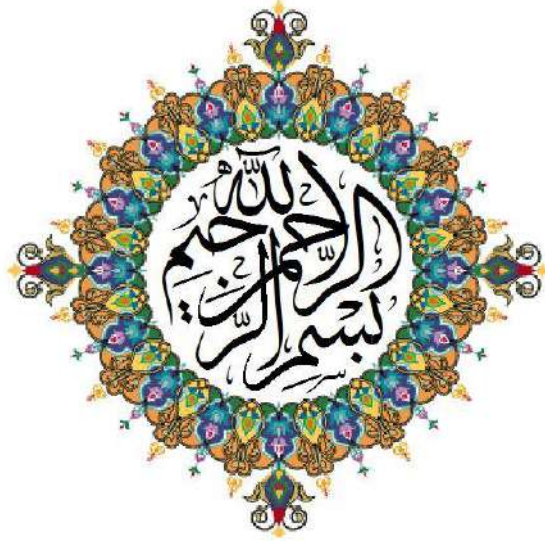
واللجنة إذ تمنحه هذه الدرجة فإنها توصيه بتقوى الله ولزوم طاعته وأن يسخر علمه في خدمة دينه ووطنه.

والله ولي التوفيق،،،

مساعد نائب الرئيس للبحث العلمي والدراسات العليا

أ.د. فؤاد علي العاجز





[ذَٰلِكَ فَضْلُ اللَّهِ يُؤْتِيهِ مَن يَشَاءُ وَاللَّهُ ذُو الْفَضْلِ الْعَظِيمِ]

الآية (4) الجمعة

Abstract

Water desalination plants produce huge amounts of reject brine, which are usually sent back to the sea, where they could, in the long run, result in detrimental effects on the aquatic life as well as the quality of the seawater in the area.

The major goal of this study is to investigate the effect of brine disposal of Deir El-Balah desalination plant on the quality of seawater. The negative impact relatively features with high temperature, high salinity and low dissolved oxygen in water.

This study was conducted on the status-quo of Deir El-Balah desalination plant. The capacity of Deir El-Balah desalination plant today is around 2600 m³/d with a recovery rate of 42%. It depends in water desalination whether on the saline well that was drilled in the plant or the beach wells. The study focused on figuring out the characteristics of the seawater in its natural status without the effect of brine by considering a reference point (R) which is 1600 m away from the south of the disposal point. In addition, the characteristics of the seawater in the discharge area after the Brine discharge were studied and the difference in the measured parameters referring to the reference point R was observed.

It is noteworthy that the study was through two seasons of the year, summer and autumn and the process of sampling was done in three rounds in total of thirty points distributed within an area of 200 m² surrounding the brine disposal point. Seawater parameters that are the most important in this issue, salinity (measured by EC), temperature, dissolved oxygen (DO), turbidity and pH were measured according to the previous studies due to its effect on the seawater quality and the marine life.

After the analysis of the above-mentioned parameters, the study explained that brine of Deir El-Balah desalination plant has no effect on the seawater quality, since the maximum values from the three rounds measurement of EC, temperature, DO, Turbidity, and pH are 60.2 mS/ cm, 29.4 C°, 9.2 mg/l, 5.36 NTU, 8.349 respectively. This may be due to the small volume of the brine quantity that is resulted from the desalination process which is considered relatively little to influence the seawater and represents nothing comparing with the physical and chemical continuous changes in the seawater.

The study has recommended that all environment interested authorities as environment quality authority and other responsible institutions should conduct monitoring and evaluation programs for large scale desalination plant and using modeling to simulate reality precisely throughout the year, in order to know the best options to build desalination stations that neither affects the seawater quality nor causes negative effect on the sea environment.

Abstract in Arabic

الملخص

ينتج عن محطات التحلية كميات كبيرة من المحلول الملحي، والذي عادة ما يتم إرسالها إلى البحر مرة أخرى، مما قد يتسبب بآثار ضارة على الأمد البعيد على الحياة البحرية و جودة مياه البحر في المنطقة. الهدف الرئيسي من هذه الدراسة هو معرفة تأثير المحلول الملحي، والذي ينتج عن محطة تحلية دير البلح على جودة مياه البحر. يكمن الأثر السلبي للمحلول الملحي في الحرارة العالية، الملوحة العالية ونقص الأكسجين المذاب في الماء.

أجريت هذه الدراسة على الوضع القائم بالنسبة لمحطة تحلية دير البلح. تقدر القدرة الإستيعابية للمحطة حالياً بـ 2600 (م³/اليوم) و نسبة الإسترجاع 42%. تعتمد المحطة في تحلية المياه إما عن طريق مياه البئر والذي يوجد داخل المحطة أو الآبار الساحلية. تركزت الدراسة على معرفة خصائص مياه البحر في وضعها الطبيعي وبدون تأثير المحلول الملحي عليها، وذلك باعتبار أن النقطة R هي النقطة المرجعية والتي تبعد 1600 متر جنوباً عن نقطة التصريف وهي قبالة منطقة البحرية. بالإضافة لخصائص مياه البحر - التي تم دراستها بعد تصريف المحلول الملحي - في منطقة التصريف، فقد تم مراقبة الفرق في جودة العناصر المقاسة بالنسبة لنفس العناصر عن النقطة المرجعية.

يشار إلى أن فترة هذه الدراسة كانت خلال فصلين من السنة وهما فصل: الصيف والخريف، حيث تمت عملية أخذ العينات على ثلاثة محاولات، وكان ذلك لثلاثين نقطة موزعة على 200 متر مربع حول نقطة تصريف المحلول الملحي. تم قياس عناصر البحر الأكثر أهمية في هذا المجال وهي (الملوحة متمثلة بالتوصيلية الكهربائية، الحرارة، الأكسجين المذاب في الماء، العكارة و الرقم الهيدروجيني)، وكان ذلك في ضوء أصول أخذ العينات ونصائح الأكاديميين و الخبراء في هذا مجال. وقد تم فحص عناصر البحر الأكثر أهمية في هذا الشأن وفقاً للدراسات السابقة والخبراء في هذا الشأن لما لها من تأثير على جودة مياه البحر والبيئة البحرية.

أوضحت الدراسة بعد تحليل هذه العناصر المذكورة سابقاً أن المحلول الملحي لمحطة دير البلح ليس له أي تأثير على جودة مياه البحر، وذلك بسبب أن القيم العليا للقياسات في المحاولات الثلاثة كانت لكل من (الملوحة، الحرارة، الأكسجين المذاب، العكارة و الرقم الهيدروجيني) هي كتالي على الترتيب 60.2 ملي سيمنز/ سم، 29.4 درجة مئوية، 9.2 ملي جرام / لتر، 5.36 وحدة عكارة و 8.349. قد يرجع ذلك لقلة وصغر كميات المحلول الملحي الناتجة عن عملية التحلية والتي تعتبر قليلة نسبياً بالمقارنة مع تأثير البحر، فهي لا تمثل شيئاً بالمقارنة مع التغيرات الفيزيائية والكيميائية المستمرة لمياه البحر.

وقد أوصت هذه الدراسة كافة الجهات المعنية بالبيئة، كسلطة جودة البيئة، وغيرها من المؤسسات المسؤولة بأن تقوم ببرامج مراقبة وتقييم لمحطات التحلية الكبيرة واستخدام النمذجة لمحاكاة الواقع بشكل دقيق و على مدار العام، و بالتالي معرفة أفضل الخيارات لإنشاء محطات التحلية بحيث لا تؤثر على جودة مياه البحر ولا تتسبب بالتأثير سلباً على البيئة البحرية.

Dedication

- ✚ Everyone who sacrificed his life for the others to ensure better life and prosperous future for humankind.
- ✚ My parents who have always stood by me and dealt with all of my absence from many family occasions with a smile. Their support, encouragement, and constant love have sustained me throughout my life.
- ✚ To my wife and son who have been a great source of motivation and inspiration.
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- ✚ Every teacher who pays efforts to enrich our knowledge along all the studying period.
- ✚ Our martyrs' souls, who offered themselves for the liberation of Palestine.
- ✚ Every person who offers a useful science, a good deal, for the sake of the Islamic nation.

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Abbreviations and Notations

Institutions

WHO	World Health Organization
PWA	Palestinian Water Authority
EQA	Environmental Quality Authority
MoLG	Ministry of Local Government
MOH	Ministry of Health
CMWU	Coastal Municipalities Water Utility
MEDRC	Middle East Desalination and Reuse Center
NIS	New Israel Shekel
MASWDP	Middle Area Seawater Desalination Plant
PCBS	Palestinian Central Bureau of Statistics
UAE	United Arab Emirates
UNDP	United Nation Development Program
USAID	United States Agency for International Development
UG	Universal Group
IsDB	Islamic Development Bank
EU	European Union
UNICEF	United Nations International Children's Emergency Fund
Variable	

EC	Electrical Conductivity
RO	Reverse Osmosis
SWRO	Sea Water Reverse Osmosis
BW	Brackish Water
MD	Membrane Distillation
MED	Multiple Effect Distillation
MF	Microfiltration
NF	Nanofiltration
SW	Seawater
PV	Photovoltaic
TDS	Total Dissolved Solids
Temp	Temperature
UF	Ultra Filtration
ED	Electro-dialysis
MSF	Multi-stage Flash
FO	Forward Osmosis
CDI	Capacitance Deionization
GH	Gas Hydrates
HDH	Humidification Dehumidification
TBT	Top Brine Temperature
CBC	chlorinating byproducts
LTD	Low Temperature Distillation

Units

kW/hr	Kilo Watt per hour
kWh/m³	Kilo Watt per cubic meter
kV	Kilovolt
MCM	Million cubic meter
MJ	Mega Joule
MW	Mega Watt
MCM/Y	Million Cubic Meters per year
Mgd	Million gallons per day
mg/l	Milligram Per Litre
Ppm	Part Per Million
ds/m	deci Siemens per meter
NTU	nephelometric turbidity unit

Chapter 1: Introduction

1.1 Background

Water is a key to sustainable development, and the problems of water form part of the broader challenges of sustainable development. Water is more than a sector or commodity. Access to safe drinking water is a basic human need, essential for health and also for human dignity. The effective management of water resources is essential to the development of environmental, social, agricultural and industrial development in all countries, especially the developing ones.

One of the major options for the remedy of water shortages in the Gaza Strip of Palestine, and the protection of its coastal aquifer from either depletion and/or becoming saline, is the utilization of desalination technology for brackish and seawater in that region. It is expected that in the long term desalination would be an optimum to apply to different uses of human consumption, such as irrigation, domestic, and industrial. Seawater desalination has gained importance in coastal countries where conventional water sources are insufficient or overexploited. It can be considered an inexhaustible natural source that generates a high quality product and guarantees demand supply [1].

Seawater desalination contributes positively to the environment (e.g. reducing exploitation of non-renewable drinking water sources) and to humanity, but at the same time may cause negative local impacts on the environment. Besides the impacts regarding energy consumption and land use, the major impact is related to the marine environment, especially to coastal water quality [2]. Seawater desalination plants carry a number of waste products into the coastal ocean [3].

The most direct product is a concentrated salt brine discharge that may also have an elevated turbidity and temperature (latter most notable for plants with thermal desalination techniques such as multistage flash (MSF)). Other waste products relate to chemicals used for biofouling control (e.g. chlorine), scale control (antiscalants), foam reduction, and corrosion inhibition. Depending on the physical and ecological characteristics of the receiving waters, these substances can have a harmful impact on the local environment.

Especially vulnerable areas such as mangrove forests, salt marshes, coral reefs, or generally, low energy intertidal areas, while exposed rocky coasts with high energy wave action may be less susceptible [4]. Enclosed seas, like the gulf or the Redsea have limited water exchange capacities and are generally shallow and less energetic, thus more sensitive to effluent discharges. Potential impacts on local fisheries or tourism resources with considerable economic consequences are some of the conflict points that arise when planning desalination plants. In particular, increased plant capacities raise the impact concentrations of effluent constituents to levels that can become harmful to the marine environment.

Genthner [5] notes that there is increased public concern and scientific awareness on the environmental impact of desalination plants. For example, objections in the USA regarding environmental impacts have already become key issues for project permits,

often considerably influencing plant commissioning and design [6]. The necessity of sound environmental impact studies and public involvement will further increase because several countries define new regulatory strategies on protection and conservation of the marine environment [7].

From a regulatory viewpoint, many countries (e.g. USA or European Union countries) restrict the levels of aquatic pollutants both at the discharge point (“effluent standards”, e.g. chlorine, 7.5 µg/L, US-EPA) as well as within the receiving water (“ambient standards”). The former encourage source control principles and treatment and recycling technologies. The latter demand for the consideration of the ambient response often associated with the concept of the “mixing zone”, an allocated impact zone in which the numerical water quality standards can be exceeded [8].

In order to meet these regulations, optimized high efficiency mixing designs are needed for the brine effluent discharges which need to be embedded in a sustainable concentrate management plan. Together these technologies can be considered as concentrate management technologies. However, discharge designs are often not optimized regarding environmental impacts nor operational needs. In addition, regulations often lack clear guidance regarding the control of ambient standards or environmental impact studies [8].

Consequently it can be observed that the majority of discharges, especially in the Middle East North African (MENA) region, are surface discharges directly at the coastline with very low mixing capacities. Similar design deficiencies also apply for intakes, that can be harmful to fish or other species.

In addition, there is a potential for recirculation to the plant intake, reducing overall system efficiency especially for larger plants or plant complexes. Scientifically validated and efficient planning tools in the form of predictive models and expert system design guides are needed to assist desalination plant designers and plant managers in designing and operating the intake-treatment outfall scheme so that environmental impacts on the marine environment can be controlled and minimized. The preliminary results of the development of such tools are presented as follows.

1.2 Problem Statement

Brine disposal is becoming a huge problem as a consequence of the extensive application of reverse osmosis (RO) technology for desalination purposes. Recent studies confirmed the impact of discharged RO concentrates on soil, on groundwater (contamination by residual chlorine, heavy metals [9]), and on marine fauna and flora (increase of mortality of *Posidonia Oceanica* [10], damage of benthic organisms due to coagulants [11], etc.). In this context, many environmental issues are associated with desalination plant. Brine, the concentrated discharge of the desalination process, has serious impacts on the seawater quality [9].

Deir El-Balah Desalination Plant may cause negative impacts on the seawater quality and marine life since the brine composed of high value of total dissolved solids (TDS), high temperature and others which could increase the salinity, turbidity but could

decrease dissolved oxygen. Considering the fact that this research was dealt with one of the biggest environmental concern of desalination plant – the impact of brine disposal on marine environment.

1.3 Main Goal

The main goal of this study is to identify and verify the physiochemical impacts of brine of Deir El-Balah desalination plant on the marine indicators like temperature, alkalinity, dissolve oxygen, salinity and turbidity of the seawater which resultant serious effect on marine environment.

1.4 Objectives

- To study quality of the seawater before and after the processes of desalination in Deir El-Balah desalination plant.
- Evaluate and asses the current disposal of brine to the sea.

1.5 The Significance of this Research

The study contributes to solving the water problem suffered in the Gaza Strip through avoiding or minimizing negative environmental impacts of brine disposal to the sea.

1.6 Thesis Structure

This thesis consists of six chapters arranged carefully in the order to make it clear and understandable. This section presents a brief description of these chapters.

Chapter (1): Introduces the reader to the general features of the subject, statement of problem, goal, objectives of the research, and the significance of this study.

Chapter (2): Provides a general review of relevant previous studies and the main marine indicators.

Chapter (3): Represents the methodology adopted in the research, discusses the experimental details, experimental program, dimension of samples that used, materials properties that used.

Chapter (4): Represents the description of the Deir El-Balah desalination plant.

Chapter (5): Discussion and analysis of sampling results for seawater and brine.

Chapter (6): This chapter states the conclusions and recommendations.

Chapter 2: Literature Review

2.1 Introduction

Water is a key to sustainable development, and the problems of water form part of the broader challenges of sustainable development. Water is more than a sector or commodity. Access to safe drinking water is a basic human need, essential for health and also for human dignity. Together with the supply of energy and the environmental protection, fresh water is one of the three key elements for the sustainable development of every society. Fresh water is needed in agriculture, as drinking water, and as process water in a large variety of industries. According to several studies water covers over 75% of the earth surface and saline water makes up 97% of this; however just 3% is fresh and potable, used for different purposes such as domestic, industrial and agriculture demands as shown in Figure (2.1) [12].

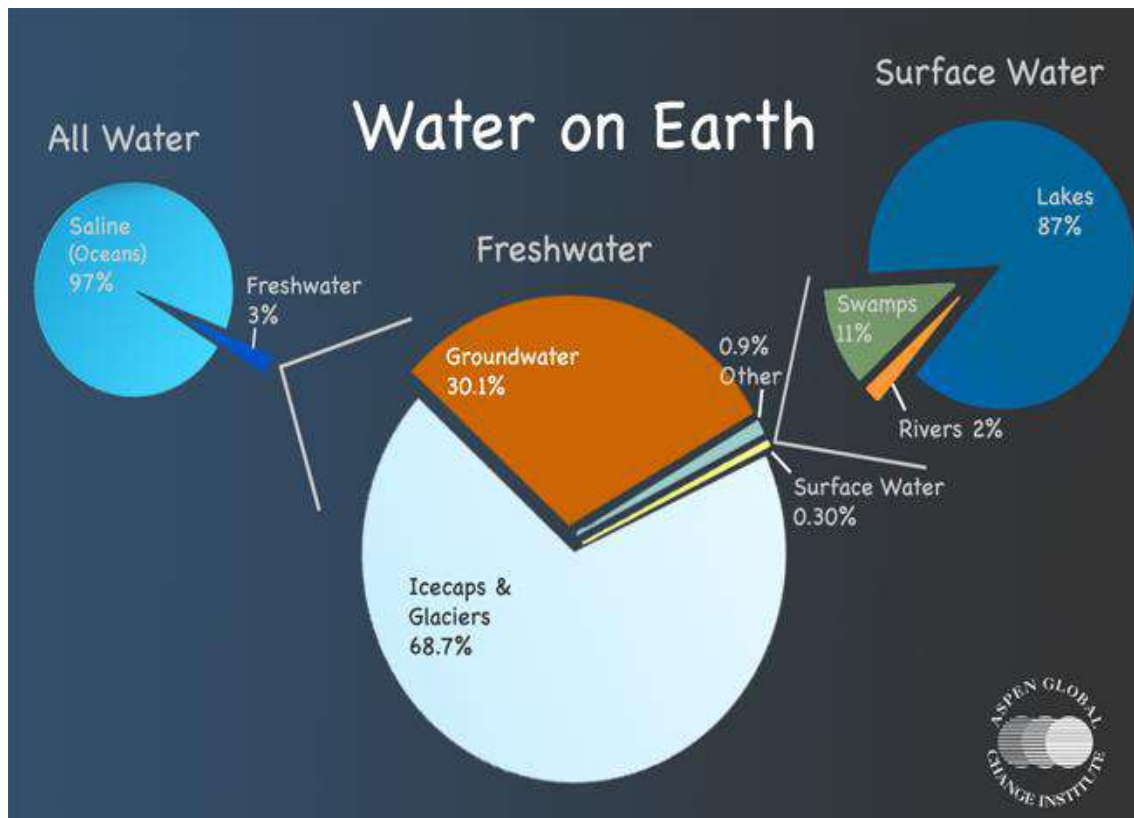


Figure (2.1): Distribution of earth's water [12]

Based on the latest figures from the United Nation's "World Water Development Report" more than 50 percent of the nations in the world will face water crises by 2025, however by 2050 about 75 percent of the world population will have a significant possibility of facing water shortages [12].

In the 21st century, recognition of a potential water shortage and the unpredictable impact of global warming on overall water scarcity posits that the first and second decades should be referred to as the "water crisis decades" [13]. This shortage can be

partially attributed to global population growth, limited natural resources, and increased industrial activities [14].

Consequently, to resolve the water scarcity problem in many regions around the world, seawater is no longer merely a marginal water resource for resource limited countries. In a recent global industry forecast [13], from as recent as many years ago the global desalination industry can be seen to be rapidly expanding, and this is just the beginning stage of desalination market expansion.

Where the availability of water cannot be carried out by using conventional sources, unavoidable appears the resort to the major water source: the sea. As a matter of fact, desalination processes represent a valid solution to the water shortage problem and their application has completely changed the situation in many arid zones in the world.

Seawater desalination is becoming increasingly popular for production of fresh potable water as many coastal municipalities and utilities worldwide are looking for new, reliable and drought proof local sources of water supply. One of the key limiting factors for the construction of new seawater desalination plants is the availability of suitable conditions and location for disposal of the high-salinity side-stream generated during the desalination process commonly referred to as concentrate or brine [15]. This research provides an overview of key environmental impacts of seawater desalination plant concentrate discharges and discusses alternatives and identify the effect of Deir El-Balah desalination plant.

The environmental impacts of seawater desalination plant operations have many common features with these of conventional water treatment plants for fresh water production from surface waters. Similar to conventional water treatment facilities, desalination plants have waste stream discharge which may impact the aquatic environment. Both desalination facilities and conventional water treatment plants use many of the same chemicals for source water conditioning, and therefore, have similar waste streams associated with the disposal of spent conditioning chemicals and source water solids [15].

2.2 Desalination Plant

Desalination can be defined as any process that removes salts from water. Desalination processes may be used in municipal, industrial, or commercial applications. With improvements in technology, desalination processes are becoming cost-competitive with other methods of producing usable water for our growing needs [16].

Current engineering and scientific efforts need to be focused in the removal of excess salt from sea and underground water. Several technologies are now available such as membrane separation, thermal processes, and physicochemical methods; Figure (2.2) shows that all of the technologies mentioned have been studied and implemented;

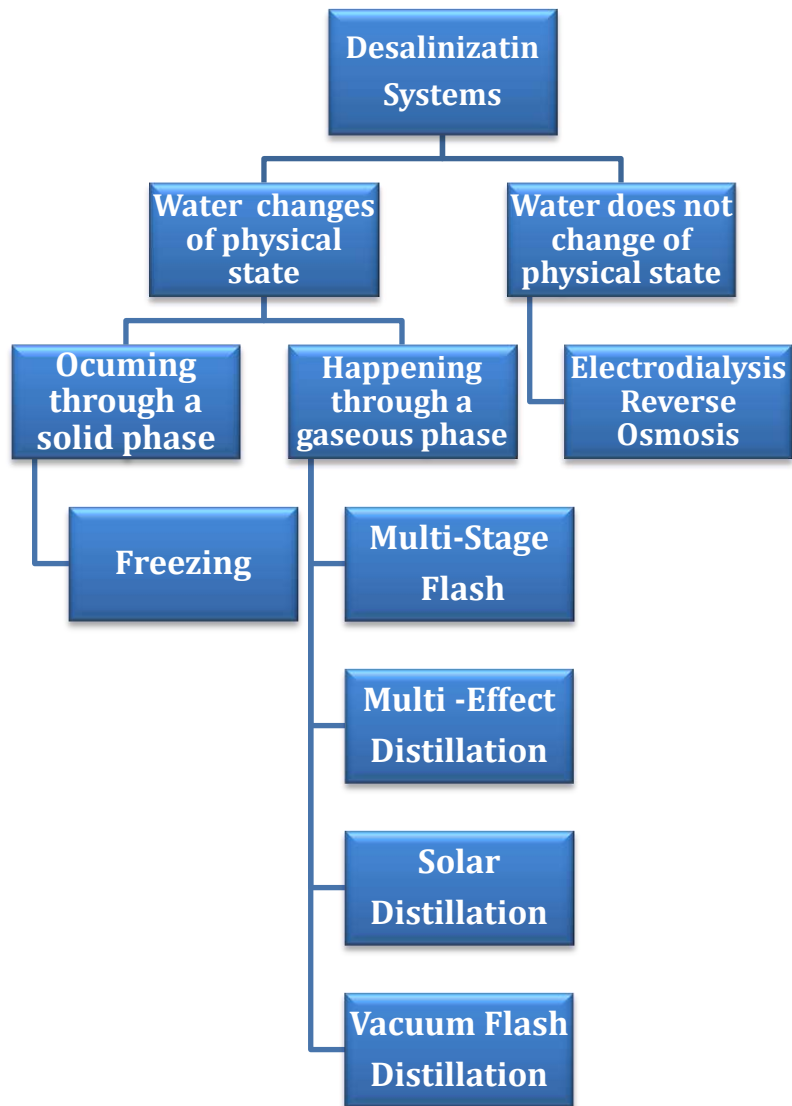


Figure (2.2): Classification of desalination techniques [17].

However, they still have disadvantages and restrictions, thus they can be optimized [18,19]. To choose the best technique for desalination, the advantages and disadvantages of the existing desalination methods were analyzed. This information is shown in Table (2.1) of the membrane technologies RO is currently the most widely implemented, ED still being far from large scale use. According to Ophir and Lokiec [20] the LT-MED is, among the thermal desalination processes, the most efficient because of low temperature drops per effect and the possibility of using low grade steam (brine evaporation temperature in the first effect does not exceed 75 C°). In contrast to MSF, LT-MED processes present lower corrosion and scaling rates due to the low operation temperatures and the plants are less expensive to build and recovery ratios are higher. Table (2.2) shows design characteristics of the LT-MED and RO technologies as the main options for desalination because they are the most widely implemented and have produced excellent results worldwide.

Table (2.1): Advantages and disadvantages of desalination technologies [17,21].

Desalination method	Advantages	Disadvantages
Multi-stage flash	<ul style="list-style-type: none"> •Plants can be constructed to handle large capacities •Minimum pretreatment requirements •High quality of product water (<10 mg/L TDS) •It can be combined with other processes 	<ul style="list-style-type: none"> •Plants are expensive to build and operate •Requires a high level of technical knowledge to operate it •Low recovery ratio
Electrodialysis	<ul style="list-style-type: none"> •Plants can produce high recovery ratios (85–94% for one stage) •Plants can treat feedwater with a higher level of salt concentration •Minimum pretreatment requirements •The membranes are not susceptible to bacterial attack or silica scaling 	<ul style="list-style-type: none"> •Leaks sometimes occur in the membrane • Process does not affect bacteria, nonionic substances and residual turbidity.
Reverse osmosis	<ul style="list-style-type: none"> •Processes can remove a great amount of contaminants in the water as well as salt •Low energy requirements •Plants have high production ratios •Compatibility with other processes except with natural coagulants 	<ul style="list-style-type: none"> •High membranes and operating cost •The operation has interruptions with high amounts of suspended particles •Pretreatment and posttreatment is complicated •Smaller flows than the MED •Operation problems with pH out of range (2–11) and high chlorine concentrations >1 ppm
Multi-effect distillation (MED)	<ul style="list-style-type: none"> • Minimum pretreatment requirements • High quality of produced water (<20 ppm) • Operation requirements are minimal • High production capacity • Low capital cost • Energy input independent of concentration • Plants can treat feed water with a higher level of salt concentration 	<ul style="list-style-type: none"> •Dependent on local power availability •Requires cooling in order to have a liquid product • Low recovery ratio •Water quality is difficult to control

Table (2.2) : Comparative matrix of main desalination technologies [17,21,22,23].

Classification	Units	Distillation	Membrane
Sub classification		LT-MED	RO
Area		Regular	Small
Initial capital cost		High	Regular
Installations	Months	12	18
Maintenance cost	USD/m ³	0.126	0.126
Chemical operation costs	USD/m ³	0.024	0.047
Pretreatment		Minimum	Extensive
Posttreatment		Minimum	Extensive
Process control		Low	High
Power consumption	kWh/m ³	2.3	4.2
Process temperature	°C	70–75	Weather
Net conversion	%	35–65	>80
Raw water quality	ppm	Up to 100,000	Up to 50,000
Product water quality	ppm	2–50	100–500
Energy required		Electricity or waste heat energy	Electricity
Energy requirement	kJ/kg	100–150	>80

2.3 Desalination Technologies

The commercial desalination technologies can be divided into two main categories: thermal distillation (MSF and MED) and membrane separation (RO) [24]. Also, there are hybrids plants which integrate thermal and membrane technologies [25]. In addition, there are other commercial technologies of less application due to their small units' size such as vapor compression (VC) or their application of low salinity such as electro dialysis (ED).

Moreover, there are different emerging technologies which are still under research and development (R&D), including forward osmosis (FO), membrane distillation (MD), capacitance deionization (CDI), and gas hydrates (GH), freezing, humidification dehumidification (HDH) and solar stills. Other supporting technologies include ultra/nano/ionic filtration (UF/NF/IF respectively) [26].

Figure (2.3) shows the global desalination capacity by process, highlighting the high capacities shares of RO and MSF. As for the feed water quality used, seawater is the most used, followed by both brackish and river waters Figure (2.4) [27].

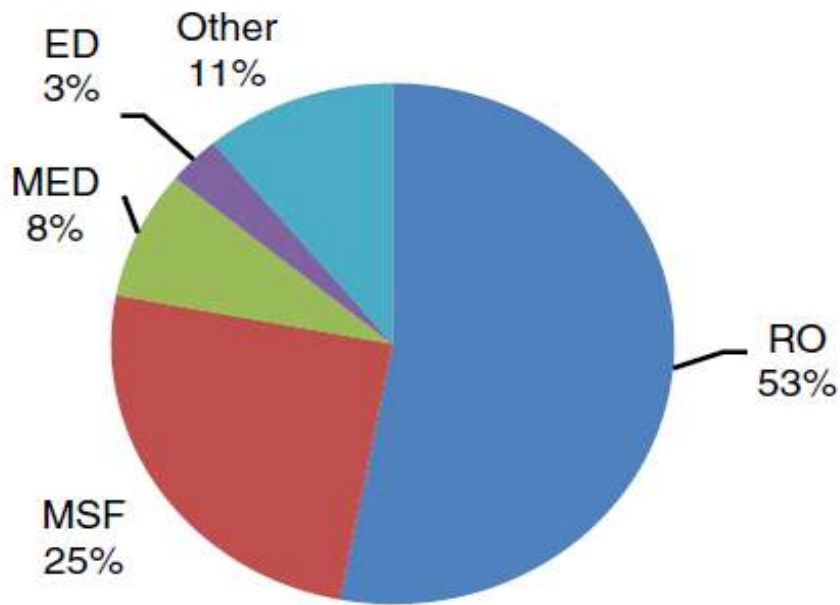


Figure (2.3): Global desalination capacity by process [27].

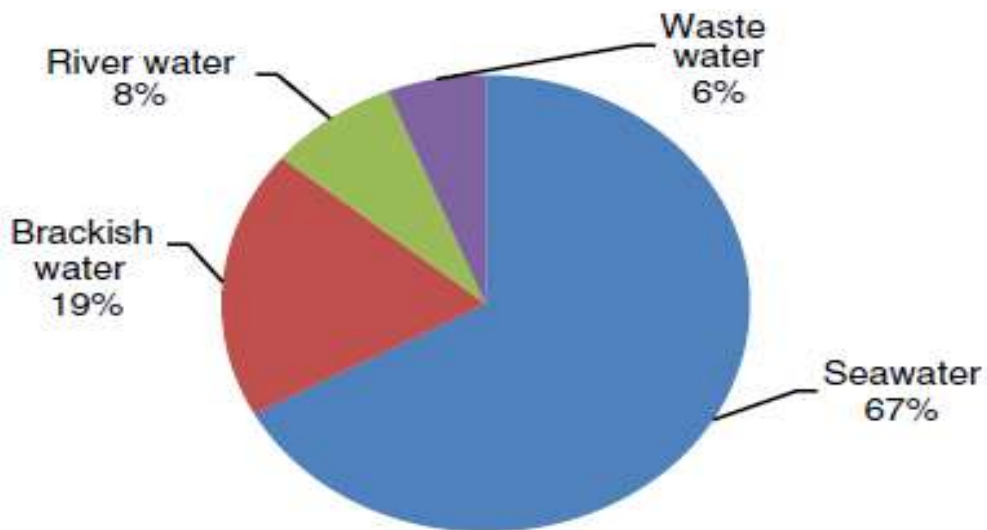


Figure (2.4): Worldwide feed water quality used in desalination [27].

2.3.1 Membrane technologies

Membrane processes work by prohibiting or permitting the passage of certain salts ions. Reverse osmosis (RO) is the major commercial membrane process. RO is used for both brackish and sea water.

2.3.1.1 Reverse osmosis (RO)

In RO process, the saline water is pumped into a closed vessel where it is pressurized against a membrane; pure water permeates through the membrane whereas the brine left

behind is discharged. The brine discharge may have a concentration ranging from 20% to 70% depending upon the salt content of the feed water [28]. An RO system is made up of a pretreatment process, high-pressure pump, membrane assembly and post treatment process. Most modern reverse osmosis plants have an energy recovery system. The brine discharge is usually at very high pressure whereas the fresh water is at low pressure. The pressure energy in the brine is fed back to the feed water using pressure exchangers. The usage of energy recovery systems and improved membranes has resulted in an overall reduction in the cost of RO-based desalination[28].

An RO system requires a pretreatment process, high-pressure pump, membrane assembly, and post treatment process. Pressure exchangers can be used to partially recover the energy from outgoing brine. RO is nowadays the world leading technology of a 53% world share in desalinated water production, as shown in Figure (2.3) and Figure (2.4).

The energy required for RO unit, varies based on different parameters, but mainly water salinity. Specific energy consumption is the lowest as compared to other commercial technologies. The operating costs of RO have reduced over the years due to development of low-cost efficient membranes and usage of pressure recovery devices. Seawater RO cost has gone down to about 0.53\$/m³ in large plant of Ashkelon at the Mediterranean Sea [29]. However, in the case of high water salinity, high turbidity, high feed water temperature, high marine life presence (as in some Gulf sites), the cost will be high (near to MSF and MED) as the RO unit will need expensive pretreatment system.

As the specific energy consumption is less, the greenhouse gas emissions of RO will be less than emissions by an MSF or MED. The waste discharge from RO could have high salinity due to the higher recovery rate of about 30–50% and TDS increases from 50% to 80% above feed water [30]. Moreover, the chemicals added for the pretreatment add to the toxicity of the brine discharge. In RO, the brine is discharged at ambient temperature; i.e. no thermal pollution as in thermal technologies. On the other hand, RO employs large pumps for generating high pressures which results in noise pollution [31].

RO has a dominating presence in the brackish water desalination and increase towards the use of RO for seawater desalination. The trend of growth in RO will continue and may be strengthened by the growth in water demand and the development of low pressure membranes. Integration of NF for pretreatment, preheating of feed water, improves pressure recovery efficiency, and development of larger size and low pressure membranes improves the RO recovery and performance and specific energy consumption [30].

2.4 Supporting Technologies

2.4.1 Microfiltration, ultrafiltration and nanofiltration

These processes are not desalination techniques; however, they are used in the pretreatment processes of desalination plants [32]. Microfiltration (MF) is used to reduce turbidity and remove suspended solids and bacteria. MF operates via a sieving mechanism under a low pressure. Ultrafiltration (UF) is used for removal of

contaminants that affect color; for example, high-weight dissolved organic compounds, bacteria, and some viruses. UF also operate via a sieving mechanism. Nanofiltration (NF) is used for water softening, organics, sulfate and virus removal. Removal is done by combining sieving and solution diffusion. NF is a major process for desalination in USA [33].

2.4.2 Ion exchange

Ion-exchange process uses resins to remove undesirable ions in water. At much diluted concentrations, ion exchange is used for the final polishing of waters that have had most of their salt content removed by other desalination technologies [33].

2.5 High Salinity Water

2.5.1 Properties of high salinity water

High salinity water (or concentrate) and clean water are the products of desalination processes. Brine is a concentrate stream which has a high TDS concentration of more than 36,000 mg/L. Concentrates are one of the aspects that affect the environment and the marine life due to their disposal. The intensity of the hazard of concentrates depends mainly on their temperature, TDS and density [34].

The relations are as follows: the higher the temperature of the concentrate, the more its impact; the higher the density of the concentrate, the more its impact; the higher the TDS of the concentrate, the more its impact. If the concentrate's density is high, it will sink to the bottom of the sea and will harm the marine life, as opposed to a low density where it will float and cause less damage [34].

The temperature and density are related similarly. Recovery rate, which is defined as the ratio of the product water to the feed water, also affects the TDS of the concentrate. The higher the recovery rate, the higher the TDS of the concentrate. Of course the concentrate does not solely include brine; on the other hand, it includes chemicals used from pretreatment and posttreatment, which are added to the pipe of the concentrate before its disposal and add to the negative impact of the concentrate. These chemicals are shown in Table (2.3) with their purposes [34].

Concentrates have more severe effects in membrane processes (RO and ED) than thermal processes (MSF, MED and VC). One of the reasons is because the concentrate of the thermal processes is mixed with a stream of cold water to dilute its salt concentration before discharging it, while this is not the case for membrane processes. There are properties other than the temperature of the concentrate that differ from process to process.

Table (2.3): Chemicals used in pretreatment and post-treatment of desalination plants [34,35].

Pretreatment		Post-treatment	
Chemical	Purpose	Chemical	Purpose
NaOCl	Prevention of biological growth	Enzymes	Breaking down of bacteria
FeCl ₃ /AlCl ₃	Flocculation and removal of suspended matter from water	Detergents, surfactants and caustics	Resuspension of particulate matter and dissolving of organic material and silica
H ₂ SO ₄ /HCl	Adjustment of pH	Biocides	Killing bacteria
NaHSO ₃	Neutralization of chlorine in feedwater	Chelators	Removing scale
Scale inhibitors	Prevention of scale formation	Acids	Dissolving inorganics

2.5.2 Concentration of hazardous materials

As mentioned above, the concentrate is comprised of salts and chemicals used from pretreatment and post-treatment. Their concentration in the concentrate depends on the type of desalination process used. Some of these chemicals are toxic while others are very low in toxicity [36]. The low-toxicity chemicals include: metals (iron, nickel, chromium and molybdenum), antiscalants (polycarbonic acids, phosphonates, polyphosphates and sulfuric acid), coagulants (ferric-III-chloride and polyacrylamide), anti-foaming agents (polyethylene and polypropylene glycol) and cleaning chemicals (alkaline solutions, acidic solutions, detergents, oxidants, disinfectants and inhibitors, for example, dodecylsulfate, dodecylbenzene sulfonate, sodium perborate, sodium hypochlorite, hydrogen peroxide, formaldehyde, glutaraldehyde, isothiazole and benzotriazole derivatives).

2.6 Chemical Aspects of Brine Discharge

Chemicals are used both in inland brackish water desalination and seawater desalination, however seawater desalination use much more. Chemicals are used in pretreatment, posttreatment, membrane cleaning etc. There are uncertainties regarding the environmental impact of chemicals. Some people say that the use of chemicals does have an impact, and some people say that since the brine only contain relatively minor amounts of chemicals, it is not expected that there will be any contamination problems [37].

2.6.1 Chlorine

Chlorine is mainly used to prevent biofouling. Chlorine and its compounds are toxic and affect biological and enzymatic processes of living organisms [38]. It either kills the organisms or creates conditions making it difficult or impossible to settle [39]. Chlorine is a highly effective biocide which can have detrimental effects on aquatic life even in low concentrations. In U.S.A., it is classified as a pollutant and in California, discharge is not allowed [40].

In the presence of hydrocarbons in the water, like in the arabian gulf due to oil mining and oil spills, chlorine can form chlorinating byproducts (CBC), like trihalomethane (THM) which has carcinogenic properties above certain concentration levels [38]. In RO plants using polyamide membranes, there is no chlorine in the discharged brine as dechlorination must be done before the membranes as chlorine causes scaling to occur. Chlorine has a detrimental effect on marine organisms but decays with time [41].

2.6.2 Antiscalants

Typical antiscalants are polyacrylic and polymaleic acids, but polyphosphates also still occur. Dosages are normally 2 ppm which means that an RO plant with an recovery of 33.3 % would have a load of 6 kg/day for every 1000 m³ of permeate produced. The knowledge about the stability, residence times and ecotoxicity of the antiscalants is limited [40].

Standard biodegradation tests has shown that the degradation rate of polyacrylic acid is almost three times as high as polymaleic acid with 52 % of the polyacrylic acid degraded after 35 days compared to 18%. These polymer antiscalants have similar properties as natural organic (humic) matter and the LC50 value is rather high indicating a low toxicity [40]. Some types of anti-scalants, like phosphate based additives will encourage red and green algae formation [38].

2.6.3 Acids

Membrane cleaning is done 3-4 times a year using weak acids and detergents like citric acid, sodium polyphosphate and EDTA. This rinse water is usually collected in a container and then treatment in the form of titration and neutralization is performed before discharge to authorized salt disposal sites or by releasing small quantities of the rinse water continuously together with the brine to the sea [42].

2.7 Environmental Impact of Brine Discharge Plume Current

The largest impact of desalination plant on the surrounding environment is often considered to act on marine life. The discharge brine has the ability to change the salinity, alkalinity and the temperature averages of the seawater and can cause change on marine habitat [43].

The plume of discharge brine might contain all or some of the following constituents [43]:

- High salt concentration and chemicals used in the pretreatment stage
- High total alkalinity content as a result of the double content of seawater in calcium sulfate, calcium carbonate and other elements
- High temperature range of the discharge brine due to the elevated temperature rate in the desalination facility
- Toxic heavy metals due to the metallic materials used in the desalination plants' components.

In general, the salinity and total alkalinity of the discharge brine is almost double that of average seawater and thermal pollution may occur from the high temperature of the brine discharge. This change in salinity, alkalinity, and temperature could possibly lead to a significant impact on aquatic life [43].

The seawater average salinity, temperature [44] and alkalinity are:

- Salinity of sea and ocean water worldwide varies between 30-37 ppt (part per thousand).
- Temperature of the sea and ocean water surface differs from the two polar areas to the equator between 15-27° C (summer).
- Total alkalinity is approximately $2.32 \times 10^{-3} \text{ mol/kg}$.

More sensitive to effluent discharges are enclosed seas, such as Red Sea and Arabian Gulf, which have limited water exchange capacities and are generally shallow and less energetic. Another potential environmental impact of brine disposal is eutrophication, due to the high levels of phosphates in the brine effluent. Discoloration in receiving water is attributed to the high concentration of ferric constituents of brine, also to high level of suspended solids of the untreated backwash water [4].

The high specific weight of the brine creates a plume at the outlet and this prevents mixing and makes the brine plume sink to the bottom. What is created is a “salty desert” in the area near the outlet affecting the benthic environment negatively. The chemicals used are also a concern regarding the marine organisms and plants [45].

The specific impact of the brine is a function of the ecosystem in the area and conservative estimates show that benthic environments are tolerant to salinity increases of 1 ppt [46].

The following are marine disturbances in the vicinity of the outlet from ocean brine disposal caused by:

1. Salinity gradient: There exists an osmotic balance between the marine organisms and the surrounding environment and disruptions may have negative consequences. The main effects are on marine biota, particularly benthic and planctonic organisms [45].

Increasing salinity can have a great effect on plankton populations (mainly young individuals) as this can lead to dehydration of cells resulting in increased turgor pressure and ultimately extinction [45]. The sensitivity of crustaceans to increasing salinity varies, but generally the species with long abdomen are more sensitive than the species with short abdomen and of course younger individuals are more sensitive [45].

Some planctonic algae, especially the siliceous algae, have high tolerance towards salinity and certain species can tolerate salinity variations after some time of acclimatization. However, most of the marine species will not survive in the case of high increases in salinity [42]. Increased turbidity is also an effect of increasing salinity. The use of additives like iron further enhances this effect as some of these additives are dark in colour. This has the effect of preventing the penetration of light and therefore disrupting photosynthesis [45].

2. Temperature gradient: This will cause an increase in the seawater temperature resulting in a reduction of dissolved oxygen which is a necessity for the respiration of marine organisms [38].

3. Use of chemicals: See section on chemicals to find out the impact that the use of chemicals has on the environment.

4. Corrosion of equipment: This can cause heavy metals like copper, titanium and nickel to be discharged to the sea. They can be toxic towards marine organisms and humans and can accumulate in for example fishes posing a threat to humans [38].

Monitoring of the brine impact on marine environment is important in order to assess environmental impacts. The Dhekelia plant in Cyprus carried out monitoring every 6 months for a period of 4 years and the results showed that the marine environment within a perimeter of 200 m from the outfall point were affected [37]. This was evident by the disappearance of certain marine species [42]. Monitoring was made at the plant of Maspalomas II in Canary Islands where it was noted that the dilution at the surface of the sea was sufficient but sinking of a brine plume in a underwater river-like fashion was observed [37].

The brine might be rejected directly either into the ocean and sea or combined with other discharge. There are particular factors that play significant role in the discharge plume and the diffusion into the seawater.

These influencing parameters are [47]:

- Direction of the wind and speed. These factors have a large impact on the diffusion of the discharge brine into the ocean and can affect the dilution of the highly concentrated plume into seawater in a short distance.
- Wave height and speed. Another factor playing major role in the variation of seawater properties and may have significant effects on the ambient environment
- Bathymetry and the tidal mean and average. The brine discharge could potentially have a minimum impact on the variation to the physical properties, according to scientific researches. Great changes on salinity and alkalinity will occur during the high tide in a shallow depression [48].

Breaking waves induce considerable turbulence and larger waves help create more mixing, tidal currents generate turbulence by friction of the seafloor, and wind drives surface current which is also turbulent. When any of these elements is large, rapid diffusion will be occurred which means more diffusion and more dilution of the discharge brine into the ocean water. Therefore the zone of risk is reduced but the area of low risk is increased.

All of these three aspects have an ability to affect the current and the rate of diffusion of the discharge brine into the sea or the ocean. The turbulence level plays a role in the rate of diffusion in the ocean current fluctuation [49].

Therefore these three factors have to be considered as a significant influence on the diffusion and mixing of the brine discharge into the ocean and the faster the dilution the less will be any impacts on the seawater quality. Dilution models for effluent discharges by the American Environmental Protection Agency is recommended as a model to experiment and document the diffusion rate of the brine discharge into the seawater [50].

2.7.1 The impact of salinity changes on the marine environment

Changes to salinity can play a significant role in the growth and size of aquatic life and the marine species disturbance. Knowledge of tolerance limits of marine life to different salinity degrees is an important aspect in assessing marine disturbance and population. Changes in the salinity can play two opposite roles on the marine organisms' existence; it can be of benefit for some of these organisms such as shellfish and at the same time can have an adverse impact on other species. The salinity alteration that will be mentioned ranges between 35 ppt to 70 ppt. Water salinity changes may influence; [51]

- Development of species and the propagation activity and faster individual growth.
- Survival of larval stages of animals and life expectancy (shorter or longer generation time).
- Population density of organisms (higher or lower population growth rate).
- Breeding of species and reproductive traits.

The salinity around the outlet discharge varies from about 80 ppt to reach the actual seawater salinity 35-37 ppt in balance with the surrounding environment.

According to some studies the excess salinity level of seawater from the discharge brine is a direct function of the distance from the desalination charge site. The salinity of seawater might not be remarkably different in profile from the surface to the bottom of the sea; however in the ambient area of the discharge brine outfall it can significantly fluctuate between the surface and ten meters depth for instance [52].

Figure (2.5) shows the seawater salinity profile from surface to eleven meters depth in the surrounding area of Barke desalination plant in Oman.

A direct relationship can be clarified between the rates of change of environmental salinity and the effects on marine organisms such as population, size and behavior [53].

However, some of the sampling evidences for some fish species indicate that these fish are not very sensitive to the salinity fluctuation [54].

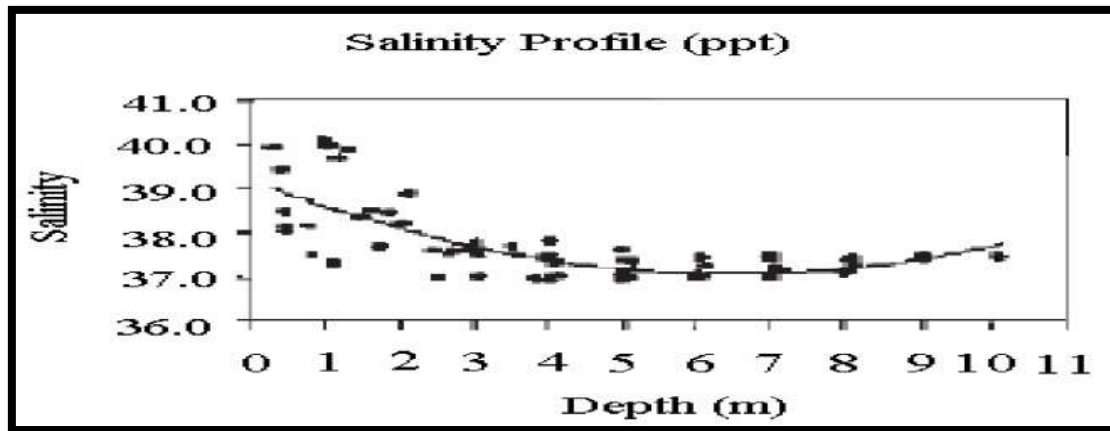


Figure (2.5): Distribution of the seawater salinity profile of the outfall of Barke desalination plant [52].

According to some studies about the effects of changes in the salinity of sea water on marine organisms, the primary and apparent changes might occur firstly in mobile species such as plankton and fish, the reaction will be highest in those organisms with a plankton stage in their life history [55].

Parry's experiment presents the impact of changing the seawater salinity on some marine species. Salinity alteration plays a significant role on the marine species size, population and behavior; however, these impacts differ between different sorts of organism. It shows that increasing the salinity level up to 50 ppt could possibly have an enormous impact on the size of several types of fish and the survival rate, but the impact on salmon seems to be less than rainbow trout, which on the other hand can survive salinity changes better than the brown trout [56].

According to Moser and Gerry salinity alteration would probably play a considerable function in the fish distribution, while some of the fish juvenile such as croaker fish offspring are more vulnerable to salinity fluctuation than the spot progeny; however an adult generation of these sorts of fish will have an ability to tolerate a vast range of salinity alteration [57]. Gunter believes there is a direct negative correlation between the number of marine species and the salinity increment of the seawater [53]. There are very limited numbers of documented studies or experiments have been done about the impacts of salinity and temperature fluctuation on the flora species neither sedentary organism.

2.7.2 The impact of temperature alteration on the marine environment

Another impact of the discharge brine is the thermal pollution that can occur by rising the temperature of the seawater. Thermal pollution, which results from cooling water being discharged to the sea, can be defined as "a major change in the sea temperature". Different consequences can be addressed in order to determine the impact of the

temperature alteration on the ambient environment. Generally, the water mass is subdivided vertically by temperature into three main classes.

Several studies have been carried out in order to determine how the distribution and abundance of marine flora and fauna species react to a change in temperature. The temperature of the brine discharge is one of the major concerns for any desalination plant project; this temperature is higher than the ambient ocean water temperature. Marine biologists believe that a significant impact can occur to the natural balance and distribution of the marine life if a temperature alteration applied to the ambient environment [58].

A direct correlation can be determined between the temperature alteration and the behavior of marine species. Sea temperature is one of the key variables to monitor and can play a great role in the marine flora and fauna's life [59].

The highest temperature value in the surrounding area of the brine discharge has been found to occur very close to the mouth of the outfall diffuser. Abdul-Wahab study presents a direct link between the temperature of the seawater and the distance from the discharge site [52]. The discharge temperature can spike to as high as 57°C at the mouth of the plume discharge [47].

These figures present the difference of temperature changes in the ocean water and on the surrounding area of the discharge brine, it shows more considerable fluctuation can be defined around the discharge brine and varies in significant range from 10 to almost 40 C°, while in general ocean environment the varies between 10 to just under 25 C°.

Temperature can have an influence on the growth and reproduction of marine species. Mobile species such as plankton and fish are the first most likely sort of marine life to be influenced due to changes in the seawater temperature [55].

Changes in the temperature values can have an impact on the marine habitat, a study about the plankton shows that increasing the temperature of the ambient environment will lead to a positive effect on reproduction biology and the growth rate of several species of plankton [60].

A decrease in the time of the eggs development of several types of fish and increasing the rate of the population growth has occurred due also to an increase in temperature [61]. He et al. studied the effect of temperature on the growth and reproduction rate, and the maturity age of the *Moina Mangolica*, the maturity age reduced from 5.8 days at 20 C° to 3.4 days in the 30 C°, the reproduction rate has decreased from 4.1 days at 20 C° to once a day at 28 C° and the longest life span was 10.8 days at 25 C°, but reduced to 4.2 days at 35 C°. So temperature can have positive or negative impacts on the marine flora and fauna depending on the species and extent of the change in temperature. A very limited experimental data have been documented about the impact of the temperature changes on several kinds of marine flora and fauna species [62].

2.7.3 The impact of total alkalinity changes on the marine life

An understanding of the oceanic total alkalinity tolerance (positive or negative) of marine species is important in many branches of marine chemistry, ecology and biology. The alkalinity of the seawater is defined as the number of equivalents of calcium carbonate in the seawater [63].

The total alkalinity tolerance of the marine life and the changes rate of alkalinity that the brine discharge cause to the seawater has not been exactly determined yet due to a very limited number of experiments. As far as marine biologists are aware, this phenomena has not been adequately documented and very limited experimental data exists. There is also limited literature available, which explores the impact of total alkalinity on marine life [63].

Desalination seawater plant has the ability to increase the total alkalinity level of the brine discharge and to the seawater in the area of discharge afterwards. Therefore testing the total alkalinity level out in the diffuser and the ambient environment would be recommended to declare any impact on the marine flora and fauna species [63].

2.8 Brine Disposal Alternatives

The mitigation of environmental implications of concentrate disposal is most closely related to the means through which it is managed. Several means for disposal of the concentrate are practiced worldwide including: direct surface water discharge, discharge to a sewage treatment plant, deep well disposal, land application, evaporation ponds, brine concentrators as well as mixing with the cooling water or sewage treatment effluents prior to surface discharge. the sea quality.

Table (2.4) outlines advantages and disadvantages of various brine disposal methods. Evidently, brine discharge into surface water bodies is the most commonly used and least expensive disposal method in practice today [64,65,66].

Minimal adverse impacts are expected if rapid mixing and dilution are ensured in the discharge zone [67,68]. These optimal mixing conditions can be attained by the careful design and construction of outfalls that account for local circulation patterns, hydrographic currents, and the hydrodynamic characteristics of the discharge area. Outfalls should avoid lagoons, shallow water and inter-tidal areas with limited circulations and look for rather exposed coastal stretches with strong flushing capabilities [67,69,70, 71].

Table (2.4): Advantages and disadvantages of brine disposal options

Disposal methods	Advantages	Disadvantages
Direct surface water discharge	<ul style="list-style-type: none"> • Least expensive • Can accommodate large volumes 	<ul style="list-style-type: none"> • Depends on natural circulation patterns and hydrographic currents in the area
Discharge to a sewage treatment plant	<ul style="list-style-type: none"> • Lowers the BOD of the resulting effluent • Dilutes the brine concentrate 	<ul style="list-style-type: none"> • Can inhibit bacterial growth • Can hamper the use of the treated sewage for irrigation due to the increase in TDS and salinity of the effluent • Overload the existing capacity of the sewage treatment plant
Deep well Disposal	<ul style="list-style-type: none"> • Viable for inland plants with small volumes of brine • No marine impact expected 	<ul style="list-style-type: none"> • Expensive • Needs a structurally isolated aquifer • Increases the salinity of groundwater
Land applications	<ul style="list-style-type: none"> • Can be used to irrigate salt tolerant species • Viable for inland plants with small volumes of brine • No marine impact expected 	<ul style="list-style-type: none"> • Requires large parcels of land • Can affect the existing vegetation • Can increase the salinity of groundwater • Can increase the salinity of underlying soil
Evaporation ponds	<ul style="list-style-type: none"> • A viable option for inland plants highly and regions • Can commercially exploit the concentrate 	<ul style="list-style-type: none"> • Expensive option • Can increase salinity of groundwater • Can increase salinity of underlying soil • Needs dry climates with high evaporation rates • Requires large parcels of land with a level terrain • Needs regular monitoring
Brine concentrator s/ zero discharge	<ul style="list-style-type: none"> • Can produce zero liquid discharge • Can commercially exploit concentrate • No marine impact expected 	<ul style="list-style-type: none"> • Expensive • High energy consumption • Production of dry solid waste
Mixing with the cooling water discharge	<ul style="list-style-type: none"> • Achieve dilution of both effluents prior to discharge • Combined outfall reduces the cost and environmental impacts of building two outfalls • Necessary to reduce salinity if disposing in fresh water bodies 	<ul style="list-style-type: none"> • Dependent on the presence of a nearby thermal power plant
Mixing with the sewage treatment effluent	<ul style="list-style-type: none"> • Achieve dilution of brine effluent prior to discharge • Does not overload the operational capacity of sewage treatment plant • Necessary to reduce salinity if disposing in fresh water bodies 	<ul style="list-style-type: none"> • The brine could enhance the aggregation and sedimentation of sewage particulates that can impact benthic organisms and interfere with the passage of light in the receiving water body

In fact, the United States Environmental Protection Agency (USEPA) prohibits the discharge of any effluent in shallow near-shore water bodies and requires the construction of offshore outfalls. In Cyprus, the new Larnaca RO plant (capacity 54,000 m³/day) was required to be equipped with an outfall exceeding 1 km in length and discharging at least 10 m below sea surface to limit brine impact on existing biota [42]. Submerged discharge outfalls however are more costly, particularly in the Gulf region since the distance required for laying down the pipes is relatively long due to the shallowness of the Arabian Gulf.

The adoption of submerged multi-port diffusers is expected to be cheaper than single port submerged outfalls in the case of the Arabian Gulf since multi-ports are capable of ensuring rapid mixing even in shallow water bodies thus reducing the costs associated with placing pipes over long distances. This is attributed to the presence of a multitude of nozzles in the diffuser that increase the plume's contact area with the ambient water, increase initial mixing rates, and reduce the downstream distance traveled by the plume before meeting the environmental regulatory requirements [73,74].

The usual way of dealing with high salinity water is disposing of it. There are many ways of disposal which include: surface (both surface water and submerged), sewer system blending (front and end of wastewater treatment plant), land application, deep well injection, evaporation ponds and zero liquid discharge [1]. The selection of disposal method depends on eight factors, which are: volume of concentrate, quality of concentrate constituents, geographical location of discharge point of concentrate, availability of receiving site, permissibility of the option, public acceptance, capital and operating costs, and ability of facility to be expanded [30]. Due to all of the factors of selection, different countries use some of these disposal methods and do not use others. A brief description of each method as well as their environmental concerns and alleviation methods are explained below.

2.8.1 Deep aquifer injection

This disposal method includes the injection of the brine through drilled wells to deep, consolidated aquifers that contain non-potable water. This is only possible where these deep aquifers exist whereas the ability to monitor the discharges is limited resulting in an uncertainty of environmental impacts. Furthermore, this method is a costly procedure [80]. It is extensively applied in good hydrogeological conditions of the region [79].

2.8.2 Deep well injection (DWI)

Deep well injection is currently applied worldwide. This technology is considered as a viable option for brine disposal from surface ground of desalination plants. This alternative method ultimately stores the liquid waste in subsurface geologic formations [81].

A well is used to transfer the brine waste a short distance below the ground surface where it is released into a geologic formation. This method is affected by various factors such as site availability, well classification, concentrate compatibility, and public perception. The site must have favorable underground geology lead to deep-well

injection, with a porous injection zone capable of sustaining adequate injection rates over the life of the facility [82].

According to Mickley [79], the disadvantages of this technology are: the cost of conditioning the waste brine, the possibility of corrosion and subsequent leakage in the well sheath, the seismic activity which could damage the well and subsequently result in ground water contamination. Mickley has developed models for estimation of capital and operating costs, for conditions of stable well performance. This technology is considered as the most cost effective system for land based desalination plants [83].

2.8.3 Aquifer reinjection

Aquifer reinjection is mainly applied to smaller desalination plants. This method involves reinjection of the brine into the same aquifer used as feed in order a gradually increase of the salt concentration in the feed water to be achieved. By diverting part of the brine volume for various other disposal options, the full reinjection effects can be reduced. There are also some significant factors that should be taken into consideration as total salt load that is returned, the size of the aquifer and the salt concentration in the aquifer. Moreover, the distance between the intake well and the reinjection well should be adequate [79].

2.8.4 Discharge to wastewater treatment plants

This method is usually applied when the desalination plant is located near a wastewater treatment plant. However, there are some factors to be considered such as the volume and composition of the brine in relation to the treatment capacity of the wastewater treatment plant and the possible impacts of brine on the wastewater treatment plant equipment like the calcium carbonate precipitation on filters. Brine discharge can have an adverse effect on a wastewater treatment plant [84].

2.8.5 Discharge to sewage system

Discharge to sewage system is mainly applied to smaller membrane desalination plants. In this method, if the wastewater is mixed with the brine, the level of salinity in treated wastewater is increased having effects on the microorganisms of the system and the water may be rendered unsuitable for irrigation use. Additionally, this method lowers the biological oxygen demand (BOD) in treated wastewater that can be beneficial under some circumstances [85].

2.8.6 Discharge to open land

This method is applied in Saudi Arabia. Brine is simply discharged to a “natural pond”, the desert [87]. Through this method the TDS level of groundwater may be increased. Consequently, the infiltration rate of water and the soil aeration are reduced. Results relating to soil properties indicated that the soil pH, electrical conductivity values and the concentrations of soluble ions were higher in soils closed to the pond [86].

2.8.7 Reuse for agriculture or landscaping

Water reuse for landscape, ornamental and agricultural applications is an alternative method. In Florida for example, this method is applied to the high salt-tolerant turf grass [80]. An important factor regarding irrigation of plants tolerant to high salinity with brine is that there must be an alternative disposal method available for periods of heavy rainfall [84]. The main criteria for using brine water as feed for irrigation purposes include land requirements, hydraulic loading rates, site selection, selection of vegetation and surface runoff control [85].

2.8.8 Disposal in coastal locations

Discharge to the sea is the disposal method used almost exclusively for desalination plants at the coast or near the coast. There are mainly four different ocean disposal alternatives.

➤ Discharge by pipe far into the sea

The major factor is that there should be suitable distance between the intake and the outlet as to avoid or minimize risks of feed water deterioration. The disposal of brine by pipe should therefore be sufficiently far out into the sea [31]. This option requires some mitigation measures that can be done in order to reduce impacts on the marine environment.

➤ Direct discharge at the coastline

This is normally not a viable option. It can be considered for smaller plants at insensitive shores. Even if the dilution is somewhat satisfactory, during days of calm conditions the dilution would be negligible and the impact on the shore environment would be high [31]. Brine disposal directly on the shoreline can have an effect of increasing the salinity along the coastline and therefore intensify the saline intrusion effect instead of reducing [89].

➤ Discharge at a power stations outlet

This is used quite extensively for thermal desalination plants are common where both production of water and production of energy. Main advantage is the high dilution which is achieved [31].

➤ Discharge to a plant for salt production

This presents an environmental and economical option. The main limitations for this method is the existence of salt production plants in the region close to the desalination plant [31].

Finally, it can say that the reject brine from the seawater desalination is generally discharged to the sea, while in the inland desalination plants of brackish water and reject brine is disposed to evaporation ponds. Although brine disposal to sea is one of the cheapest alternative, but it may have impact on the sea quality.

2.9 Dilution Process

The dilution process is a function of two constituents: the primary and the natural dilutions. The parameters that affect the primary dilution are the following: the difference in the density between the brine and the receiving water body, the flow rate of the brine, the velocity and the flow rate at the effluent pipe, the diameter of the pipe and the depth at the outlet to the seafloor [51].

The natural dilution follows the primary one and is influenced by diffusion and mixing which are caused by waves and currents. Natural dilution is enhanced by the use of diffusers at the effluent pipe by increasing the pressure of the brine entering the seawater and therefore allows the brine to be diluted to a larger volume of seawater. The efficiency of dilution depends on the angle that the diffuser is installed to the seafloor and as a result the brine flow is directed upwards. According to Jones and Kenny, breaking waves cause turbulence and larger waves incur better mixing, tidal currents generate turbulence by friction of the seafloor, and wind drives surface current which is also turbulent. The turbulence level influences the rate of diffusion in the ocean current fluctuation [51].

Whether any of these features exists, then rapid diffusion will be occurred and as a result better diffusion and dilution of brine discharge into the ocean water will take place. According to Kimes knowledge about the topography and the prevailing currents in the area are two very important considerations for selection of brine outlet point as they affect the dilution rate a lot. The faster dilution of brine discharge entails less potential impacts on the seawater quality. Therefore, the zone of risk will be reduced nevertheless the particular low risk area will be increased. All the above mentioned parameters have a serious effect on the current and the rate of diffusion of brine discharge into the sea [51].

2.10 Marine Life Indicators

2.10.1 Dissolved Oxygen

Dissolved oxygen refers to the level of free, non-compound oxygen present in water or other liquids. It is an important parameter in assessing water quality because of its influence on the organisms living within a body of water. In limnology, dissolved oxygen is an essential factor second only to water itself [90].

Oxygen is soluble in water and the oxygen that is dissolved in water will equilibrate with the oxygen in atmosphere. A dissolved oxygen level that is too high or too low can harm aquatic life and affect water quality.

Oxygen tends to be less soluble as temperature increases, with warmer water containing less oxygen than colder water. Water salinity also has an effect on dissolved oxygen levels, with higher saline reducing the availability of oxygen in the water.

As shown in Figure (2.6) , the dissolved oxygen of fresh water at sea level will range from 15 mg/l at 0 C° to 8mg/l at 25 C°. Concentrations of unpolluted fresh water will be

close to 10 mg/l at 15 C°. In general, the concentration of dissolved oxygen can be affected by the biological activity by marine life such as fish, aquatic plants, and bacteria found in the water [91,92].

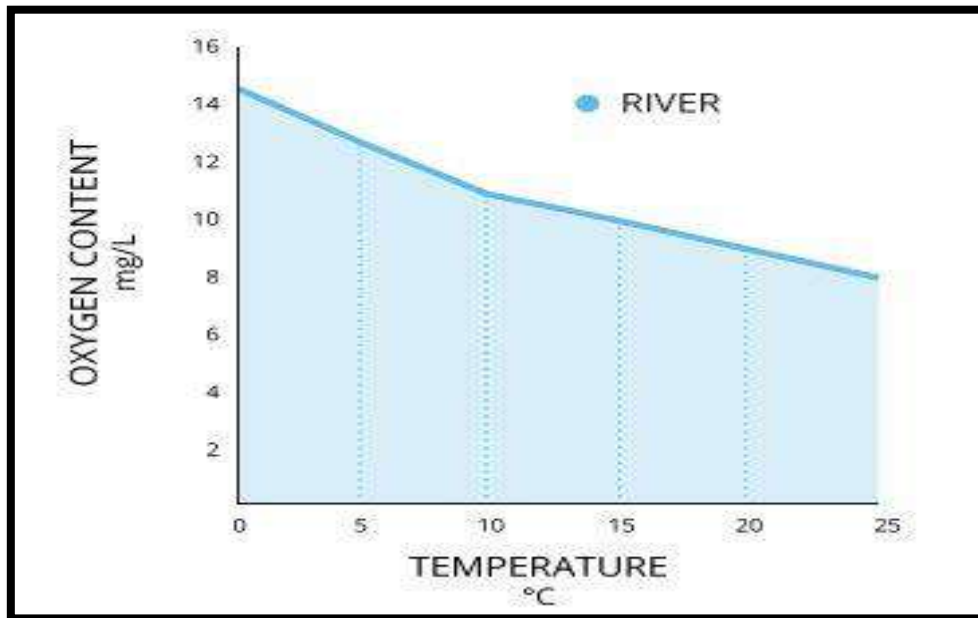


Figure (2.6): Temperature and Dissolved Content Relationship [91,92].

While water equilibrates toward 100% air saturation, dissolved oxygen levels will also fluctuate with temperature, salinity and pressure changes. As such, dissolved oxygen levels can range from less than 1 mg/L to more than 20 mg/L depending on how all of these factors interact. In freshwater systems such as lakes, rivers and streams, dissolved oxygen concentrations will vary by season, location and water depth [93].

Rivers and streams tend to stay near or slightly above 100% air saturation due to relatively large surface areas, aeration from rapids, and groundwater discharge, which means that their dissolved oxygen concentrations will depend on the water temperature [90].

Oxygen depletion until levels fall below 2 mg/L [94]. The mean DO levels should remain near 5.5 mg/L for optimum growth and survival [95,96,97].

Walleye also prefer levels over 5 mg/L, though they can survive at 2 mg/L DO levels for a short time. Muskie need levels over 3 mg/L for both adults and eggs [96]. Carp are hardier, and while they can enjoy dissolved oxygen levels above 5 mg/L, they easily tolerate levels below 2 mg/L and can survive at levels below 1 mg/L [97].

Photosynthesis of some aquatic plants will increase the dissolved oxygen level of the water during day light hours, with the dissolved oxygen levels falling during the nighttime hours. In natural waters, man-made contamination, or natural organic material will be consumed by microorganisms.

As this microbial activity increases, oxygen will be consumed out of the water by the organisms to facilitate their digestion process. The water that is near the sediment will be depleted of oxygen for this reason. In waters contaminated with fertilizers, suspended material, or petroleum waste, microorganisms such as bacteria will break down the contaminants. The oxygen will be consumed and the water will become anaerobic. Typically dissolved oxygen levels less than 2 mg/l will kill fish.

Coldwater fish like trout and salmon are most affected by low dissolved oxygen levels. The mean DO level for adult salmonids is 6.5 mg/L, and the minimum is 4 mg/L. These fish generally attempt to avoid areas where dissolved oxygen is less than 5 mg/L and will begin to die if exposed to DO levels less than 3 mg/L for more than a couple days [90]. For salmon and trout eggs, dissolved oxygen levels below 11 mg/L will delay their hatching, and below 8 mg/L will impair their growth and lower their survival rates. When dissolved oxygen falls below 6 mg/L (considered normal for most other fish), the vast majority of trout and salmon eggs will die [93].

2.10.2 Turbidity

Turbidity is not a direct measurement of the total suspended materials in water. Instead, as a measure of relative clarity, turbidity is often used to indicate changes in the total suspended solids concentration in water without providing an exact measurement of solids. Water clarity is directly related to turbidity, as turbidity is a measure of water clarity [98].

In terms of water quality, high levels of total suspended solids will increase water temperatures and decrease dissolved oxygen (DO) levels. Turbidity of seawater shows the condition that degree of optical clearness of seawater is affected by the existence of dissolved matters and suspended particles.

Turbidity is a measurement of the amount of suspended materials in the water column. These suspended materials include silt, clay and sand (sediments), the phytoplankton community and detritus (decaying organic materials). These suspended materials are collectively referred to as total suspended solids, or TSS. In simple terms turbidity is measurement of the clarity of the water, where increased turbidity correlates with decreased clarity [98].

It is an important water parameter because it directly affects the amount of available light for photosynthesis by marine algae, including submerged aquatic vegetation (SAV) such as eelgrass and other macroalgae.

However, because the phytoplankton community can contribute significantly to the turbidity measurement it is important to recognize that turbid water is not necessarily a negative quality – there is a fine balance between strong primary productivity (a good thing) that results in higher turbidity values and overly high turbidity values (a bad thing) that can decrease light transmission and negatively affect SAVs.

High turbidity values caused by increased sediment transport (usually caused by erosion) are a major concern in some estuarine systems and are often correlated with

development along the coastal boundaries. Increased development leads to an increase in the amount of impervious surfaces (roadways, buildings, etc.) and can result in greater transport of land derived sediments into the system during periods of heavy precipitation [98].

2.10.3 Electrical conductivity

Electrical conductivity (EC) in natural waters is the normalized measure of the water's ability to conduct electric current [103]. This is primarily influenced by dissolved salts such as sodium chloride and potassium chloride. The common unit for electrical conductivity is Siemens per meter (S/m).

Most freshwater sources will range of EC between 0.001 to 0.1 S/m. Like many other parameters, electrical conductivity is highly temperature dependant, and can also have a negative effect on dissolved oxygen concentrations available for marine life. Most marine life also has a specific upper and lower band of dissolved salts that they will tolerate in the water. Concentration of dissolved salts that are outside of normal parameters can stress or cause die off of aquatic life.

The source of EC may be an abundance of dissolved salts due to poor irrigation management and fertilizer runoff, minerals and salts from urban rain water runoff, or other discharges. Local geology, such as the underlying rock types found within the soil nearby can also have an influence in EC levels of a water body.

EC is also the measure of the water quality parameter "Total Dissolved Solids" (TDS) or salinity. At about 0.3 S/m is the point at which the health of some crops and fresh water aquatic organisms will start to be affected by the salinity of water.

Field measurements of EC reflect the amount of total dissolved solids (TDS) in natural waters. TDS maximum instead of a conductivity limit for water quality. The relationship between TDS and EC can be described by the equation;

$$\text{TDS (mg/L)} \sim \text{EC (mS/cm)} \times 640$$

Salinity refers to the presence of dissolved inorganic ions such as Mg^{++} , Ca^{++} , K^{+} , Na^{+} , Cl^{-} , SO_4^{4-} , HCO_3^{-} and CO_3^{2-} in the aqueous solution or soil matrix. The salinity is quantified as the total concentration of soluble salts and is expressed in terms of electrical conductivity. There exists no in-situ salinity probe (based on EC alone) that can distinguish between the different ions that may be present.

Salinity is important in particular as it affects dissolved oxygen solubility. The higher the salinity level, the lower the dissolved oxygen concentration. Oxygen is about 20% less soluble in seawater than in freshwater at the same temperature [104]. This means that, on average, seawater has a lower dissolved oxygen concentration than freshwater sources. The effect of salinity on the solubility of dissolved gases is due to Henry's Law; the constant used will changes based on salt ion concentrations [105].

Most aquatic organisms can only tolerate a specific salinity range [106]. The physiological adaption of each species is determined by the salinity of its surrounding environment. Most species of fish are stenohaline, or exclusively freshwater or exclusively saltwater [109]. However, there are a few organisms that can adapt to a range of salinities. These euryhaline organisms can be anadromous, catadromous or true euryhaline. Anadromous organisms live in saltwater but spawn in freshwater. Catadromous species are the opposite – they live in freshwater and migrate to saltwater to spawn [109]. True euryhaline species can be found in saltwater or freshwater at any point in their life cycle [109]. Estuarine organisms are true euryhaline.

Euryhaline species live in or travel through estuaries, where saline zonation is evident. Salinity levels in an estuary can vary from freshwater to seawater over a short distance [110]. While euryhaline species can comfortably travel across these zones, stenohaline organisms cannot and will only be found at one end of the estuary or the other. Species such as sea stars and sea cucumbers cannot tolerate low salinity levels, and while coastal, will not be found within many estuaries [110]. Some aquatic organisms can even be sensitive to the ionic composition of the water. An influx of a specific salt can negatively affect a species, regardless of whether the salinity levels remain within an acceptable range [106].

Salinity tolerances depend on the osmotic processes within an organism. Fish and other aquatic life that live in fresh water (low-conductivity) are hyperosmotic [111]. Hyperosmotic defines a cell's ability to eliminate water and retain ions. Thus these organisms maintain higher internal ionic concentrations than the surrounding water [112]. On the other side of the spectrum, saltwater (high-conductivity) organisms are hypoosmotic and maintain a lower internal ionic concentration than seawater. Euryhaline organisms are able to adapt their bodies to the changing salt levels. Each group of organisms has adapted to the ionic concentrations of their respective environments, and will absorb or excrete salts as needed [112]. Altering the conductivity of the environment by increasing or decreasing salt levels will negatively affect the metabolic abilities of the organisms. Even altering the type of ion (such as potassium for sodium) can be detrimental to aquatic life if their biological processes cannot deal with the different ion [106].

Conductivity is dependent on water temperature and salinity/TDS [113]. Water flow and water level changes can also contribute to conductivity through their impact on salinity. When water temperature increases, so will conductivity [104]. For every 1 C° increase, conductivity values can increase 2-4% [104].

Rain itself can have a higher conductivity than pure water due to the incorporation of gases and dust particles [115]. However, heavy rainfall can decrease the conductivity of a body of water as it dilutes the current salinity concentration [115].

- **When does Conductivity Fluctuate [114]:**

- Water temperature can cause conductivity levels to fluctuate daily. In addition to its direct effect on conductivity, temperature also influences water density, which leads

to stratification. Stratified water can have different conductivity values at different depths.

- Water flow, whether it is from a spring, groundwater, rain, confluence or other sources can affect the salinity and conductivity of water. Likewise, reductions in flow from dams or river diversions can also alter conductivity levels.
- Water level changes, such as tidal stages and evaporation will cause salinity and conductivity levels to fluctuate as well.

The conductivity of seawater is dependent on the salinity and temperature of the water [113].

The surface salinity of the ocean is dependent on rainfall. In areas around the equator and coast where rainfall is high, surface salinity values are lower than average [116]. These different salinity values contribute to ocean circulation and global climate cycles [117].

2.10.4 Temperature

Water temperature is a physical property expressing how hot or cold water is. As hot and cold are both arbitrary terms, temperature can further be defined as a measurement of the average thermal energy of a substance [118]. Thermal energy is the kinetic energy of atoms and molecules, so temperature in turn measures the average kinetic energy of the atoms and molecules [118]. This energy can be transferred between substances as the flow of heat. Heat transfer, whether from the air, sunlight, another water source or thermal pollution can change the temperature of water. Temperature is an important water quality parameter that is relatively easy to measure and has a direct impact on the organisms living in the water [119]. Many aquatic organisms are sensitive to changes in water temperature, especially because water temperature changes will affect other water quality parameters, such as dissolved oxygen and salinity.

Fish friendly dams will have selective water releases where the temperature of the stream can be controlled by the depth of the water which is released. Some organisms, particularly aquatic plants flourish in warmer temperatures, while some fishes such as trout or salmon prefer colder streams [120].

Studies have shown a direct relationship between metabolic rates and water temperature. This occurs as many cellular enzymes are more active at higher temperatures [121]. For most fish, a 10 C° increase in water temperature will approximately double the rate of physiological function [122].

This increase in metabolic rate can be handled by some species better than others. Increased metabolic function can be noticed in respiration rates and digestive responses in most species. Increased respiration rates at higher temperatures lead to increased oxygen consumption, which can be detrimental if rates remain raised for an extended period of time. Furthermore, temperatures above 35 C° can begin to denature, or breakdown, enzymes, reducing metabolic function [121].

Temperature fluctuations can also affect the behavior choices of aquatic organisms, such as moving to warmer or cooler water after feeding, predator-prey responses and

resting or migrating routines [122]. Some species of sharks and stingrays will even seek out warmer waters when pregnant [122].

- **Water Temperature and Dissolved Oxygen**

The solubility of oxygen and other gases will decrease as temperature increases [123]. This means that colder lakes and streams can hold more dissolved oxygen than warmer waters. If water is too warm, it will not hold enough oxygen for aquatic organisms to survive.

- **Water Temperature and Conductivity**

Water temperature can affect conductivity in two ways. As conductivity is measured by the electrical potential of ions in solution, it is affected by the concentration, charge and mobility of those ions [104].

Conductivity increases approximately 2-3% per 1 C° increase in temperature, though in pure water it will increase approximately 5% per 1 C° [104]. This variation is why many professionals use a standardized comparison of conductivity, known as specific conductance, that is temperature corrected to 25 C° [103].

Ionic mobility is dependent on viscosity, which is in turn dependent on temperature [125]. Viscosity refers to a liquid's ability to resist flow [124]. The more viscous it is, the less fluid it is; molasses and mercury are more viscous than water. The inverse relationship between temperature and viscosity means that an increase in temperature will decrease viscosity [119]. A decrease in the viscosity of water increases the mobility of ions in water. As such, an increase in temperature thus increases conductivity [104].

Seasonal variations in conductivity, while affected by average temperatures, are also affected by water flow. In some rivers, as spring often has the highest flow volume, conductivity can be lower at that time than in the winter despite the differences in temperature [124]. In water with little to no inflow, seasonal averages are more dependent on temperature and evaporation.

The second way that temperature can affect conductivity is through ionic concentration. Many salts are more soluble at higher temperatures [126]. As a salt dissolves, it breaks down into its respective ions. As warm water can dissolve several minerals and salts more easily than cold water, the ionic concentration is often higher [125]. The increased mineral and ion content can be noticed in natural hot springs, which tout their “healing” abilities [127].

These dissolved solutes are often referred to as Total Dissolved Solids, or TDS [128]. TDS refers to all ion particles in solution that are smaller than 2 microns [129]. These salts and minerals enter the water from rocks and sediment in contact with it. As they dissolve and the ionic concentration increases, so will the conductivity of water.

The rate at which conductivity increases is dependent on the salts present in solution [126]. The solubility of KCl will increase from 28g KCl/ 100g H₂O at 0 C° to 56 g KCl/ 100g H₂O at 100 C°, while the solubility of NaCl only increases from 35.6g to 38.9g NaCl/100g H₂O over the same temperature range. In addition, there are a few salts that become less soluble at warmer temperatures, and thus will negatively affect conductivity [126].

Water bodies will naturally show changes in temperature seasonally and daily; however any changes to stream water temperature outside of the normal upper and lower bounds for that particular area will affect the ability of fish to reproduce. Many lake and rivers will exhibit vertical temperature gradients (thermal stratification) as the sun warms the upper water during the day while deeper water will remain cooler.

In the summer, the water could be released from the bottom of the dam, while in the winter the water is released from the top. This selective release will mitigate the impact the dam will have on the water temperature.

Temperature-dependence data charts are usually available for calibration solutions, but not for field samples [131]. However, temperature can still alter a reading and should be recorded with each measurement considered when analyzing the data [132].

Temperature affects conductivity by increasing ionic mobility as well as the solubility of many salts and minerals [130]. This can be seen in diurnal variations as a body of water warms up due to sunlight, (and conductivity increases) and then cools down at night (decreasing conductivity).

Environmental policies require the monitoring of stream water temperature. In most urban and industrial locations, environmental permits are required to help minimize the temperature loading to streams. A direct correlation can be determined between the temperature alteration and the behavior of marine species.

The discharge temperature can spike to as high as 57 C° at the mouth of the plume discharge. Presents the difference of temperature changes in the ocean water and on the surrounding area of the discharge brine, it shows more considerable fluctuation can be defined around the discharge brine and varies in significant range from 10 to almost 40 C°, while in general ocean environment the temperature varies between 10 to just under 25 C° [49].

2.10.5 pH

pH is a determined value based on a defined scale, similar to temperature. This means that pH of water is not a physical parameter that can be measured as a concentration or in a quantity. The term pH was derived from the manner in which the hydrogen concentration is calculated by the negative logarithm of the hydrogen ion concentration.

The logarithmic scale means that each number below 7 is 10 times more acidic than the previous number when counting down. Likewise, when counting up above 7, each number is 10 times more basic than the previous number [133]. Therefore at a higher

pH, there are fewer free hydrogen ions, and a change of one pH unit reflects a tenfold change in the concentration of hydrogen ions .

pH stands for the “power of hydrogen” [134]. The numerical value of pH is determined by the molar concentration of hydrogen ions (H^+) [134]. This is done by taking the negative logarithm of the H^+ concentration ($-\log(H^+)$). For example, if a solution has a H^+ concentration of 10^{-3} M, the pH of the solution will be $-\log(10^{-3})$, which equals 3.

This determination is due to the effect of hydrogen ions (H^+) and hydroxyl ions (OH^-) on pH. The higher the H^+ concentration, the lower the pH, and the higher the OH^- concentration, the higher the pH. At a neutral pH of 7 (pure water), the concentration of both H^+ ions and OH^- ions is 10^{-7} M. Thus the ions H^+ and OH^- are always paired – as the concentration of one increases, the other will decrease; regardless of pH, the sum of the ions will always equal 10^{-14} M [133]. Due to this influence, H^+ and OH^- are related to the basic definitions of acids and bases.

There are many factors that can affect pH in water, both natural and man-made. Most natural changes occur due to interactions with surrounding rock (particularly carbonate forms) and other materials. pH can also fluctuate with precipitation (especially acid rain) and wastewater or mining discharges [135]. In addition, CO_2 concentrations can influence pH levels.

Oceanic organisms like clownfish and coral require higher pH levels. pH levels below 7.6 will cause coral reefs to begin to collapse do to the lack of calcium carbonate [100]. Sensitive freshwater species such as salmon prefer pH levels between 7.0 and 8.0, becoming severely distressed and suffering physiological damage due to absorbed metals at levels below 6.0 [99].

Seawater has a pH around 8.2, though this can range between 7.5 to 8.5 depending on its local salinity. pH levels will increase with salinity until the water reaches calcium carbonate ($CaCO_3$) saturation [101]. The oceans generally have a higher alkalinity due to carbonate content and thus have a greater ability to buffer free hydrogen ions [102].

The pH of water determines the solubility, the amount that can be dissolved in the water, and biological availability, the amount that can be utilized by aquatic life, of chemical constituents such as nutrients like phosphorous and nitrogen and heavy metals like lead and copper. For instance, in addition to affecting how much and what form of phosphorous is most abundant in the water, pH also determines whether aquatic life can use it. In regards to heavy metals, the degree to which they are soluble determines their toxicity; metals are more soluble and hence toxic at a lower pH . Natural variations in pH occur due to photosynthesis.

Since hydrogen molecules are used in this process when plants convert light into energy, this causes the concentration of hydrogen ions to decrease and therefore the pH to increase. For this reason, pH may be higher during daylight hours and during the growing season, when photosynthesis is at a maximum.

Although the pH scale goes from 0-14, the pH of natural water is generally around 6.5-8.5. Values for pH are reported in standard pH units, usually to one or two decimal places depending upon the accuracy of the equipment used.

The majority of aquatic creatures prefer a pH range of 6.5-9.0, though some can live in water with pH levels outside of this range.

Pure water free of dissolved gases will naturally become ionized;



2.11 Institutional Framework and Standard Regulation in Palestine

Environmental impact studies are considered a very essential tool to integrate environmental, political, economic and socioeconomic conditions. They protect society from an adverse impact, which could result from the construction of such large projects as desalination plants.

In general, in the West Bank and Gaza Strip, the two leading bodies of the regulatory framework in the water and wastewater sector are the National Water Council (NWC) and the Palestinian Water Authority (PWA). Coastal Municipalities Water Utility (CMWU), municipalities, village councils and joint service councils are responsible for operating and maintaining water and wastewater facilities.

2.11.1 Palestinian environmental law (PEL)

In general, the development of specific and comprehensive standards regarding the discharge of brine concentrate to water bodies is still lacking because the desalination industry-regulatory interface is relatively new and in developmental stages [88].

Palestinian Authority legislates and regulates the activities and projects concerned water and coastal zones as followed as stated in Article (28) regulate water standards issues. Environmental Quality Authority (EQA) in cooperation with the specialized agencies shall specify the standards for the quality and characteristics of fresh water ". While the following articles regulated the activities concerned with coastal zone as follows [88]:

Article (31): The Ministry, in coordination with specialized agencies, shall set standards for the quality of sea water specifying the norms, instructions and conditions necessary to control sea pollutants.

Article (32): It shall be forbidden, for everyone, to perform any action, which may cause pollution of sea water in a manner that contradicts with the standards, instructions or conditions prescribed for the purposes of marine environment protection against pollution.

Article (33): The Ministry, in coordination with the specialized agencies, shall specify the necessary environmental conditions required for the establishment of any coastal or offshore buildings or facilities. It shall be forbidden to perform any action, which may

affect the natural track of the beach, or adjust it inside or far from the sea unless an environmental approval is obtained from the Ministry.

And finally in Article (35): " The Ministry shall prescribe rules and regulations for the prevention of pollution, preservation and control of the marine environment, against what is generated by the different activities that occur in the free economic zone; or the continental drifting or the activities occur in the sea bottom which are subject to the jurisdiction of Palestine.

2.11.2 Palestinian environmental assessment policy (PEAP)

PEAP is set to support sustainable development and ensure adequate standards of life and avoiding irreversible environmental damage, and mitigating reversible environmental damage from development activities. According to the policy the proponent of any proposed activity should have approval of the Environment Quality Authority (EQA) through a particular process where stakeholder consultation is a crucial component of the policy [78].

2.11.3 Environmental quality authority (EQA)

Although the EQA are not responsible for water resource management they do generate relevant environmental regulation in the form of policy, standards or laws which are drafted and implemented by EQA. The regulations place limits, constraints and requirements on the water resources management actions. The influence of the EQA on the water sector as a whole concerns both the water quality and water quantity issues. All projects in the water and wastewater sector need to be reviewed for their impact on the environment. This assessment should be carried out by the EQA in conjunction with the PWA. There is no regulation and standard available in Palestine for brine disposal either into the sea or elsewhere [88].

2.12 Discharge monitoring plan

The governmental level management is mainly represented by PWA supported by other ministries and governmental agencies including Environmental Quality Authority (EQA), Ministry of Local Government (MoLG), and Ministry of Health (MOH). PWA is responsible for coordination of activities with other agencies in order to ensure smooth implementation of the project from the inception phase of the project to construction and operation. PWA will mainly focus on regulatory water aspects such as water quality, groundwater abstraction, and some selected economic aspects (such as the adherence to national water tariff guidelines).

Ministry of Health (MOH) is responsible for monitoring the public health related issues such as hygiene and microbial contamination of the produced drinking water in addition to the water borne diseases and to report to CMWU if available. EQA is responsible for regulation and monitoring, the seawater quality, air quality, noise and other related environmental issues.

Monitoring of brine water quality at the disposal point is very important for the protection of marine environmental from elevated concentrations of chemicals or from

elevated temperature. The monitoring should be done immediately at the disposal point and at five points at least at 150 meters distance from the disposal point at different directions [88].

2.13 Askelon Seawater Desalination Plant Discharge Quality Standards

The Israeli government has introduced framework dealing with the environmental regulations and guidelines with regard to the operation of desalination plants lying along the Mediterranean coastline. Israel has set the establishment of desalination plants as a national goal encouraging three main types of desalination discharges, namely seawater (SW), brackish water (BW) and effluent (EW) [136].

During operational phase, discharging brine to the sea can take place, as LBS law sets, according to a valid permit and after applying the best available technology (BAT). BAT is related mainly to the design of brine outfall (dilution and dispersion effects, sediment transport etc.), applied additives and pretreatment method (organics, nutrients removal) [136].

It has to be noted that the Israeli central government has also put in place an extended monitoring program to keep a close eye on monitoring implantation of the goals set. In essence, the discharge composition quality is to be examined on a case by case basis, however, for solely indicative purposes. For instance, the respective table below represents an evidence of the discharge quality standards of Askelon seawater desalination plant in Israel [136]. Table (2.5) shows the Askelon discharge standards.

Table 2.5): Askelon Seawater Desalination Plant Discharge Quality Standards (DQS) [136]

Parameters	Units	Max Concentration
Suspended Solids 105 C	mg/l	20
Turbidity	NTU	10
BOD	mg/l	<1.0
pH		9.0>pH>6.5
Ferric (temporary)	mg/l	2.0
Temperature – After conducting	C	4 above ambient seawater
Nitrogen Species	mg/l	Not exceeding 1.7 times ambient seawater concentration
Phosphorous Species	mg/l	Not exceeding 1.7 times ambient seawater concentration
Heavy metals (Ag, Cd, Cu, Cr, Hg, Ni, Pb, Zn)		Not exceeding 1.7 times ambient seawater concentration

Chapter 3: Research Methodology

3.1 Study Area

Gaza Strip is located at the eastern coast of the Mediterranean Sea at (31 25 N, 34 20 E). The Strip borders, Israel on the south, east and north and Egypt on the southwest. It is about 41 kilometers long, and between 6 and 12 kilometers wide, with a total area of 360 Km² [72]. The Strip mainly divided into five governorates: North Gaza, Gaza, Deir El-Balah, Khanyounis and Rafah.

The study area is Deir El-Balah City where the Deir El-Balah Seawater Desalination Plant is located, as shown in Figure (3.1). The desalination plant is placed 900 meters from the Mediterranean coast of Deir El-Balah.

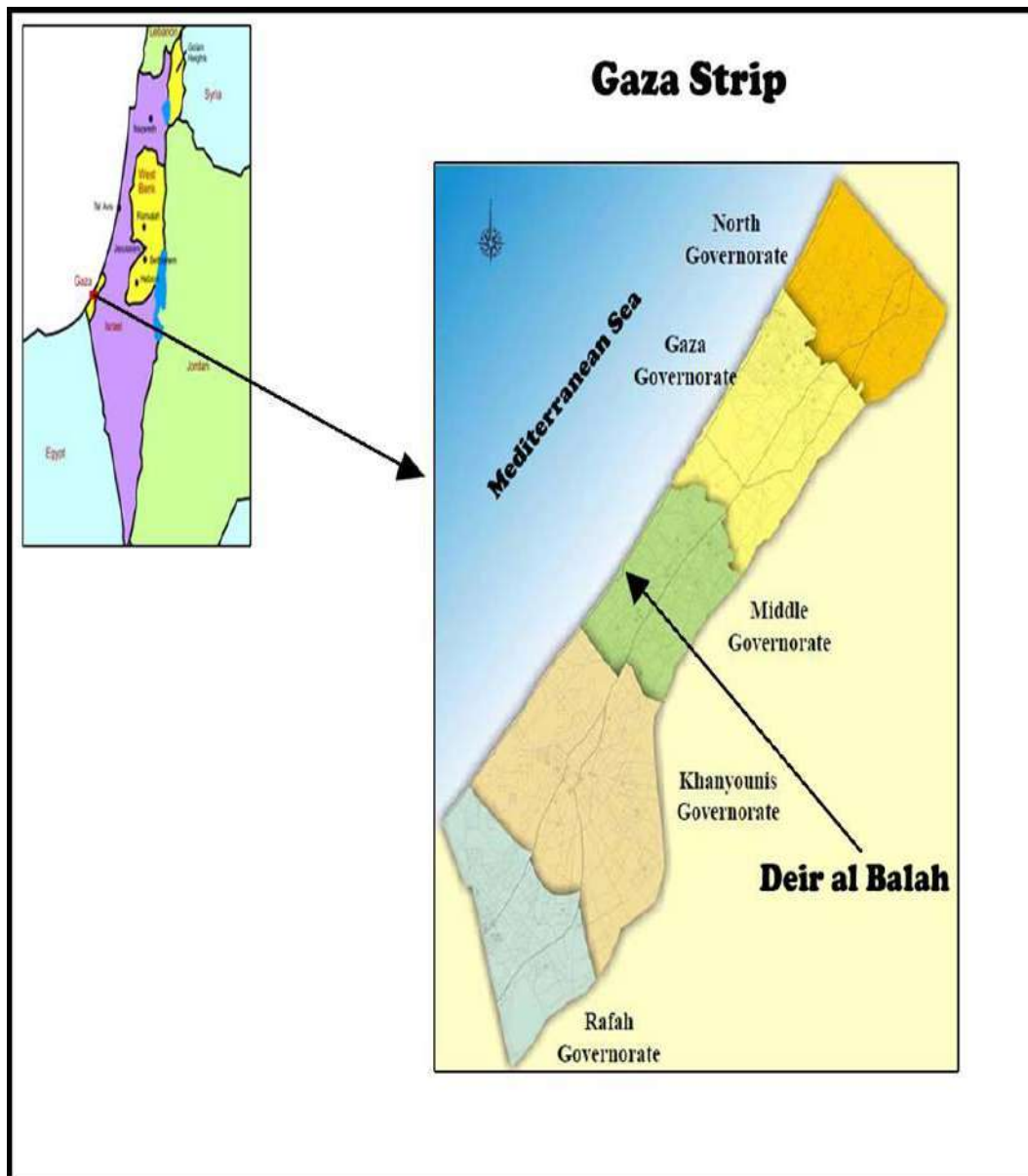


Figure 3.1): Gaza Strip Map

New RO plant was established during the monitoring program on May 2014. The capacity of Deir El-Balah Desalination Plant recently is 2600 m³/d with a recovery rate of 42%.

Influent of this plant is saline water from wells drilled directly at the beach and sometimes from well drilled in the desalination plant site as alternative resource. The depth of beach well is about 45 m, but the depth of saline well is 52 m. The distance from the beach wells and the desalination plant is approximately 1500 m.

3.2 Sampling Design

The primary design questions that need to be addressed before sampling commences are [77]:

1. What, how, when resource is to be sampled ?
2. Where is sampling to commence ?
3. How many samples are needed ?
4. What statistical tests should be used in the analysis of any data collected ?
5. When addressing these questions there are two main considerations ?

First, it must be chosen a sampling method that is not selective, and that is efficient at sampling the resource. It is recommend that the investigator assesses the selectivity of the proposed sampling method by consulting the appropriate literature or by conducting in situ selectivity tests as in this study. Second, the investigator must consider the horizontal and vertical distribution of the resource, and subsequently the spatial design of the sampling program [77].

3.3 Sampling Methodology

Data from monitoring of the dispersion and effects of the brine effluent originated by desalination plants are very scarce. The objective is to present the monitoring, on time and space, of the brine discharge originated by the Deir El-Balah desalination plant. Two stations have been selected; one in front of the desalination plant discharge and the other one 1600 meters to the south of discharge point.

3.3.1 Field Rounds

Three rounds were made in order to determine the seasonal and spatial distribution of the brine plume and its dilution along the area. These rounds have been done in June and November 2014. In each round a grid of sampling stations near the brine discharge place was established, with the purpose of delimiting the brine plume and its dilution along the area.

Influent of this plant was saline water from beach wells in first and second rounds but it was from well drilled in the desalination plant site in third round.

➤ First Round

The first round was carried out on 15, June 2014. This round was represented by 5 points which only two of them was surrounded the disposal point but the other points were next to El Bahrea area to measure marine indicators without brine effect. The sampling depth was a round 30 cm from the sea surface water in all rounds.

Point 3 in this round was taken as a reference point R to identify the sea water quality and properties, as shown in Figure (3.2) Point R is located 1600 m to the south of the brine disposal where it is assumed that there will be no effect of the brine in the sea.

Position of reference point R was right to avoid brine effect since the currents dominant are in the southern direction.

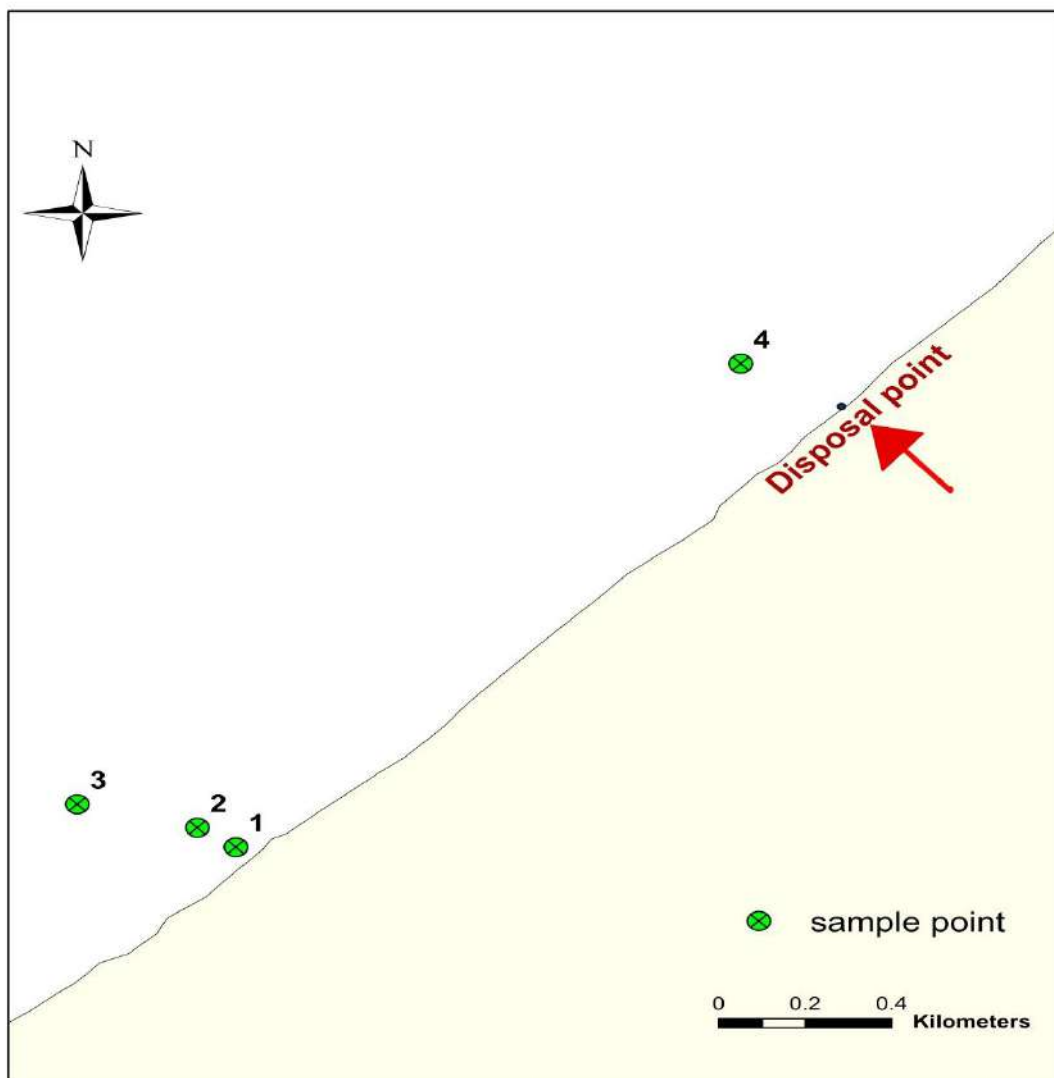


Figure 3.2): Locations of the first observation points

➤ Second Round

The second round was carried out on 28, June 2014. This round was surrounded the brine disposal point to measure marine life indicators after brine effect. This round was represented by 5 points, all of them were in the disposal area as shown in Figure (3.3).

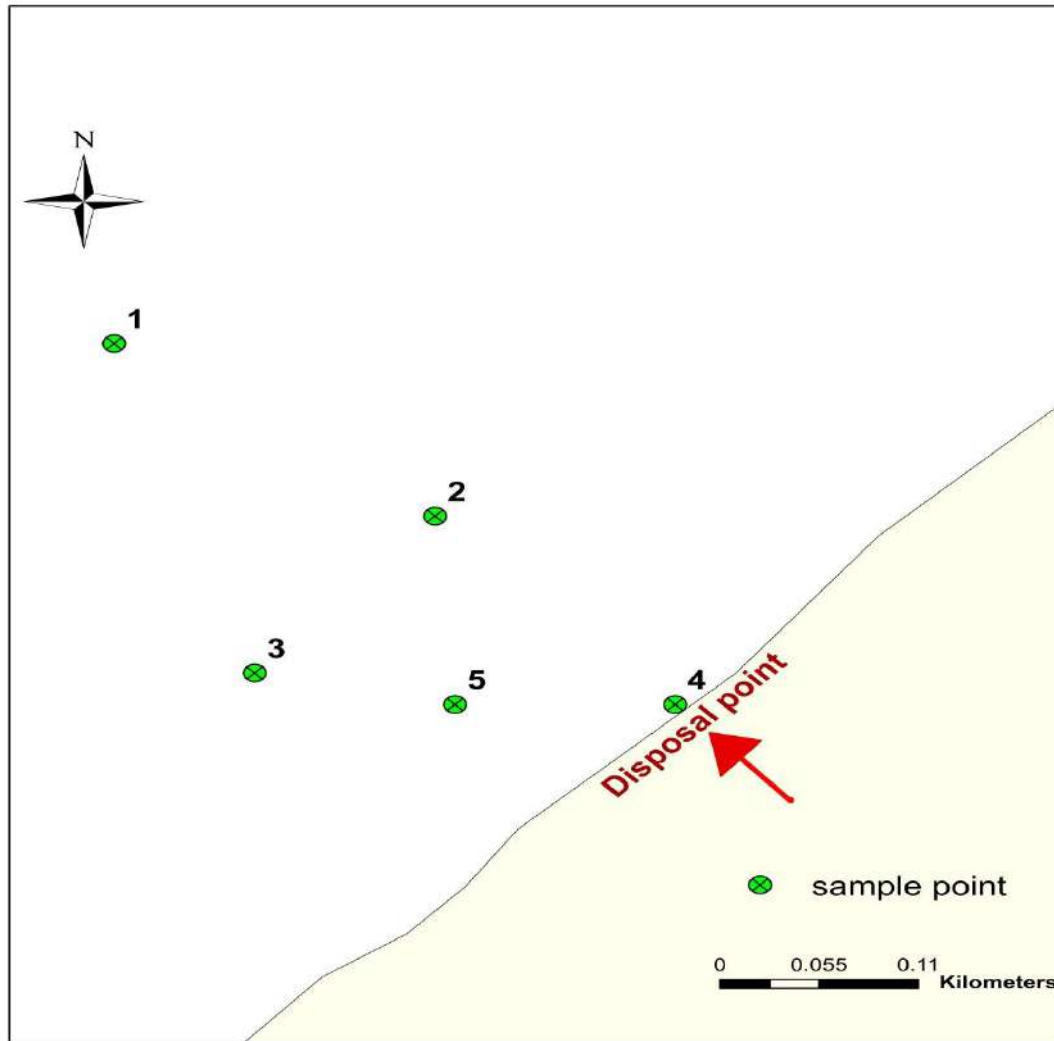


Figure (3.3): Locations of the second round observation points

➤ Third Round:

The third round was carried out on 13, November 2014. This round was surrounded the brine disposal point to measure marine life indicators after brine effect. This round was represented by 20 points, as shown in Figure (3.4).

Point 18 in this round was taken as a reference point R which was in the same location of point 3 which was measured in the first round to identify the seawater quality and properties.

Sample no. (16, 17, 19 and 20) in the same location of sample no. (1, 2, 3 and 4) which was measured in the second round.

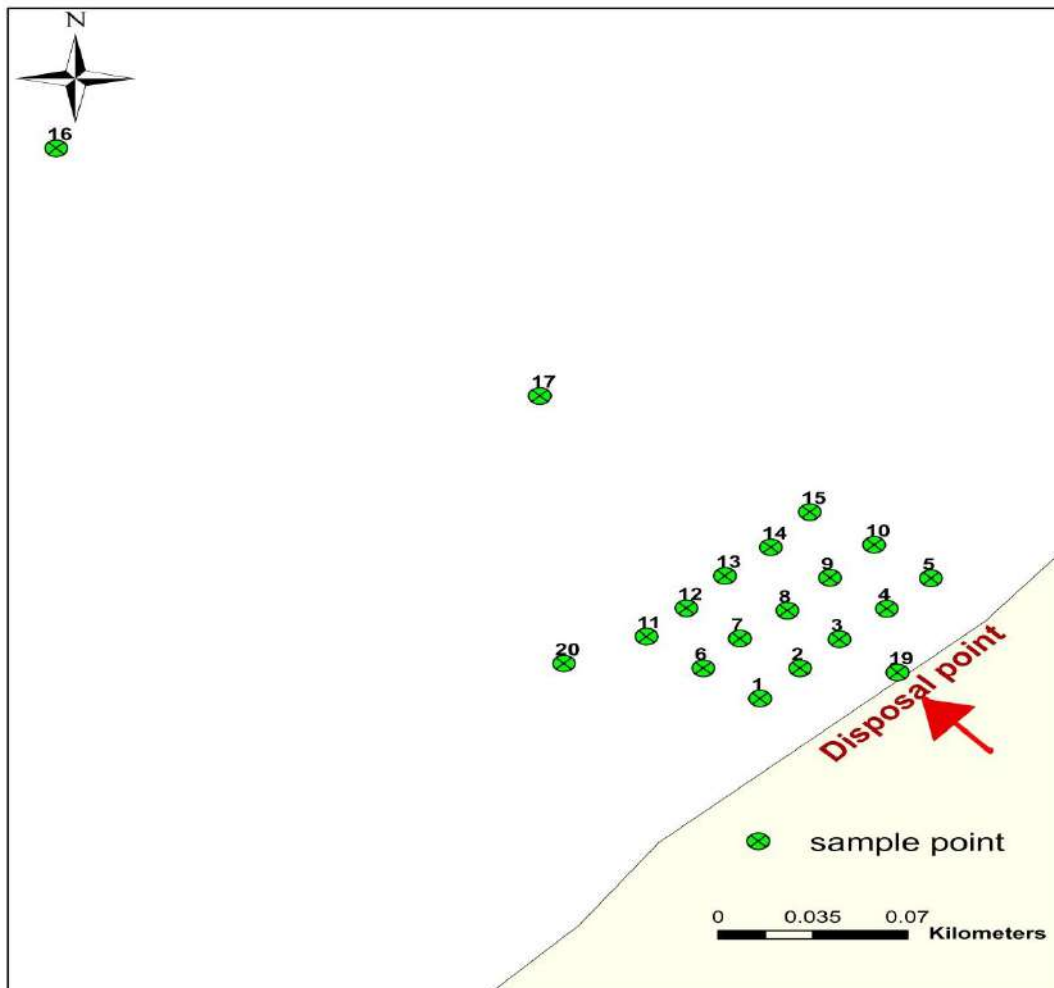


Figure (3.4): Locations of the third round observation points

3.3.2 Water Sample Preparation

- Calibration the DO meter, thermometer, turbidity meter, and a multipurpose EC pH meter, and check and record reagent expiration dates. It is recommended that these products be performed before going into the field.
- In order to avoid contamination, sample bottles were meticulously cleaned with dilute HCl and rinsed with deionized distilled water (DDW) before use. Samples were stored frozen until analysis.

3.4 Spatial Data Representation

An interpolation of the data obtained in each round was made using the kriging technique, with the purpose of getting a real representation of the salinity, turbidity, dissolved oxygen, temperature and pH variable in the study area. Before using this

methodology, it must be probed some kind of spatial correlation between data. Then the results that were obtained from the field and laboratory test were exported to excel 2010 and ArcGIS 10.1 to draw the spatial distribution of the surface chemical concentrations in the studied area.

Table (3.1): Sampling coordinates

Point No.	N	E
Desalination Plant	31° 25' 47.90''	34° 21' 14.46''
Disposal Point	31° 25' 54.01''	34° 20' 37.71''
1	31° 25' 53.59''	34° 20' 36.07''
2	31° 25' 54.08''	34° 20' 36.55''
3	31° 25' 54.55''	34° 20' 37.02''
4	31° 25' 55.04''	34° 20' 37.59''
5	31° 25' 55.53''	34° 20' 38.12''
6	31° 25' 54.08''	34° 20' 35.39''
7	31° 25' 54.56''	34° 20' 35.83''
8	31° 25' 55.01''	34° 20' 36.40''
9	31° 25' 55.54''	34° 20' 36.91''
10	31° 25' 56.07''	34° 20' 37.44''
11	31° 25' 54.59''	34° 20' 34.71''
12	31° 25' 55.05''	34° 20' 35.19''
13	31° 25' 55.57''	34° 20' 35.65''
14	31° 25' 56.03''	34° 20' 36.20''
15	31° 25' 56.60''	34° 20' 36.67''

3.5 Materials and Methods

The area was covered the saline mantle which surrounding the brine disposal point (discharge point). The parameter of pH, DO, Turbidity, Temperature and TDS are measured in field using situ sensors and by laboratory experiments. All sample containers must be labelled with at least the following information: date, time of day collection was made, station name and location, depth, method used to collect sample, replicate number, water property to be analyzed for, name of collecting agency.

3.5.1 In situ equipments

The equipments used in this research are Salinometer, Thermometer, Dissolved oxygen meter, Multipurpose EC pH meter Small plastic container (soda bottles), GPS, Ship, ice box, Camera, Field log notebook and pens, Sample tags, armored thermometer, centigrade.

3.5.2 Laboratory equipment and materials

In the lab the following equipments and materials were used:

Goggles or safety glasses for handling, Data form, Sealable container for collecting liquid reagent, armored thermometer, centigrade and Whirl Pak or another sterile

container and gloves for handling chemicals. All equipments are inspected upon receipt from the manufacturer. Each equipment is inspected for completeness, breakage, and to ensure it is operating correctly. Figure (3.5) shows the pH meter in laboratory.



Figure (3.5): pH meter in Laboratory

Table (3.2) shows the mechanisms data by each parameters have been calculated.

Table (3.2): Summary of the analytical method

#	parameters	Reference and method number	Summary of the analytical method
1	pH	4500-H ⁺ B. electrical method	The pH of a sample is determined electrometrically using either a glass electrode in combination with a reference potential or a combination electrode.
2	EC	2520 B. Electrical Method	TDS, EC and pH were measured in situ by a multipurpose EC pH meter.
3	Turbidity	2130 B. nephelometric method	The turbidity was measured turbidity meter
4	Temperature	By thermometer.	Temp. measured in situ by a thermometer.
5	Salinity	2510 B. laboratory method	TDS, EC and pH were measured in situ by a multipurpose EC pH meter.
6	DO	4500-O C. Azide Modification	The Dissolved oxygen was measured by DO meter in the field and by Azide Modification method in lab

Chapter 4: Description of Deir El-Balah Desalination Plant

4.1 Introduction

Water is a key to sustainable development, and the problems of water form part of the broader challenges of sustainable development. Water is more than a sector or commodity. Access to safe drinking water is a basic human need, essential for health and also for human dignity. The effective management of water resources is essential to the development of environmental, social, agricultural and industrial development in all countries, especially the developing ones [137].

Gaza Strip is considered one of the poor and limited water resources areas in the region. According to El Sheikh, the Coastal Aquifer being the only water resource in Gaza Strip suffers from deficit in the water budget which has been leading to deterioration in the quality and quantity of groundwater. This results from Over-pumping of the aquifer and reflects on the increase of sea water intrusion [72].

4.2 The Current Water Situation in Gaza Strip

Gaza strip is considered one of the most water scarce places in the world, where the main source is the ground aquifer. The water situation is disastrous due to the deficit either on water quality or quantities due to many reasons such as rainfall scarcity, continuous urbanization with limited land area, and population increase, which all leads to a critical situation.

4.3 Marine life in Gaza Strip

According to the Gaza Coastal and Marine Environmental Protection and Management Action Plan report, an arbitrary number of 201 fish species has been recorded in the Mediterranean of the Gaza Strip. The majority of the species are bony fishes consisting 81% of the fish community. Cartilaginous fishes (sharks, rays and other forms) constitute the rest percentage (19%) [88].

The most important habitat for bony fishes in the Gaza Strip is the rocky substrate, while the majority of cartilaginous fishes use the soft bottoms, muddy and sandy substrates. Many species of macrobenthos have been identified in the coastal zone of the Gaza Strip with no further details. The higher taxa include Molluscs, Crustaceans and Polychaeta. Preliminary current investigations revealed the presence of tens of both bony and cartilaginous fish species in the Gaza Strip [88].

4.4 Seawater Quality

Water quality testing is an important part of environmental monitoring. When water quality is poor, it affects not only aquatic life but the surrounding ecosystem as well.

These sections detail all of the parameters that affect the quality of water in the environment. These properties can be physical, chemical factors. Physical properties of

water quality include temperature and turbidity. Chemical characteristics involve parameters such as pH and dissolved oxygen. These parameters are relevant not only to surface water studies of the ocean, sea, lakes and rivers, but to groundwater and industrial processes as well.

Water quality monitoring can help researchers predict and learn from natural processes in the environment and determine human impacts on an ecosystem. These measurement efforts can also assist in restoration projects or ensure environmental standards are being met.

The study chapters discuss the effect of brine disposal of Deir El-Balah Desalination Plant on seawater quality parameter specifically.

4.5 Design Data and Process Description For Seawater Desalination Plant (Deir El-Balah)

4.5.1 General information and design criteria

The plant produces almost 600 m³ of fresh water a day throughout desalinating the seawater. During the current research period, the plant was upgraded to produce another 2000 m³/day and was connected with a reservoir for blending the desalinated water with other water supply (brackish water wells) to bring the water quality to an acceptable drinking water.

The plant has been served the communities of Deir El-Balah and Al- Zawaida municipalities in the middle. The additional quantities of 2000 m³/d is relatively small compared to the future regional plant (60 Million m³/year) but the plant highly contributes to lessen the fresh water shortage problem in the Gaza Strip especially in the Middle Governorate where groundwater is being deteriorated in this area. Therefore, upgrading the plant will produce more fresh water and will reduce the aquifer deteriorations and will be very beneficial. PWA stated that they are in the process of fund appraisal to the regional desalination plant which will be financed by European Union (EU) and Arab Fund, were EU and United Nations International Children's Emergency Fund (UNICEF) is currently working on the first stage of the regional plant to produce 6000 m³/d [138].

Gaza needs water and that will be through upgrading the existing desalination facility in Deir El-Balah which will be financed through Islamic Development Bank (IsDB) to be 2600 m³/day with specific unit production cost of not more than US\$ 0.8/ m³ (equivalent to 3 NIS per cubic meter of desalinated water) and using the RO system technology will reduce the current energy consumption [138].

The plant seawater intake is from an existing beach wells drilled along the shoreline. The depth of each well is about 45m with a maximum capacity of 75m³/ h each. The raw seawater is delivered through a pressure pipe (DN 200) to the raw water tank which has a capacity of 150 m³ and is installed at the plant site [138].

Existing intake pipe lines from beach wells and brine rejection pipes (diameter of 18 inch) will remain the same while upgrading the plant because it still accomodate the

additional quantities of 2000 m³/d (the brine pipe was designed to hold 5000 m³/d of desalinated water with 40% desalination plant efficiency) [138]. The brine from the desalination plant will be pumped to a reservoir (200 m³ capacity) near the seaside, and the outfall diffuser will be installed at the end of brine rejection pipe in the sea. Figure (4.1) shows the existing brine outlet of Deir El-Balah desalination plant



Figure (4.1) : Brine Outlet

The mechanical and electromechanical equipment of the reversed osmosis unit itself was designed for a max. capacity of 600 m³/d potable water at a first stage.

4.5.2 Technical data and design criteria (Desalination Plant of 600 m³/day) [108].

Table (4.1): Plant capacity [108]

Plant design capacity:		
per day	600	m ³ /day
per hour	26,0	m ³ /hr
Design temperature	17	Deg C
Water recovery rate	40	%
Required raw water flow	65	m ³ /h
Brine flow	39	m ³ /h

4.5.2.1 Feed water quality

The commonly accepted water quality indicators of RO feed water are SDI, turbidity, and suspended solid (SS) concentration. Lower values of these indicators and salinity

allow for higher permeate recovery rates. Seawater is taken from deep wells with the following specification. Table (4.2), Table (4.3) show the concentrations of total dissolved solids and the climatic conditions.

Table (4.2): Total Dissolved Solids (TDS) [108]

TDS:		
Design value	42.000	ppm
Operation range	35000 – 42000	ppm
Oily matters & matters harmful to the membranes	Not present	
Total Fe (iron)	less than 0.5	ppm
Manganese Mn	less than 0.15	ppm

Table (4.3): Climatic Conditions [108]

Character of climate	Mediterranean -tropical Semi-arid
Ambient air temperature indoor	max. 45 °C
Ambient air temperature outdoor	max. 50 °C
Relative humidity	max. 95 %
Annual rainfall	200 to 400 mm
Distance to shore	700 m, aggressive salty atmosphere
Sun radiation	Extreme sun-radiation during long, hot and dry summers
Wind	Sand – carrying winds possible

4.5.2.2 Product water quality

The quality of the produced potable water in general meets the WHO drinking water guidelines as specified in the 1996 issue, to avoid any risk for the health of consumers. As shown in Table (4.4) water quality after the post treatment is to be met and are to be considered as guarantee values:

Table (4.4): Product water quality [108]

Total dissolved solids	norm	~ 500	mg/l
	Max.	1000	mg/l
Chlorides	max.	200	mg/l
Sulfates	max.	< 250	mg/l
Nitrates	max.	< 50	mg/l
Total hardness	min.	50	ppm as CaCO ₃
	max.	200	ppm as CaCO ₃

m-Alkalinity	Min	30	ppm as CaCO ₃
	max.	100	ppm as CaCO ₃
pH value	Min/max	7	
	Max	9.0	
Langlier Saturation Index	Positive	+ 0.1 – 0.3	
Turbidity	max.	5	NTU
Residual Chlorine:	min	0.3	mg/l as Cl ₂
	max.	1	mg/l as Cl ₂

4.5.2.3 Required chemicals

Chemicals in general are used in pretreatment, posttreatment, membrane cleaning. Table (4.5) shows the operation chemicals and there sample.

Table (4.5): Operation chemicals [108]

Type	Concentration %	Purpose	Dosing rate (expected) (g/m ³)
Hydrochloric acid	HCl Liquid 30 % wt	pH adjustment for scale control	100 - 150 *
Sodium hypochlorite	NaOCl Liquid with 12 % wt Cl ₂	Desinfection	10 – 20 *
Ferric Chloride	FeCl ₃ 40 % wt	Flocculation	5 –15 *
Sodium metasilicate	Na ₂ SiO ₃ Powder	Chlorine removal	2 – 3 *
Antiscalant	AS Liquid (Hypersperse MD220)	Scale control	2 – 3 *
Caustic soda	NaOH Liquid 30 %	pH adjustment in the potable water	5 – 10 **
Limestone	Grains CaCO ₃	Potable water Rehardening	50 **

* dosing rate expressed for each m³ of feed water

** dosing rate expressed for each m³ of permeate (desalted water)

4.5.3 Process description

The seawater desalination plant consists in general of following process units, as shown in Figure (4.2) [108] :

- Seawater intake (beach wells)
- Seawater pretreatment plant
- Reverse Osmosis Desalination Plant
- Posttreatment Plant (Potabilization)
- Potable water storage and distribution system

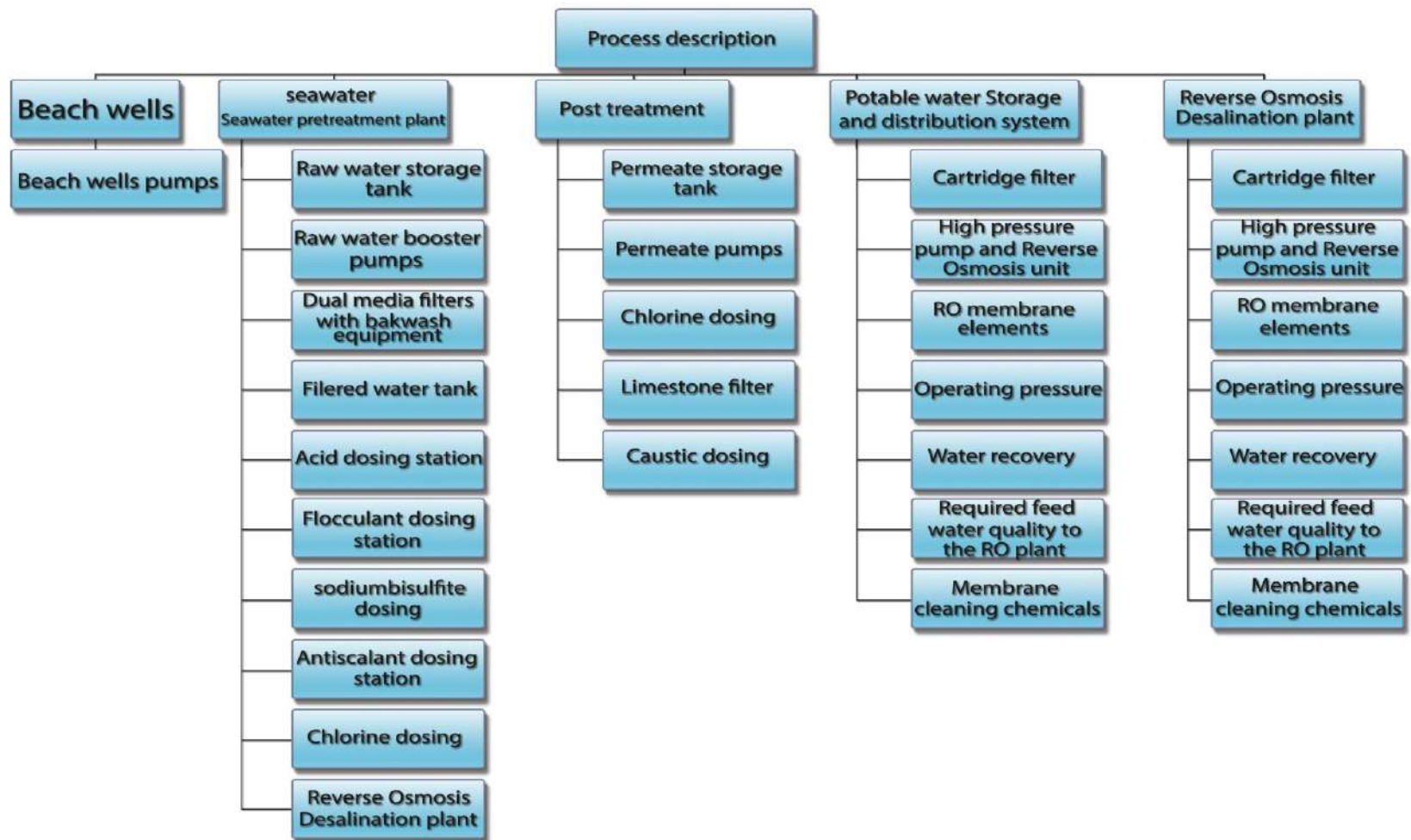


Figure (4.2) : Processes Description

4.5.3.1 Beach Wells (Seawater intake)

- **Beach well pumps**

The seawater is taken from two wells, drilled along the shoreline. The depth of wells is about, 45 m with a maximum capacity of 75 m³/h each. The distance to the desalination plant is approximately 1500 m. For the first stage of the project, both beach wells operate alternatively. While one beach well is in operation, the other well acts as shifting unit according to the operation hours of each well. For the future extension a total raw water quantity of 150 m³/h can be made available for treatment. Each well is equipped with a well pump P-01A/B a water level measuring system. The operating pumps are controlled by an automatic change over switch. The raw seawater is delivered through a pressure pipe (DN 200) to the raw water tank which has a capacity of 150 m³ and is installed at the plant site. The water level switching system of this tank controls the operation of the well pumps. The electric power for the operation of the well pumps is supplied by an earth buried cable from the desalination plant.

4.5.3.2 Seawater pretreatment plant

The seawater pretreatment consists of :

- Raw water storage tank
- Raw water booster pumps
- Dual media filters with backwash equipment
- Filtered water tank
- Acid dosing station
- Flocculant dosing station
- Sodiumbisulfite dosing
- Antiscalant dosing station
- Chlorine dosing.

- **Raw water storage tank**

The raw seawater is delivered into the raw water storage tank T-10A which serves as break and storage tank located in the desalination plant.

- **Filter feed pumps**

From the raw water tank the water will be pumped to the pretreatment system with the filter feed pumps P-10A/B pumps, each with a flow of 70 m³/h and a pressure of 4,5 bar, where one pump is stand by.

- **Dual media filters**

For the filtration of the seawater, three dual media filters F-10A/B/C operating in parallel are provided to remove any suspended particles of organic and inorganic nature which may be present in the raw sea water.

The filters are designed for filtration velocity of about 12 m/h which will produce a low SDI-Index for the feed water to the RO. The filter backwash is initiated by the differential pressure, or respectively after a certain operation time started by the operator. After a differential pressure of up to 0.6 to 0.8 bar is reached the filter operation is stopped (as well the RO unit) and the filters are backwashed with filtered water and air. For backwashing of the dual media filters, filtered water which is stored in the backwash tank T-11A is used which is supplied with the backwash pump P-11A. to the filters. The backwash air is supplied from the air blower V-10A.

- **Acid dosing**

Hydrochloric acid HCl is dosed into the filtered water, to lower and adjust the pH value for carbonate scale control to avoid calcium carbonate scaling in the RO membrane elements. The bicarbonates and carbonates of the water, which have a low solubility, are converted into Calcium sulfate and CO₂ and lower the pH-value of the water.



The pH value in the feed water to the RO unit is set to about pH 6,5.

The Calcium carbonate/-bicarbonate-hardness solubility in seawater is defined with the Stiff & Davies Saturation Index S&DI.

S&DI Index = 0 water is in balance

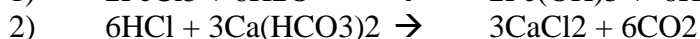
S&DI Index > 0 positive value the water is calcium carbonate scale forming

S&DI Index < 0 negative value the water is calcium carbonate scale dissolving

The calculation of the S&DI index takes into account of the TDS, Calcium, Alkalinity and the Temperature of the seawater. This factor have an influence of the carbonate scaling tendency of the water. In the RO system the bicarbonates are concentrated according to the concentration factor, while the CO₂ which keeps the carbonates in solution, passes the membrane. If no antiscalant is used in the RO system the S&DI in the brine must be negative < - 0.1 to avoid scaling. With the use of antiscalants the crystallization of calcium carbonate is inhibited and the S&DI can be in the positive up to + 1.0 depending from the dosing rate.

- **Flocculant dosing**

The FeCl₃ solution is dosed into seawater to destabilize and flocculate fine and colloidal particle to bring them in a filterable form. The FeCl₃ solution neutralize the negative charges of the colloids, the forms hydroxide flocs which absorbs this particles, the acid reacts with the carbonate hardness if the water



The dosing of flocculant is only required if the Silt Density Index (SDI₁₅) in average less than 3 max. 4 can not be achieved with normal filtration. This SDI value in the feed

water to the RO unit is specified by the membrane supplier to keep the colloidal fouling within the limits.

- **Sodium bisulfite dosing**

The sodium bisulfite (SBS) solution is dosed into the RO feed water after the cartridge filter for chlorine removal.

The high performance Thin Film Composite (TFC) RO membranes based on polyamide membrane material are irreversibly damaged by the oxidation potential of the chlorine Cl_2 , hypochlorite OCl and by combined chlorine (chloramines) as well. Therefore the chlorine must be removed or neutralized completely before the water enters the membranes. This is performed by dosing of sodium bisulfite NaHSO_3 which converts the chlorine to a nonoxydative sodium bisulfate and sodium chloride.



The sodiumbisulfite solution is prepared from sodium metasulfite powder $\text{Na}_2\text{S}_2\text{O}_5$. A stoichiometric dosing rate of 1.34 mg/l of $\text{Na}_2\text{S}_2\text{O}_5$ is required for the neutralization of 1 mg Cl_2 /l. However for safety reasons 3 g/ m^3 for 1 g Cl_2 / m^3 are added to the feed water. Sodium metasulfite when added into water converts to sodium bisulfite as shown in the following equation.



The Oxidation-Reduction Potential (ORP) is measured after the dosing point with the two instruments to check the SBS dosing. If sufficient SBS is dosed and reacted the ORP will have a zero to negative Millivolt (mV) value (reducing state) and no chlorine will be present. If the ORP is in the positive range and exceeds the range of + 200 to 300 mV an alarm is indicated and the danger of chlorine or an oxidizing chemical is present which have a destructive impact on the membranes and operation of the plant will be stopped.

Note:

A prepared SBS solution will slowly degraded by the oxygen in the air, therefore it is strictly recommended that the amount of the prepared solution is used within 1 week. In case the consumption is lower, a smaller amount shall be prepared in this case.

- **Antiscalant dosing**

The antiscalant solution is dosed into the RO feed water if this have an high content of Calcium, Sulfates, Barium or Strontium to stabilize this sparingly soluble salts to avoid precipitation. The antiscalant solution is an organophosphate solution, supplied by specialized chemical manufacturers only (e.g. GEBetz, Hypersperse MD220) when dosed into the seawater in small amounts prevents the formation of crystallization.

For normal seawater application the dosing of an antiscalant is not required and not recommended.

- **Chlorine dosing to raw water**

A chlorination of the raw seawater is required if the raw seawater has a high bacteriologic content (colony forming units) and with a high tendency to create biological fouling on the membranes. In this case an intermittent chlorination with a sodium hypochlorite NaOCl solution shall be applied for disinfection. For seawater taken from wells, does not contain normally marine life like palncton , algea,etc, and thus chlorination is normally not required.

If a chlorination is applied, special care must be taken that all chlorine is removed by SBS dosing as mentioend above is removed and no chlorine can come to the RO membranes which will damage the membranes irreversible.

4.5.3.3 Reverse Osmosis Desalination plant

- **Cartridge filter**

Before entering the RO units the water is filtered by a 5 micron cartridge filter F-20A to protect the RO element from particles. The cartridge filter is equipped with a difference pressure transmitter if this reaches max. 1.5 bar the cartridge has to be changed to new cartridges.

- **High pressure pump and Reverse Osmosis unit**

After the water has passed the cartridge filters, the high-pressure pump pressurizes the pretreated seawater to a the required operation pressure of 65 to 70 bar and feeds the seawater into the RO unit. The Reverse Osmosis consists of one unit X-20A with a design capacity of 600 m³/day.

The RO unit are equipped with spiral wound Thin Film Composite RO membrane elements of 8 inch diameter and 40 inch length. Six pieces of this RO membrane elements may be installed in the pressure vessels . In total 9 pcs of this pressure vessels are arranged in parallel RO block to achieve the required output. About 40 % of the feed water is recovered as permeate (desalted water) and the remaining 60 % brine stream is discharged . The high pressure feed pump system consist of the pumps connected in series.

The first pump is connected with a pelton turbine to recover the energy form the high pressure brine stream. The second pump is equipped with a speed controlled electric motor to increase the pressure to the above mentioned operation pressure. With this system an energy saving of 30 % are achieved. The feed booster pump is equipped with speed controlled motor to increase slowly the pressure and adjust the required feed pressure. In order to adjust the recovery ratio and to handle pressure differences due to temperature changes the speed controlled motor and a flow adjustment valve before the turbine is provided.

An automatic flushing of the pressure vessel, the RO elements, high-pressure pump and pipework is performed at every plant stop with permeate with flushing pump P-26A.. By displacing the brine solution inside the RO modules as well in the high pressure pump and turbine pump with permeate scaling and corrosion shall be prevented during stop period.

- **RO membrane elements**

In the RO desalination process the salts are retained by a semipermeable membrane which holds back the salt molecules and let pure water pass.

- **Operating pressure**

To force the water through the membrane a certain pressure is required, which results from the osmotic pressure of the water and the required net driving pressure (NDP) of the membrane. In our case we operate with a pressure of 65 to 25 bars. The water temperature has also a big impact on the operating pressure.

- **Water recovery**

From water flow rate to RO unit (Feed water) a certain amount which passes the membrane is recovered as desalted water (Permeate) while the other stream which contains the retains salts is discharged as concentrated solution (Brine). As shown in Table (4.6), the ratio of the Permeate flow to the Feed water flow rate is called the Water recovery (Y) and multiplied by 100 expressed in percent. In our case the feed water flow rate to the RO unit is 65 m³/hr, the permeate flow rate is 26 m³/h and the brine flow rate is 39 m³/h, the water recovery is therefore 40 %.

Table (4.6): Technical terms in a Reverse Osmosis plant

RO membrane element		Defines the commercial available RO membrane Spiral wound membrane element with 8 inch diameter and 40 inch length
Pressure vessel		Holds the above mentioned membrane elements. Made of Fiberglass FRP with 8 inch diameter and length to hold max. 6 elements.
Feed water flow	Q _f [m ³ /h]	Raw water inlet flow rate to RO unit ~ 65 m ³ /h
Brine flow	Q _b [m ³ /h]	Concentrated flow rate from the RO unit ~ 39 m ³ /h
Permeate flow	Q _p [m ³ /h]	Flow rate of the desalted water = 26 m ³ /h
Water recovery:		The percentage amount (yield) of water

Y= (Qp/Qf)x100	Y [%]	Recovered from the feed water $Y = (26/65) \times 100 = 40 \%$
Salt concentration factor CF: Theoretic concentration $CF = 100/(100-Y)$ Practical concentration $CF = (C_b/C_f)$ $C_f = \text{Conc. Feed (TDS mg/l)}$ $C_b = \text{Conc. Brine (TDS mg/l)}$		Number of times of the brine is concentrated in relation to the feed water $CF = 100/(100-40) = 1,67 \text{ times}$
Salt passage $Sp = (C_p/C_f) \times 100$ Cp.. Conc. Permeate (TDS or conductivity) Cf .. Conc. feed water (TDS Or conductivity)	Sp [%]	The percentage of salts which pass into the permeate in relation to the feed water $C_p = 495 \text{ uS/cm}$ $C_p = 52\,000 \text{ uS/cm}$ $Sp = (495 \text{ uS/cm} / 52\,000 \text{ uS/cm}) \times 100 = 0,95 \%$
Salt rejection: $Sr = 100 - [(C_p/C_f) \times 100]$ Cp.. Conc. Permeate (TDS) Cf .. Conc. feed water (TDS)	Sp [%]	The percentage of salts which are rejected by the membrane in relation to the feed water $Sp = 100 - [(495/52\,000) \times 100]$ $= 99,05 \%$
Net driving pressure: ND Pave $= P_f - P_o - (dp/2) - B_p$ Pf .. Feed pressure (bar) Po.. Osmotic pressure (bar) Dp.. Differential pressure Bp ..Permeate back pressure	NDP [bar]	Effective available pressure to force the water through the membrane. The NDP is reduced from the 1st stage front membrane elements to the 2nd stage end elements.

Flux rate	F= [l/m ² .h]	Permeate flow rate per m ² membrane area and day
F= (Q/A) x 24		
Qp.. Permeate flow rate (l/h)		
A .. Membrane area (m²)		

- **Required feed water quality to the RO plant**

The feed water (entering the RO unit) should be within the following limits as indicated in Table (4.7):

Table (4.7): Required feed water quality

Analysis		Normal range	Min/ Max. Values
Water temperature during operation		18 - 28	15 – 30
Water temperature during cleaning		40	Max. 45
pH value operation		6,7 – 7,0	6,5 – 7,3
pH value for cleaning		--	3 – 11
Langlier Saturation Index	S&DI	< + 1,0 with antiscalant	Max. + 1,5 with antiscalant
TDS, max	mg/l	41 000	42 000
Turbidity	NTU	< 0,5	< 1
Silt Density Index	SDI	< 3,0	4 , peaks max. 5
Free chlorine	mg/l	0	0
Total chlorine	mg/l	0	0
Sulfite content	mg/l	2 – 3	
Oxidation- Reduction Potential ORP	mV	< + 250	Max. + 350
Iron Fe	mg/l	< 0,05	< 0,1

- **Membrane cleaning chemicals**

In case of fouling and scaling on the membranes this residuals can be removed with certain chemicals. The membrane cleaning system serves for the cleaning of the RO membranes in the pressure vessels. The cleaning system maybe also used for the disinfection of the membranes. In the cleaning tank T-25A the required amount and concentration of the cleaning solution is prepared. The cleaning pumps P-25A/B are required for the circulation of the cleaning solution over the tank and over the RO-block. The cleaning solution can be heated up to 40 deg C with the cleaning solution heater W-25A to improve the cleaning efficiency of the solution. The cleaning solution is filtered in cartridge filter F-25A before the cleaning solution enters the pressure vessels.

4.5.3.4 Post treatment (potabilization)

The purpose of the post treatment plant is to potabilize the permeate by rehardening and disinfection with chlorine.

The post treatment plant consists of:

- Permeate storage tank.
- Permeate pumps.
- Chlorine dosing.
- Limestone filter.
- Caustic dosing.

- **Permeate tank and permeate pumps**

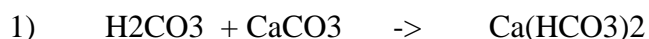
The permeate from the RO unit is delivered into the permeate tank T—30A with capacity of 50 m³ which serves as a break tank after the RO unit and as a buffer tank upstream of the post-treatment plant. This tank is store as well the water for flushing of the RO unit as describe above. The two permeate pumps P-30A/B delivers the water through the limestone filter further into the potable water storage tanks .

- **Chlorine dosing**

For disinfection reasons, sodium hypochlorite is injected in the permeate before the limestone filter and a residual chlorine content of 0,3 – 1,0 ppm Cl₂ in order to disinfect the water.

- **Limestone filters**

In the limestone filters F-30A/B filled with limestone media (CaCO₃) the free carbonic acid, resulting from the acid dosing and the freed CO₂ from the water is bounded and converted into calcium carbonate hardness.



The recommended minimum hardness for drinking water, appr. 50 ppm as CaCO₃, is produc-ed and the pH value of the water is raised to the saturation pH value. (Reference is made to Langlier Saturation Index LSI where the Calcium and Carbonates are in equilibrium). In this process the limestone media is consumed during the operation and must be refilled regularly with new limestone material. After about 15 % are consumed, limestone media have to filled up to the original level. The filter are backwash to remove the dust and then they are reday again for operation again. After each refill the filter must be backwashed to remove the fine dust, backwashing of the filters is done with permeate supplied from the permeate pumps and with air supplied from the air blower V-10A..Duiring normal operation a backwash is not necessary.

- **Caustic soda dosing**

For final pH adjustment and to achieve a positive Langlier Saturation Index LSI in the potable pro, a small quantity of caustic NaOH is dosed after the limestone filters to increase the pH value to about pH 8,0 – 8,3 After that the water is transferred to the potable water storage tanks.

4.5.3.5 Potable water storage and distribution system

- **Potable water storage tanks**

The potable water storage tanks T-40A/B serves as buffer tanks. The potable water will be distributed via pumping station to the small scale piping system, the filling stations for tankers and pickups and to the operation building for internal use. A possibility for dosing of NaOCl to the outgoing drinking water are provided for final disinfection.

- **Network supply pumps and tanker filling pumps**

The pumping station consists in total of 5 pumps, 3 (2+1) network pumps each with a capacity of 35 m³/h and 5,5 bar pressure shall be used for the piping network system and plant area. The 2 (1+1) tanker filling pumps with a capacity of each 50 m³/hr and 2 bar pressure shall be used for the tanker filling station with drinking water. For the case of breakdown of that pumps a bypass from the network pumps via a pressure reduction valve has to be installed. To balance pressure fluctuation in the network a hydrophore tank shall be provided. A second hydrophore tank has to be situated in the pipe system for the filling stations.

- **Tanker filling stations**

Two filling boxes shall serve for filling of tankers from companies, that are licensed by PWA. Those companies shall transport the treated water to the customers. Every day about 200 to 300 m³ of drinking water shall be distributed that way. At an average content of tankers of about 10 m³ approximately 20 to 30 tours are necessary. The time of filling tankers at all two filling boxes at the same time shall be possible. Each of the two boxes has to be equipped with a water meter with a total counter and a resetable counter after each tanker filling and with all required fittings. A steel construction shall carry the sun shed covering the filling station. The filling of tankers shall be made possible by using flexible rubber hoses mounted according the requirements.

- **Tanker disinfection**

To provide the people with high quality water all water transportation companies licensed by PWA shall be committed to disinfect the tankers regularly. Disinfection of tankers shall be carried out by rinsing with highly chlorinated water solution in one of the filling boxes. Rinsing shall be performed with a high pressure cleaning unit. The used rinsing water shall be discharged into the brine line.

- **Filling station for private Consumers**

This filling station with two devices shall be used by private consumers who will arrive by car and fill some cans for own use. About 20 m³ may be sold at this station within a day. The distribution shall be carried out with a coin triggered slot machine, programmable up to a single quantity of 20 l.

Chapter 5: Results and Discussion

5.1 Results of the First Round

As shown in Figures (5.1 to 5.10), point 3 was taken in this study as a reference point (Point R) to identify the seawater quality and properties. Point R is located 1600 m to the south of the brine disposal point where it is assumed there is no effect of the brine in the sea.

Table (5.1) and Figure 5.1 to 5.10 represented the first round results that were obtained from the field and laboratory tests on 15 June, 2014. After that the results were exported to excel 2010 and ArcGIS 10.1 to draw the spatial distribution of the chemical concentrations in the area of the brine disposal.

Only 5 points were used in presenting the data in these figures. The sampling depth was a round 30 cm from the sea surface.

Figures 5.1, 5.3, 5.5, 5.6 and 5.8 illustrate the comparison between the values of Dissolved Oxygen, Temperature, Salinity, and Turbidity respectively which were measured at points 1, 2, 3, 4 and 5 with the values measured at point R.

Table (5.1): Results of first round on 15 June, 2014

Sample Unit	North	East	Location	EC (mS/cm)	DO (mg/l)	Turbidity (NTU)	Temperature (C°)	TDS (mg/l)
1	31.42040	34.33125	A distance of 50m from the south of the desalination plant next El-Bahrea.	59	9.2	0.56	27.1	39600
2	31.42095	34.33040	A distance of 100m from the front of beach next El-Bahrea.	59.3	8.4	0.55	27.2	39700
3 (R)	31.42151	34.32795	A distance of 200m from the front of beach next El-Bahrea. (1600 m from the disposal point.	59.2	8.3	0.38	27	39700
4	31.43278	34.34168	A distance of 100m from discharge point.	59.3	7.8	0.79	27	39600
5	31.43454	34.34970	A distance of 200m from discharge point.	59.2	9.1	0.19	27.1	39600
7	31.43166	34.34380	From discharge point.	41.0	8.5	4.64	27	26500
9	31.42997	34.35401	From desalination plant.	93.4	7	0	27	40000

5.1.1 Dissolved Oxygen (DO)

Figure (5.1) illustrates the comparison between the value of dissolved oxygen (DO) at points 1, 2, 3, 4 and 5 with the value of DO at point R.

Figure (5.1) shows that the maximum value of DO was 9.2 mg/l at sample no. 1, but the minimum value of DO was 7.8 mg/l at sample no. 4. The value of DO at a reference point R was 8 mg/l.

The average DO value was 8.56 mg/l for all samples as the same as of brine value at a discharge point which also was 8.5 mg/l. The average DO value falls within acceptable limits and upper than 2 mg/l which requires for the marine life [91,92].

As such, dissolved oxygen levels can range from less than 1 mg/L to more than 20 mg/L depending on how all of these factors interact. In freshwater systems such as lakes, rivers and streams, dissolved oxygen concentrations will vary by season, location and water depth [93].

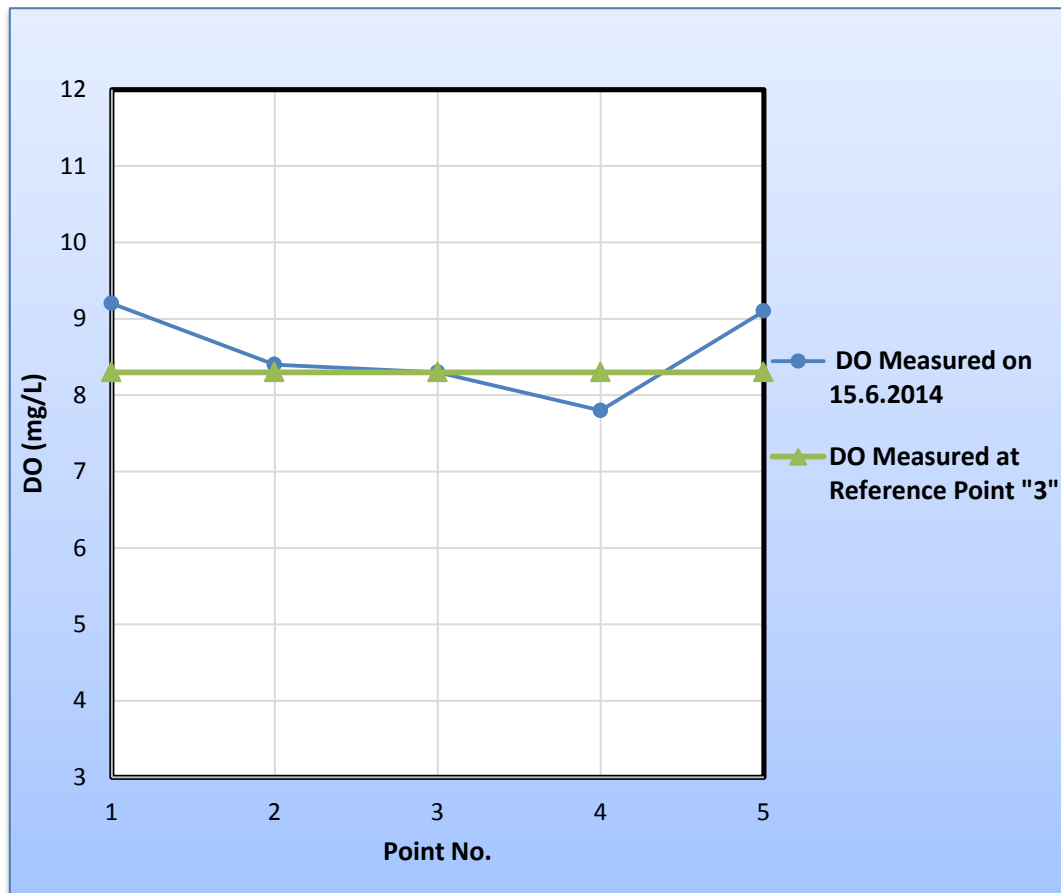


Figure (5.1): DO measured in the first round on 15 June, 2014

Figure (5.2) presented the map of DO measured in the area surrounding the brine discharge point in the first round.

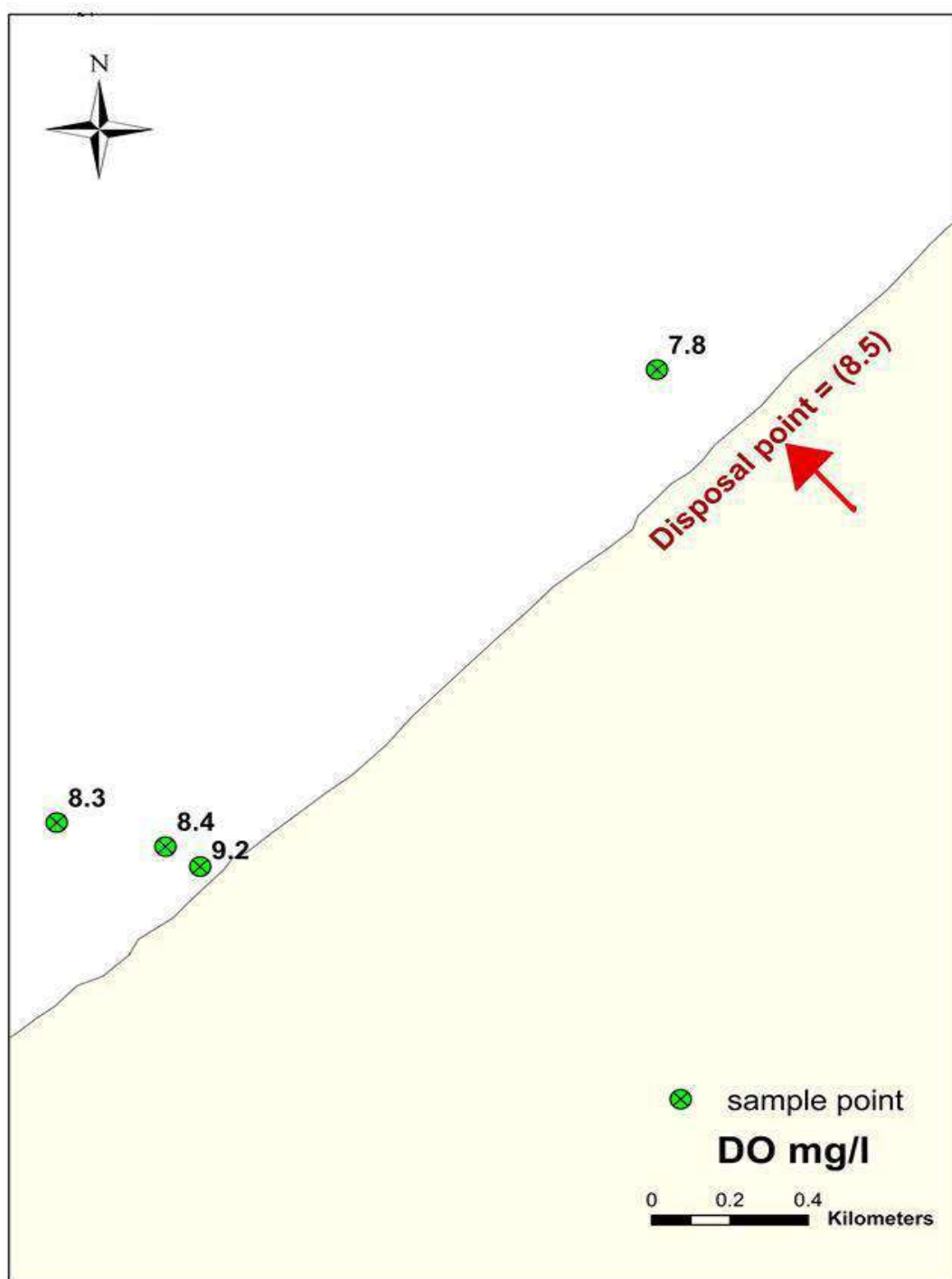


Figure (5.2): Dissolved Oxygen in the study area on 15 June, 2014
(First Round)

5.1.2 Temperature

Figure (5.3) illustrates the comparison between the value of temperature measured at points 1, 2, 3, 4 and 5 with the value of temperature at point R..

Figure (5.3) illustrates that the maximum value of temperature was $27.2\text{ }^{\circ}\text{C}$ at sample no. 2, but the minimum value was $27\text{ }^{\circ}\text{C}$ at a discharge point.

Figure (5.3) shows that the average temperature value was $27\text{ }^{\circ}\text{C}$ where the brine temperature value at a discharge point was $27\text{ }^{\circ}\text{C}$ in that round. It also shows that the temperature at point R was $27\text{ }^{\circ}\text{C}$. It is noted that the temperature of discharged brine was obviously lower than the ambient sea water temperature in that round.

It can be recognized that the discharged from RO do not have an impact on increasing the temperature of the seawater since RO has no thermal pollution compared with thermal distillation technologies [31].

It is important to note that the samples were obtained during the summer season so the temperature levels may vary with the seasons.

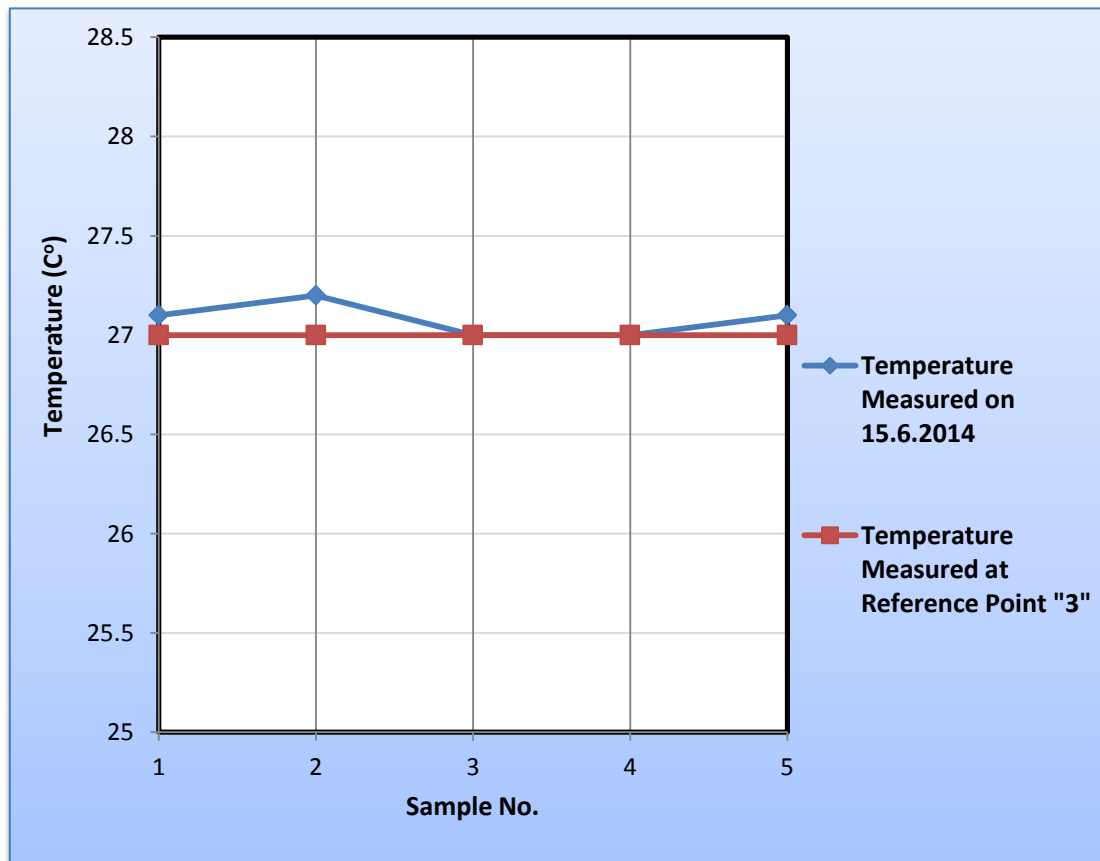


Figure (5.3): Temperature measured in the first round on 15 June, 2014

Figure (5.4) presented the map of temperature measured in the area surrounding the brine discharge point in the first round.

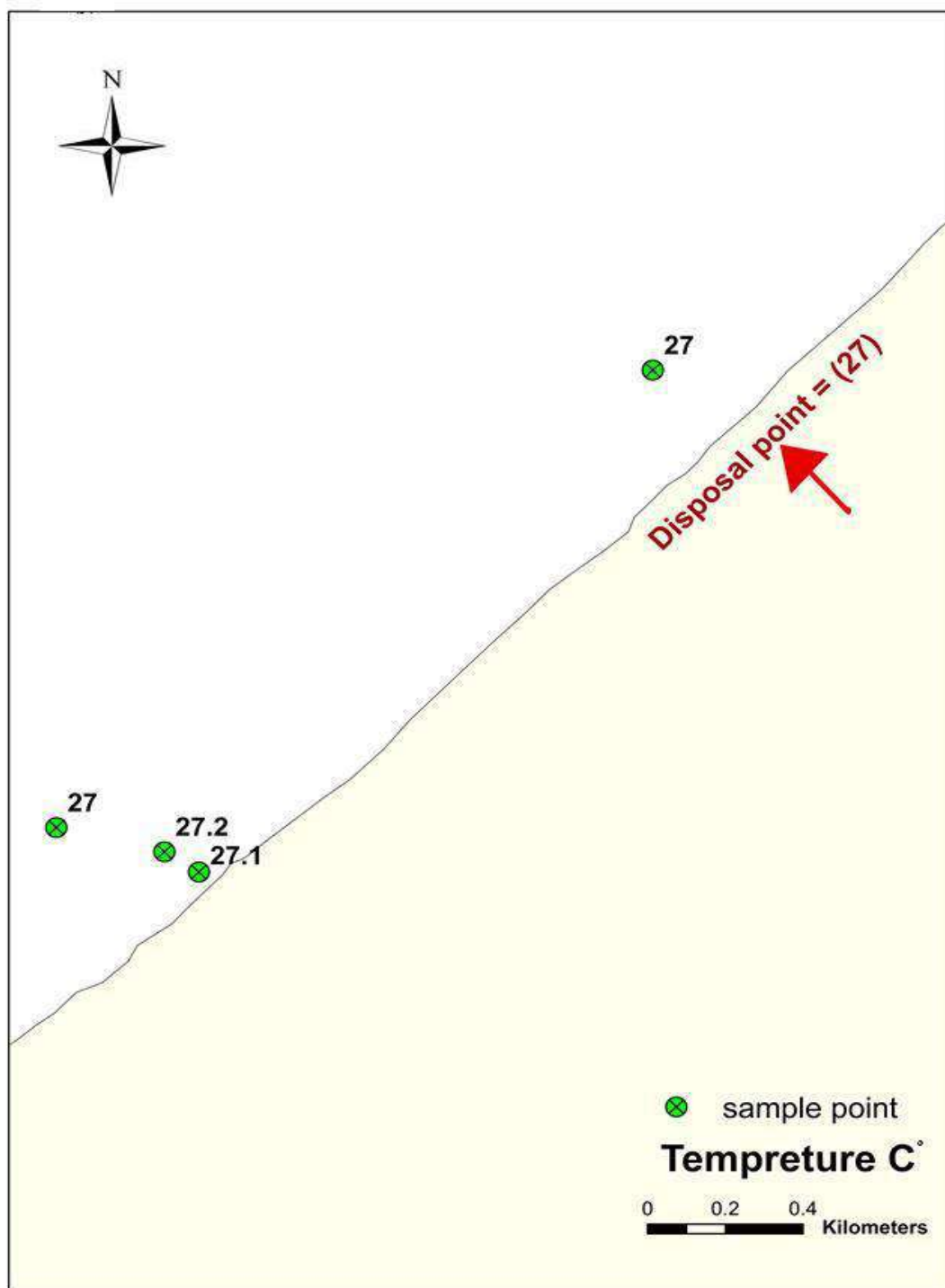


Figure (5.4): Temperature in the study area on 15 June, 2014
(First Round)

5.1.3 Electrical Conductivity and TDS

Figure (5.5) illustrates the comparison between the value of electrical conductivity (EC) measured at points 1, 2, 3, 4 and 5 with the value of EC measured at point R.

Figure (5.5) illustrates that the maximum value of EC was 59.3 mS/cm (59300 μ S/cm) and the TDS value was 39700 mg/l, but the minimum value of EC was 59 mS/cm and the TDS value was 39600 mg/l. EC value of a reference point R was 59.2 mS/cm and the TDS value was 39700 mg/l.

As shown in Figure (5.5) the average value of EC in this round was 59.2 mS/cm and the average value of TDS was 39640 mg/l. All values of EC are within acceptable limits.

It is clear that the salinity (EC) of brine at a disposal point in this round was lower than the seawater salinity. Moreover, the salinity (EC) of brine at a disposal point was much lower than brine salinity in the plant site before pumping.

Note : Taking into consideration the effluent from desalination processes is discharged into the sea through outfall pipes. The onshore section of the pipeline is 1500 m from the desalination plant to the coast. The diameter of the pipeline is 18 inch passes through shallow saline aquifer. Several manholes are connected the plant outlet towards sea outfall. It is remarkable that, saline water inflow from aquifer in Al Basa area passes through brine gravity manholes and mixed with the brine. This decreases the level of brine salinity before reaching seawater outfall, as shown in Figure (5.7) [107].

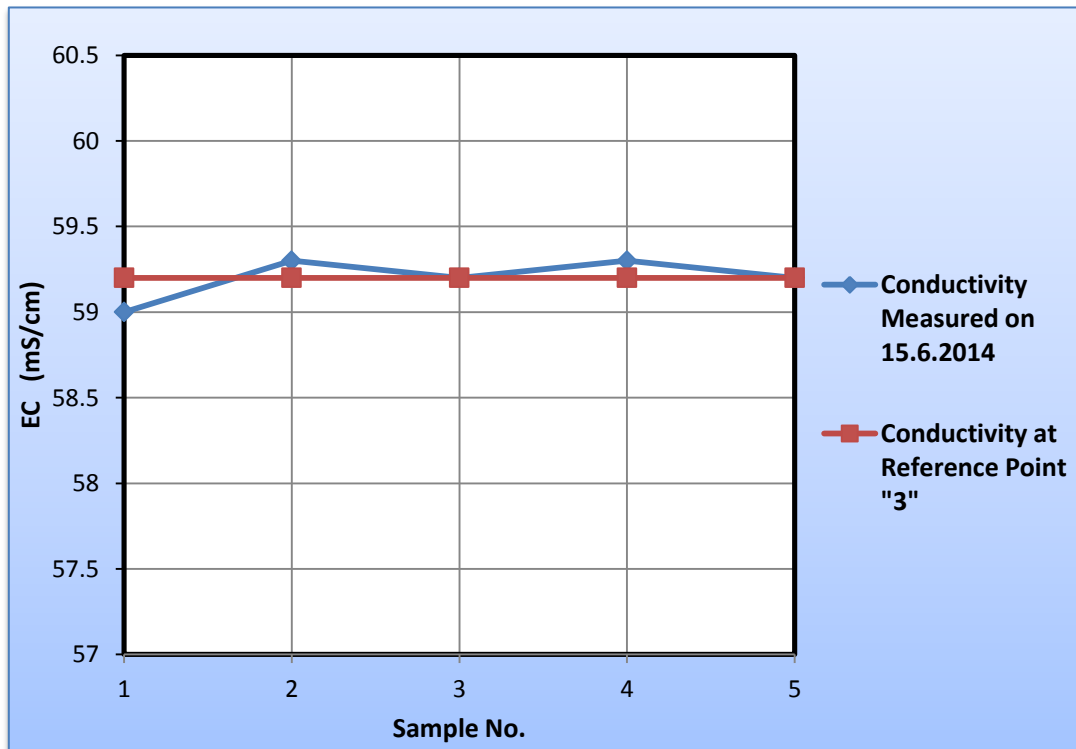


Figure (5.5): Electrical Conductivity measured in the first round on 15 June, 2014

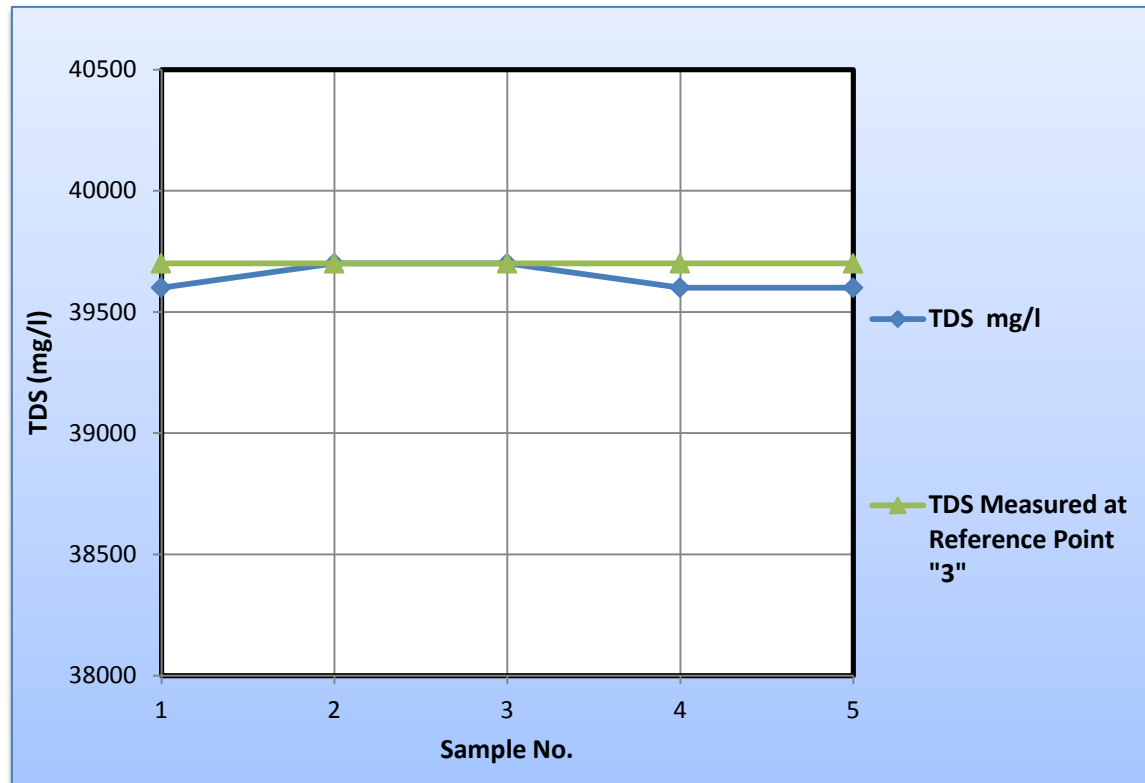


Figure (5.6): TDS measured in the first round on 15 June, 2014

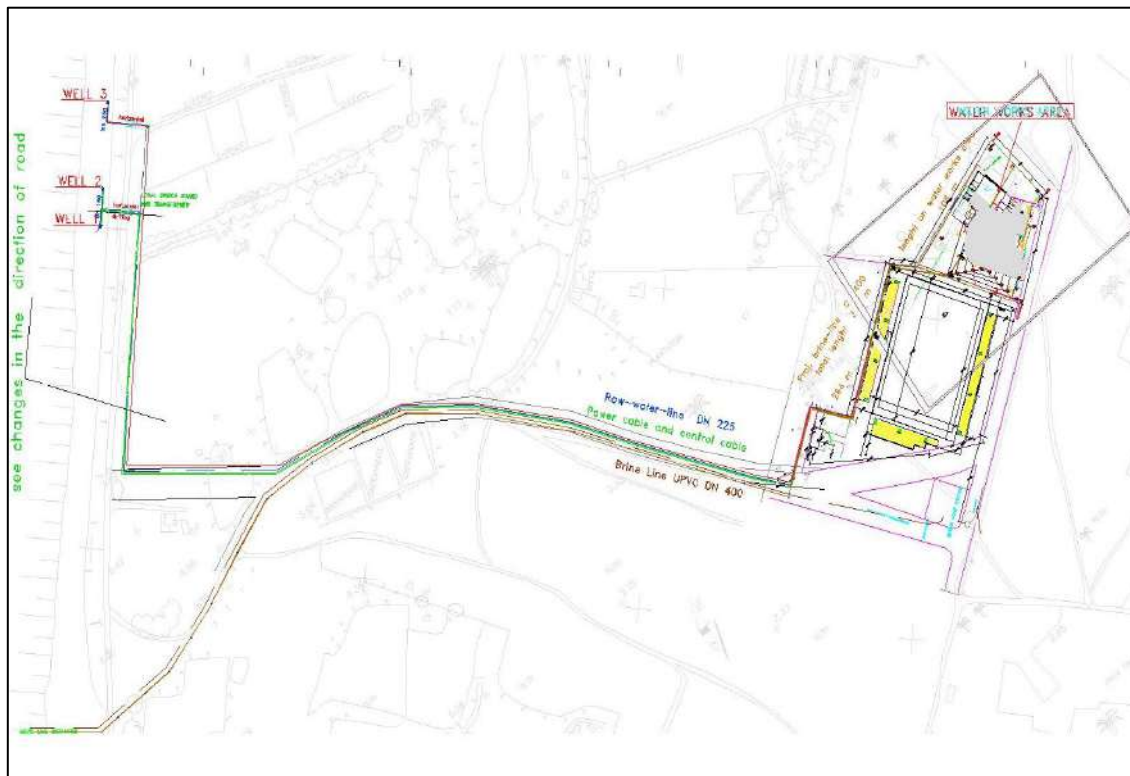


Figure (5.7): Brine disposal line

Figure (5.8) presented the map of EC measured in the area surrounding the brine discharge point in the first round.

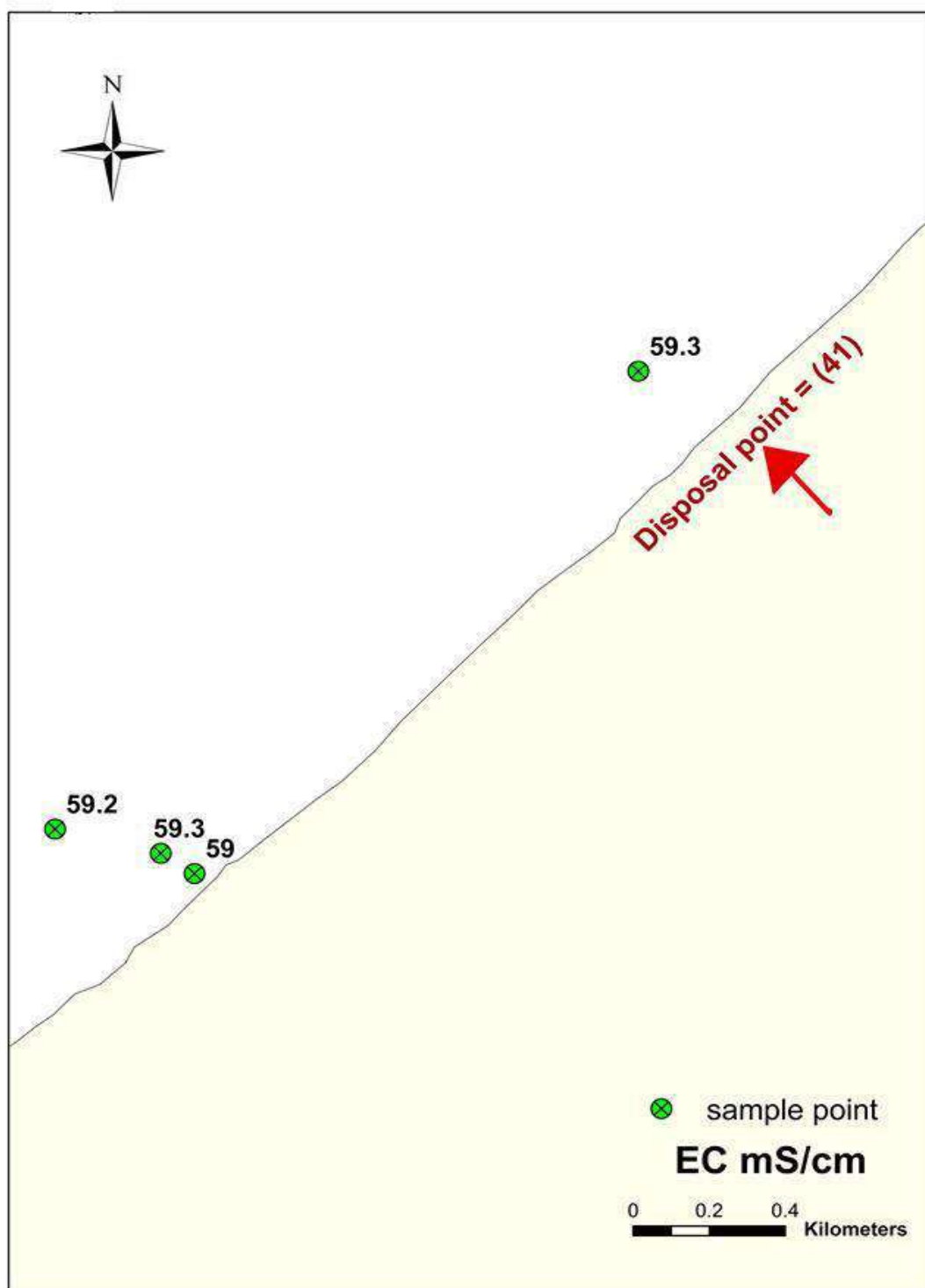


Figure (5.8): EC in the study area on 15 June, 2014
(First Round)

5.1.4 Turbidity

Figure (5.9) illustrates comparison between the value of turbidity measured at points 1, 2, 3, 4, 5, 6, 7 and 8 with the value of turbidity measured at point R.

The values of turbidity in the measurement points range between 0.19 to 0.79 (NTU) which are in acceptable limits.

The turbidity value of a reference point R was 0.38 NTU. The maximum value of turbidity was 0.79 NTU at sample no. 4, but the minimum value of turbidity was 0.19 NTU at sample no. 5. The average value of turbidity for all samples in this round was 0.494 NTU. The brine turbidity value was 4.64 NTU at a disposal point.

Turbidity of seawater indicated that degree of optical clearness of seawater is affected by the existence of dissolved matters and suspended particles.

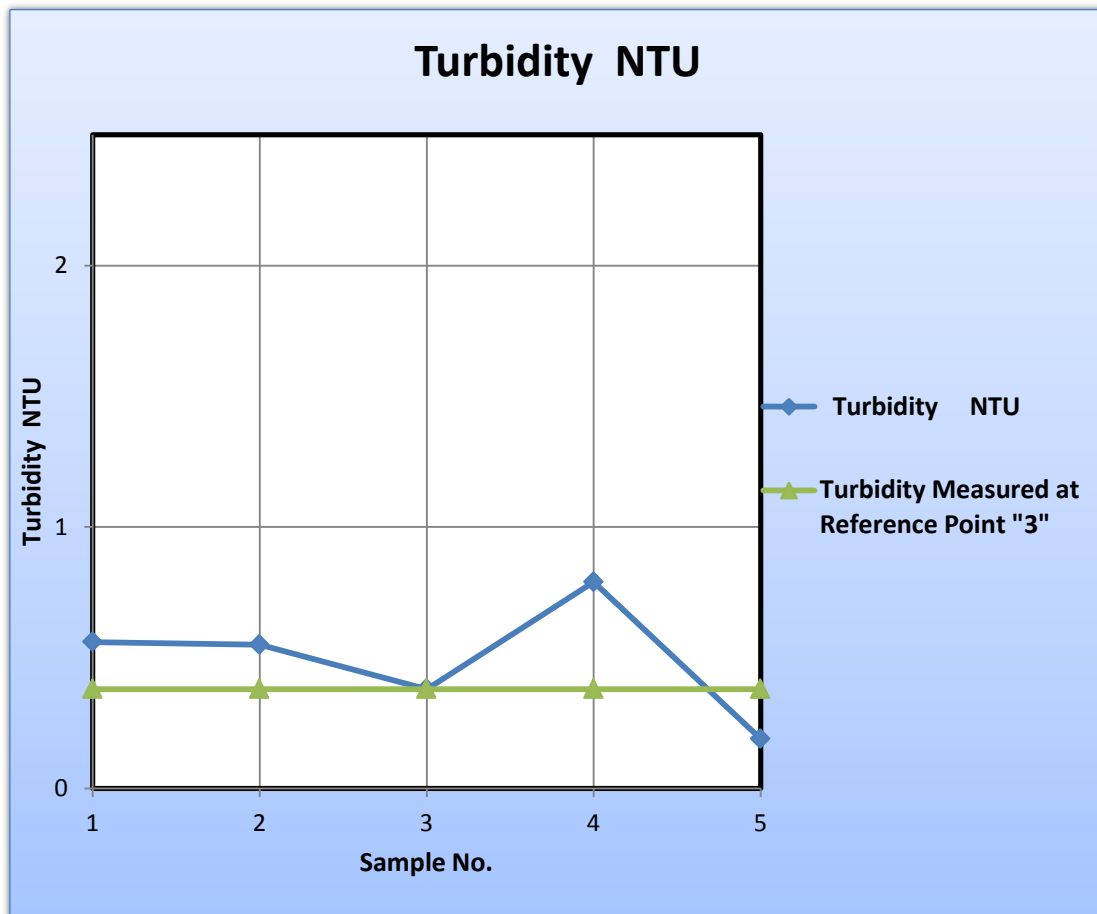


Figure (5.9): Turbidity measured in the first round on 15 June, 2014

Figure (5.10) presented the map of turbidity measured in the area surrounding the brine discharge point in the first round.

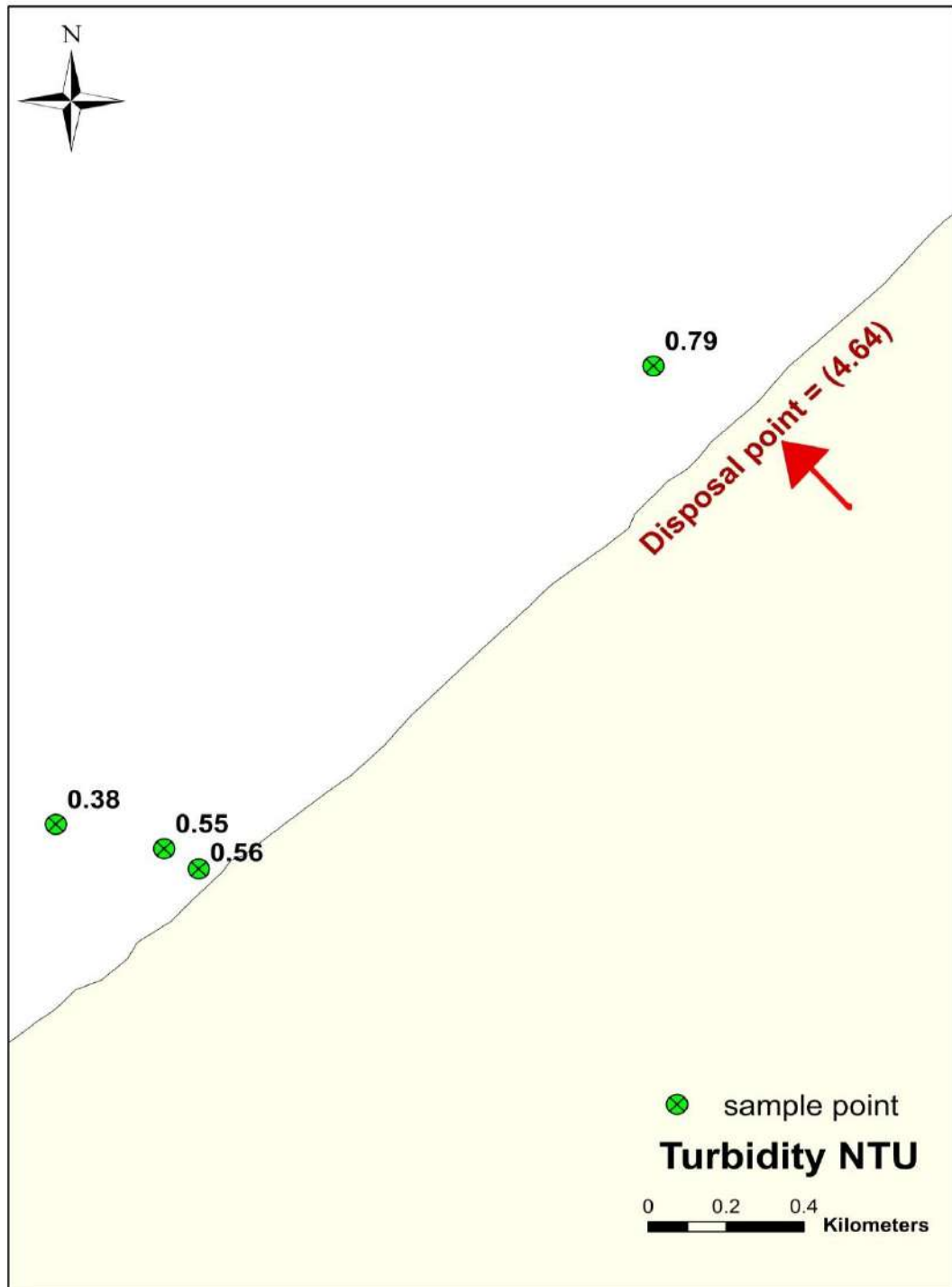


Figure (5.10): Turbidity in the study area on 15 June, 2014
(First Round)

5.2 Results of the second round

Table (5.2) and Figures 5.11, 5.12, 5.13, 5.14, 5.15, 5.16, 5.17, 5.18, 5.19 and 5.20 represented the second round results that were obtained from the field and laboratory tests on 28 June 2014 after that the results then were exported to excel 2010 and ArcGIS 10.1 to draw the spatial distribution of the chemical concentrations in the area of the brine disposal.

Sampling point 3 that was measured in the second round is different from a reference point R in the first round that was measured on 15 June. Only 5 points were used in presenting the data in the figures.

Figures (5.11, 5.13, 5.15, 5.17 and 5.19) illustrate the (Turbidity, pH, Salinity, Temperature and DO) values which were measured in this round at points 1, 2, 3, 4 and 5.

Table (5.2): Results of the second round on 28 June, 2014

Sample #	North	East	Location	EC (mS/cm)	DO (mg/l)	Turbidity (NTU)	Temperatue (C°)	TDS (mg/l)	pH
1	31.43402	34.34101	A distance of 200m from discharge point.	60.2	8.3	0	28.8	40000	8.349
2	31.43291	34.34262	A distance of 100m from discharge point.	60.1	8.2	0	29	40000	8.318
3	31.43186	34.34172	A distance of 50m from discharge point.	59.8	8.3	0	29.4	39000	8.315
4	31.43167	34.34381	A distance of 5m from discharge point.	60.2	8	0.15	29.1	40000	8.315
5	31.43171	34.34270	A distance of 30m from discharge point, from the South	60.1	7.1	0	29.1	40000	8.308
7	31.42997	34.35401	Start point. From desalination plant	89.6	6	0	26.6	60000	7.681
8	31.43166	34.34380	From Discharge Point	85.5	5.8	4.64	27	57000	7.500

5.2.1 Dissolved Oxygen (DO)

Figure (5.11) illustrates the DO values measured at points 1, 2, 3, 4 and 5. The values of DO in the measurement points range between 7.1 to 8.3 mg/l which are in acceptable limits and upper than 2 mg/l which required for the marine life [91,92].

Figure (5.11) shows that the maximum value of DO was 8.3 mg/l at sample no. 3, but the minimum value of DO was 7.1 mg/l at sample no. 5. The average value of DO was 7.98 mg/l in this round. The DO value of brine was 5.8 mg/l at a disposal point. All DO values are within acceptable limits [91,92].

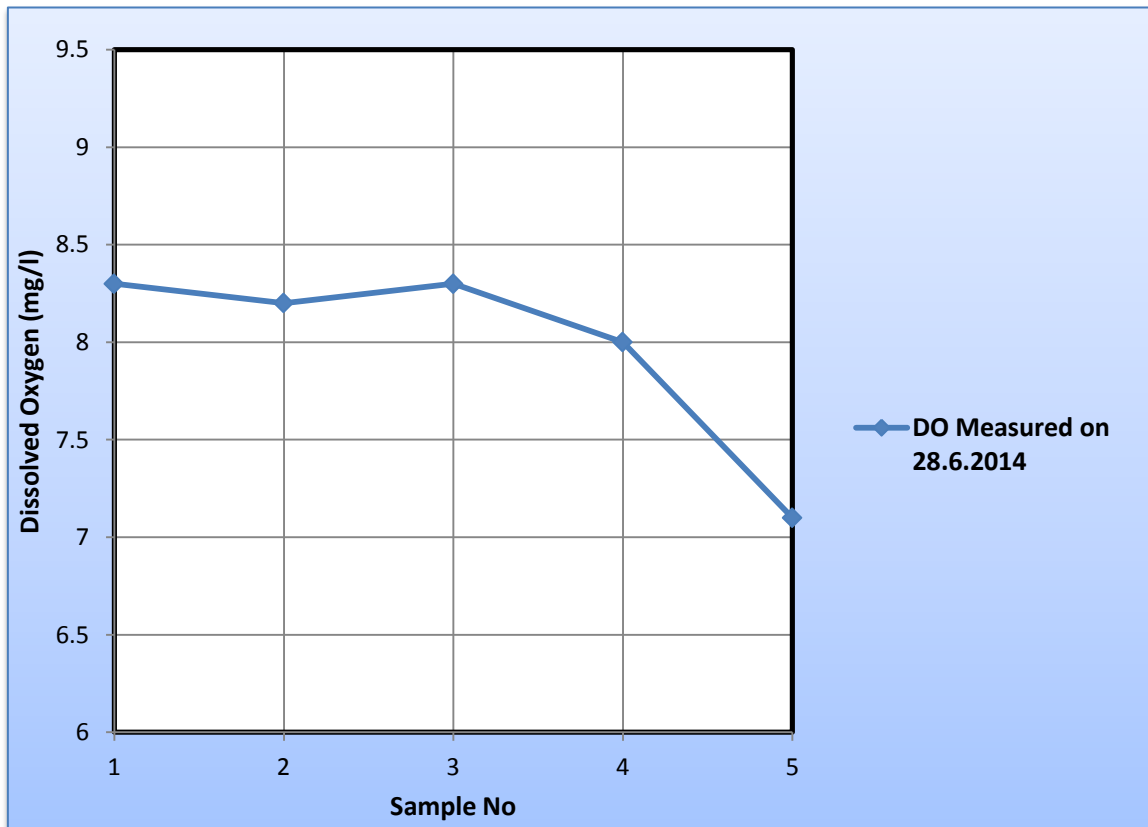


Figure (5.11): DO measured in the second round on 28 June, 2014

Figure (5.12) presented the map of DO measured in the area surrounding the brine discharge point in the Second Round.

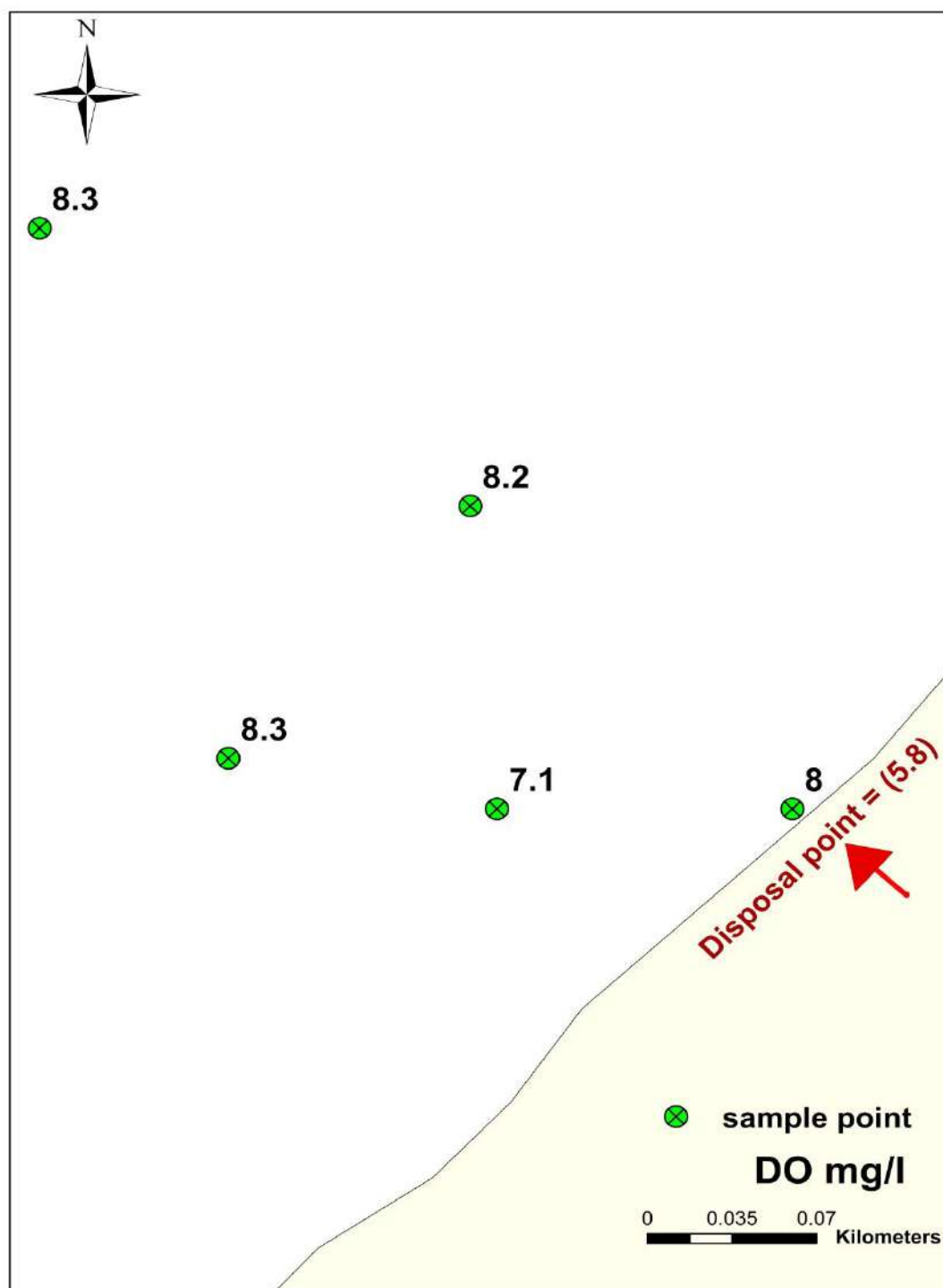


Figure (5.12): Dissolved Oxygen in the study area on 28 June, 2014
(Second Round)

5.2.2 Temperature

Figure (5.13) illustrates the temperature values measured at points 1, 2, 3, 4 and 5. Figure (5.13) illustrates that the maximum value of temperature was $29.4\text{ }^{\circ}\text{C}$ at sample no. 5, but the minimum value was $29.1\text{ }^{\circ}\text{C}$ at sample no. 3. The brine temperature value was $27\text{ }^{\circ}\text{C}$ at a disposal point. It can be recognized that the discharged from RO do not have an impact on increasing the temperature of the seawater since RO has no thermal pollution compared with thermal distillation technologies [31].

Figure (5.13) shows that the average temperature value was $29\text{ }^{\circ}\text{C}$ where the brine temperature value at a discharge point was $27\text{ }^{\circ}\text{C}$ in the second round. It also shows that the temperature at point R was $27\text{ }^{\circ}\text{C}$. It is noted that the temperature of discharged brine was obviously much lower than the ambient sea water temperature in this round.

It is important to note that the samples were obtained during the summer season so the temperature levels may be vary with the seasons since the temperature of the sea surface can also vary with respect to the adjacent air temperature but generally by not as much as over land

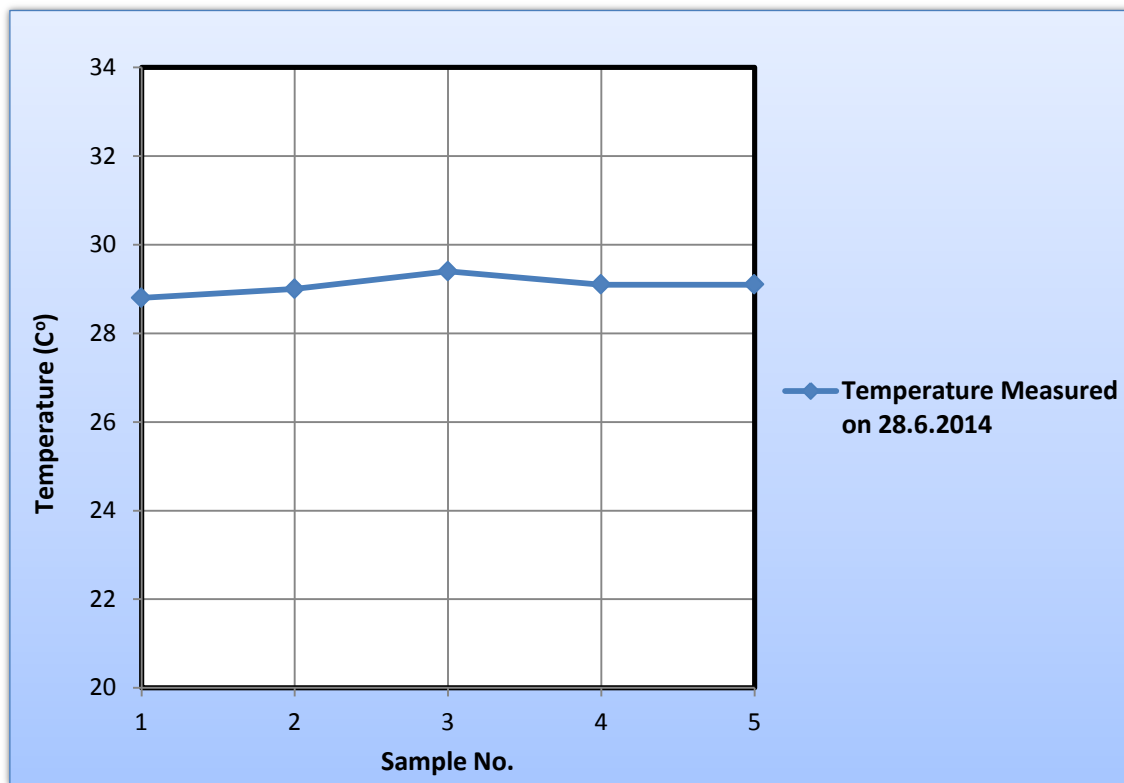


Figure (5.13): Temperature measured in the Second Round on 28 June

Figure (5.14) presented the map of temperature measured in the area surrounding the brine discharge point in the second round.

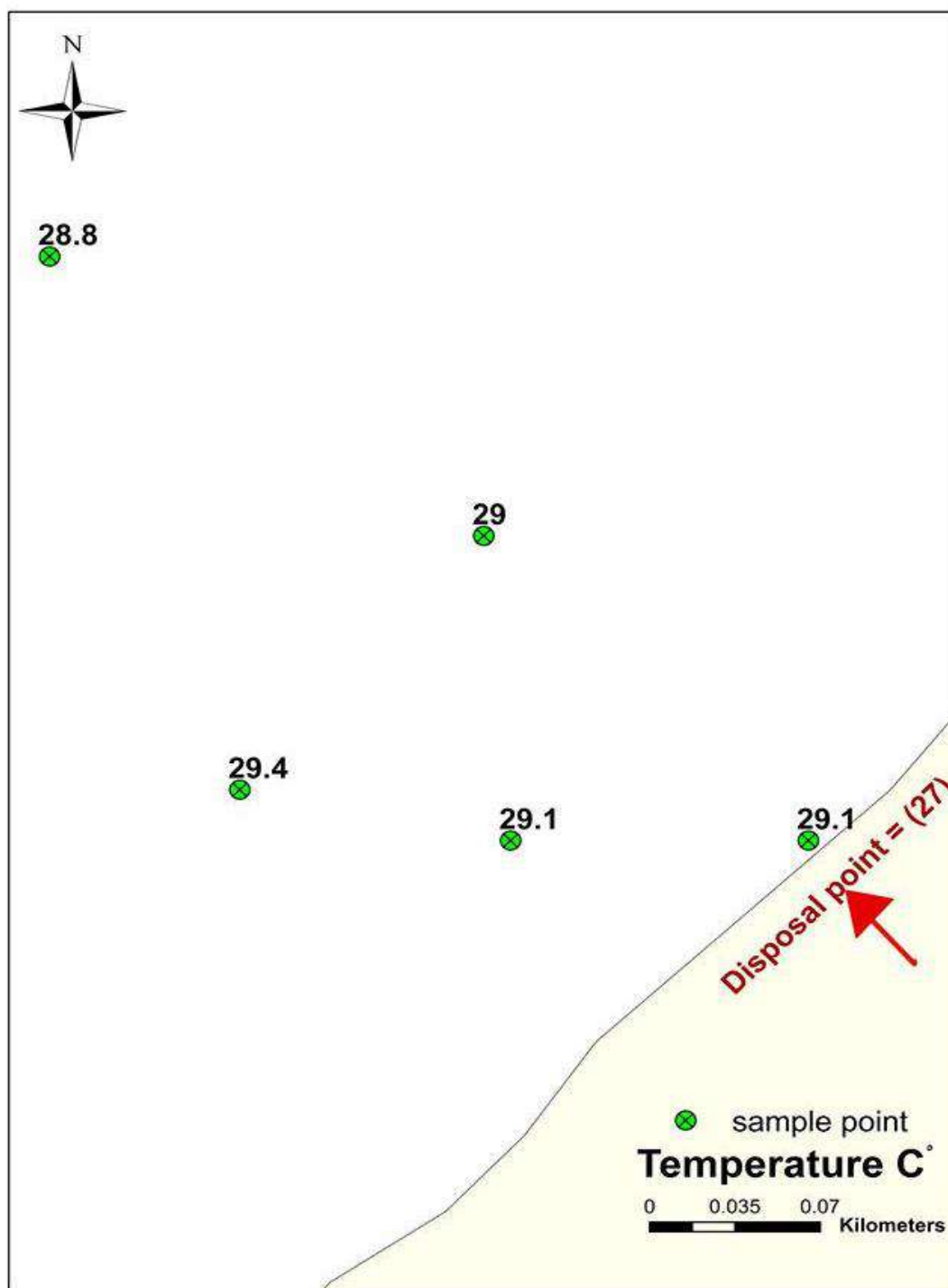


Figure (5.14): Temperature in the study area on 28 June, 2014
(Second Round)

5.2.3 Electrical Conductivity

Figure (5.15) illustrates the electrical conductivity (EC) values at points 1, 2, 3, 4 and 5. Figure (5.15) and Figure (5.16) illustrate that EC values range between (59.8- 60.2) (mS/cm) and the TDS values range between (39000- 40000) (mg/l) in the locations examined, continued to remain within an acceptable range and that although no immediate action would be required.

Figure (5.15) and Figure (5.16) conclude that the maximum value of EC was 60.2 mS/cm and the TDS value was 40000 mg/l at sample no. 4, but the minimum value of EC was 59.8 mS/cm and the TDS value was 39000 mg/l at sample no. 3. As shown in Figure (5.15), the average value of EC in this round was 60 mS/cm and the average value of TDS was 39800 mg/l.

The EC value of brine disposal was 85.5 mS/cm (85500 μ S/cm) and the TDS value was 57000 mg/l. It is clear that the salinity of brine disposal at this round was higher than the seawater salinity. Moreover, the salinity (EC) of brine at a disposal point was lower than brine salinity in the plant site before pumping due to the same reason mentioned in above [107].

All values of EC are within acceptable limits and the dilution of the brine is completely occurred.

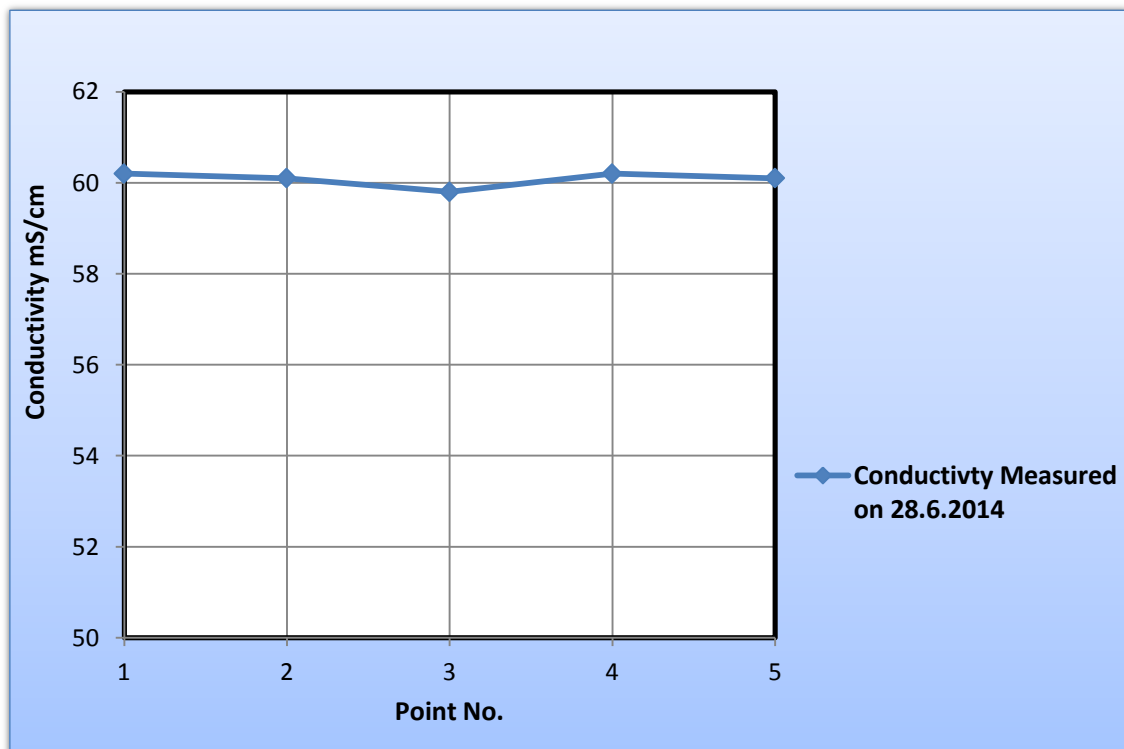


Figure (5.15): EC measured in the second round on 28 June, 2014

Figure (5.16) presented the map of EC measured in the area surrounding the brine discharge point in the second round.

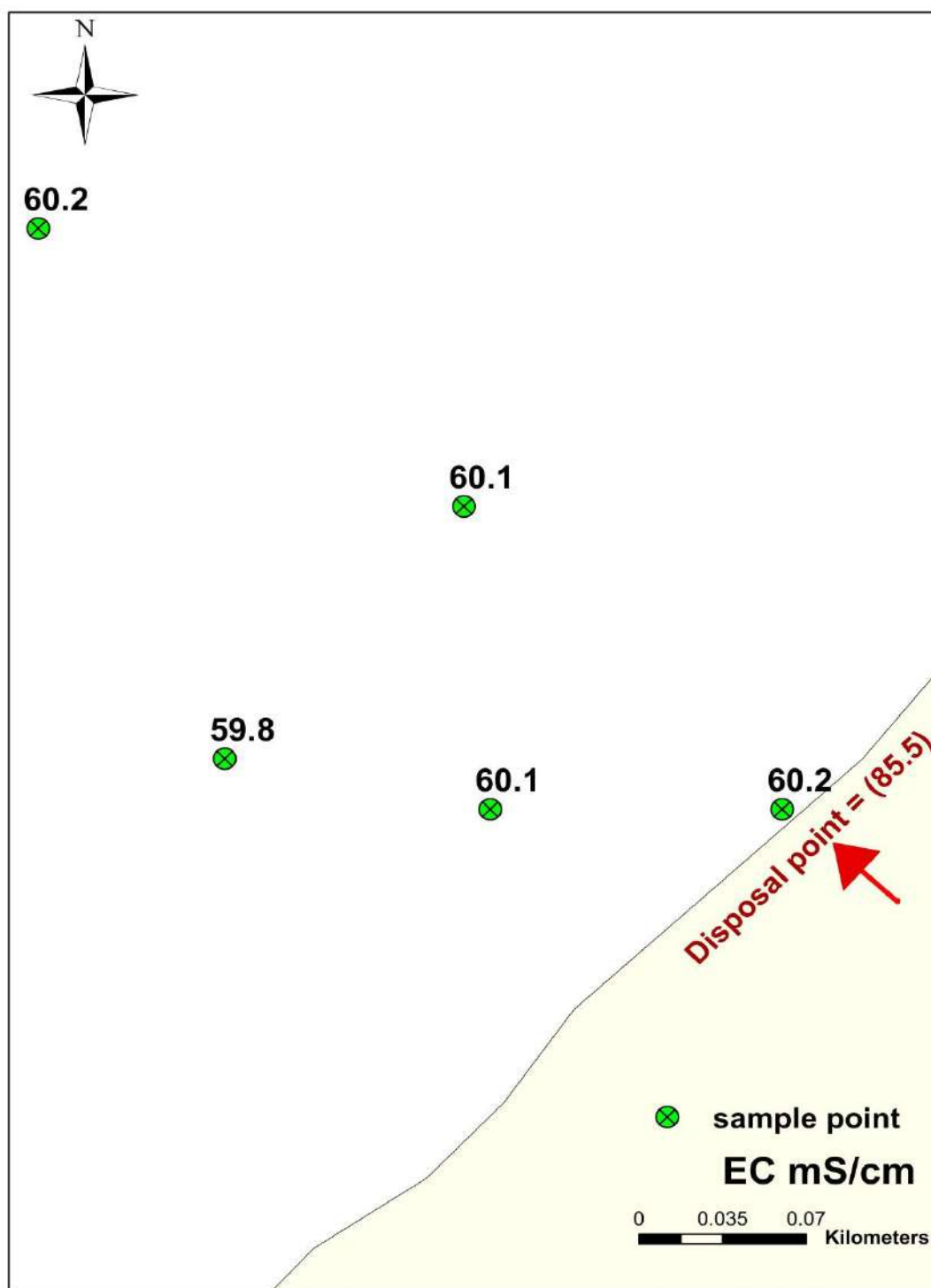


Figure (5.16): Conductivity in the study area on 28 June, 2014
(Second Round)

5.2.4 Turbidity

Figure (5.17) illustrates the Turbidity values measured at points 1, 2, 3, 4 and 5. The values of turbidity in the measurement points range between 0 to 0.15 (NTU). The maximum value of turbidity was 0.15 NTU at sample no. 4 which was near a disposal point, but the minimum value of turbidity was 0 NTU at all samples. The brine turbidity value was 4.64 NTU in this round.

Figure (5.17) illustrates the turbidity value at sample no. 4 was considered too small. The average turbidity value was 0.03 NTU for all samples. It should be noted that the samples were obtained during the summer so turbidity levels may be vary with the seasons.

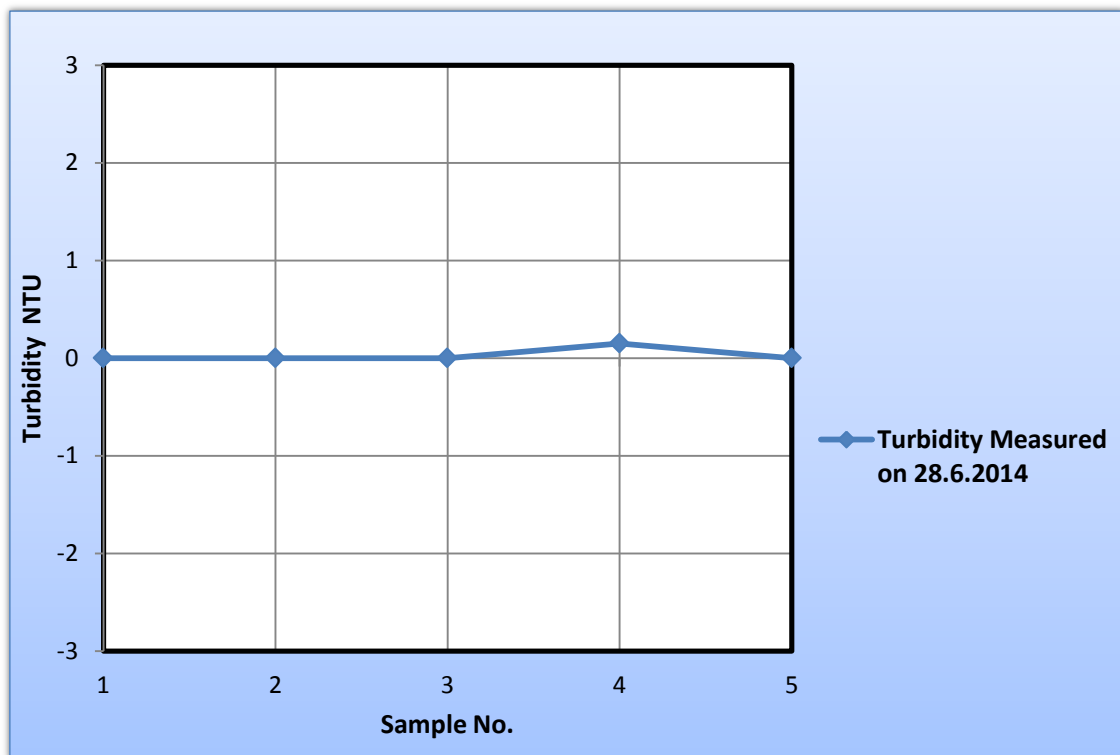


Figure (5.17): Turbidity measured in the second round on 28 June, 2014

Figure (5.18) presented the map of Turbidity measured in the area surrounding the brine discharge point in the second round.

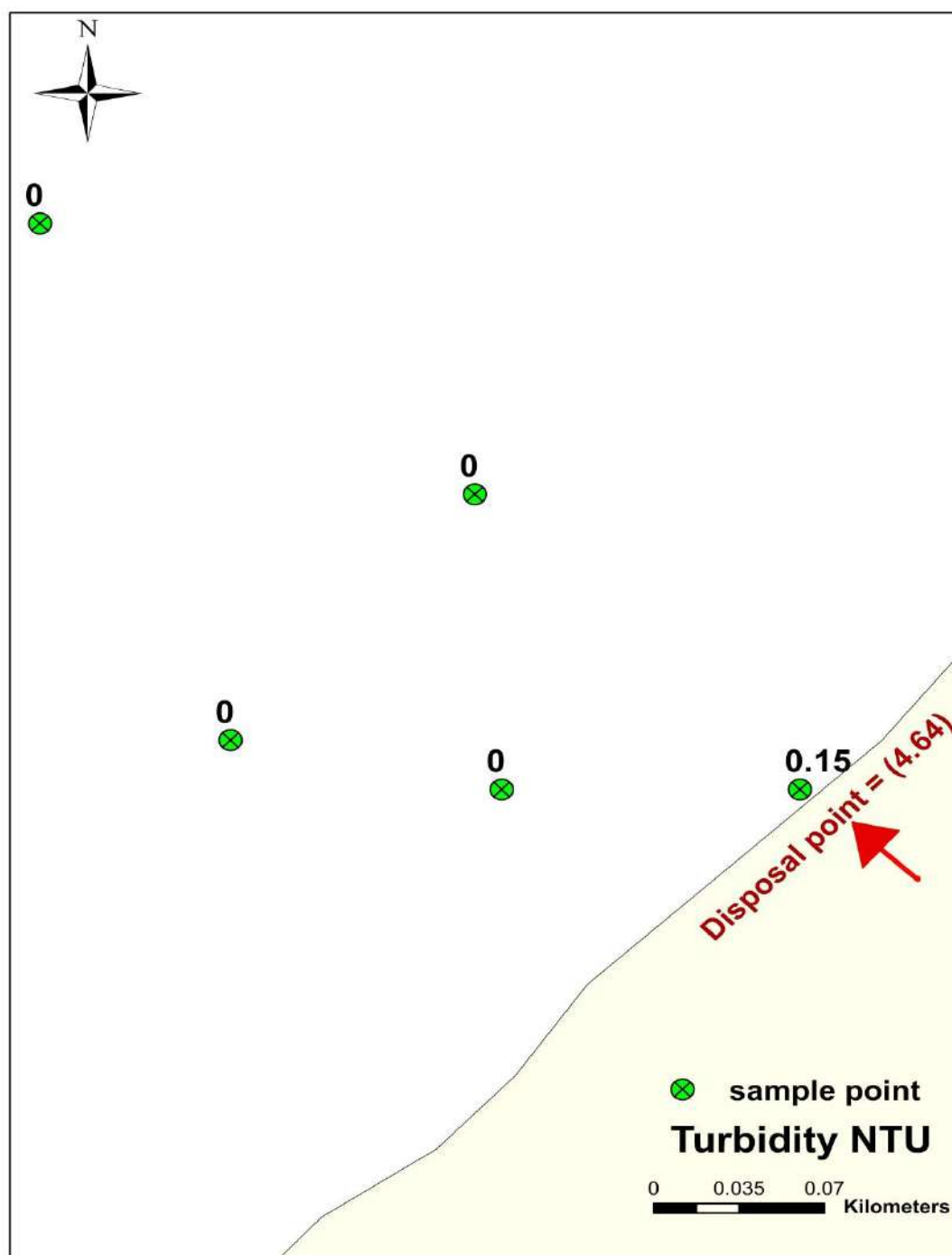


Figure (5.18): Turbidity in the study area on 28 June, 2014
(Second Round)

5.2.5 pH

Figure (5.19) illustrates the pH values measured at points 1, 2, 3, 4 and 5. Figure (5.19) illustrates that the pH range between (8.308- 8.349) in the locations examined, continued to remain within an acceptable range and that although no immediate action would be required.

The maximum pH value was 8.349 at sample no. 1, but the minimum pH value was 8.308 at sample no. 5. The brine pH value was 7.5 in this round. Average pH value was 8.32 for all samples. The pH value near a disposal point was 8.315 at sample no. 4. All pH values are considered in the normal range.

The recommended pH range for most fish is between 6.0 and 9.0 [99,100]. In chemistry, pH is a measure of the acidity or basicity of an aqueous solution. Solutions with a pH less than 7 are said to be acidic and solutions with a pH greater than 7 are basic or alkamap. Pure water has a pH very close to 7. It means that the brine did not increase the alkalinity of the sea water.

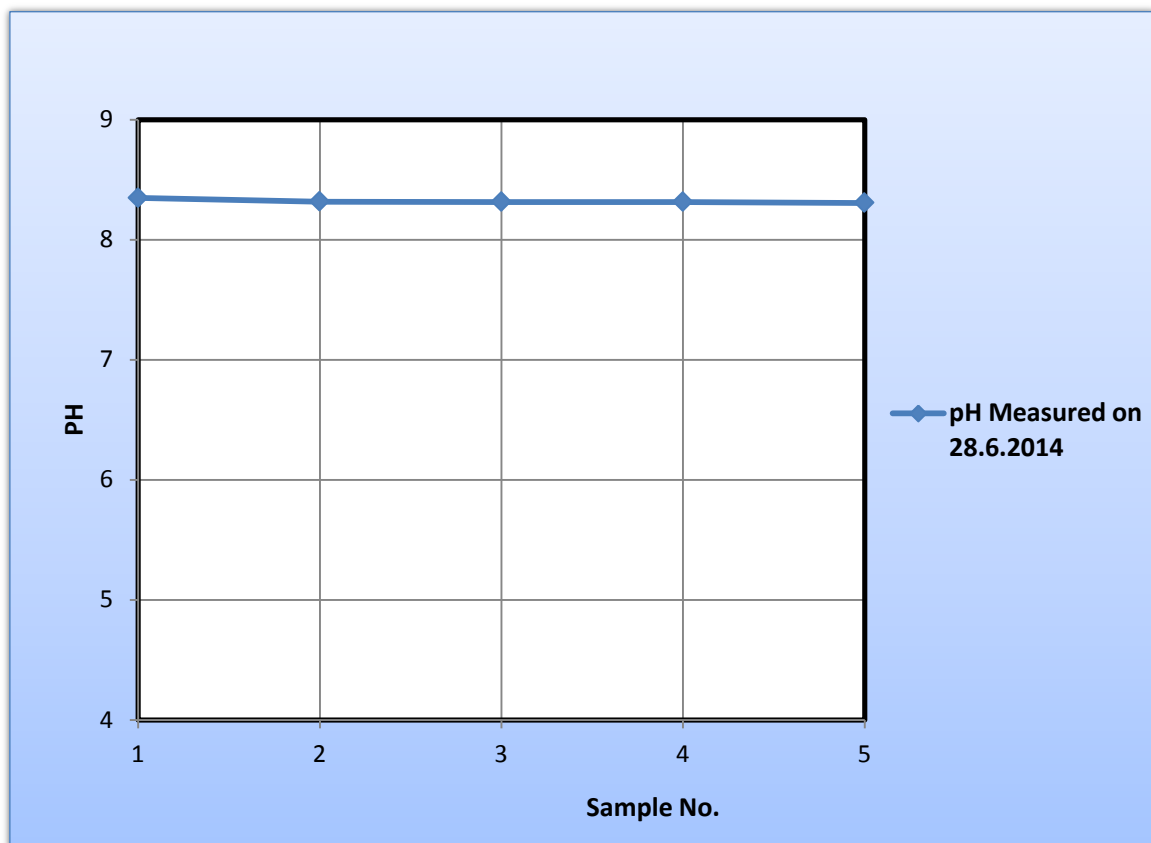


Figure (5.19): pH measured in the second round on 28 June, 2014

Figure (5.20) presented the map of pH measured in the area surrounding the brine discharge point in the second round.

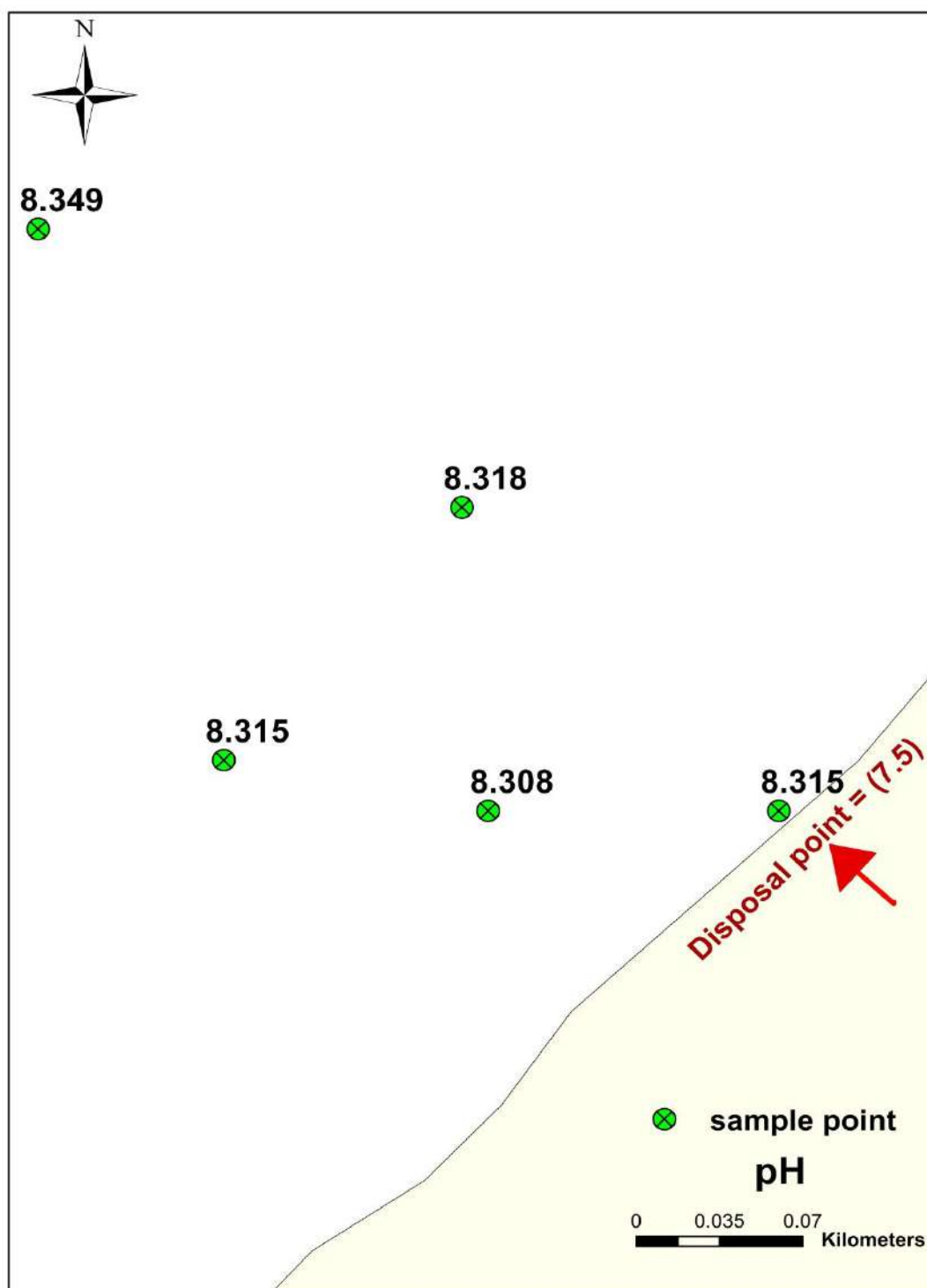


Figure (5.20): pH in the study area on 28 June, 2014
(Second Round)

5.3 Results of the third round

Table (5.3) and Figures 5.21, 5.22, 5.23, 5.24, 5.25, 5.26 and 5.28 represented the third round results that were obtained from the field and laboratory tests on 13 November 2014 after that the results then were exported to excel 2010 and ArcGIS 10.1 to draw the spatial distribution of the chemical concentrations in the area of the brine disposal.

Point 18 in this round was considered as a reference point R since it had the same location of a reference point R in all rounds.

Figures (5.21, 5.23, 5.25 and 5.27) illustrate the comparison between the values of (Turbidity, pH, Salinity, Temperature and DO) which was measured in this round at 19 points with the value measured at point 18.

It should be noted that a reference point "18" in this round was in the same location of a reference point "3" which was measured on 15 June. Sample no. (16, 17, 19 and 20) in the same location of sample no. (1, 2, 3 and 4) which was measured in the second round.

Table (5.3): Results of the Third Round on 13 November

Point No.	N	E	Temperature	Turbidity	pH	TDS	EC
Unit			C°	NTU		mg/l	mS/cm
Desalination Plant	31° 25' 47.90''	34° 21' 14.46''	23.5	0.3	6.01	35400	55.6
Disposal Point	31° 25' 54.01''	34° 20' 37.71''	24.3	4.2	7.5	15750	26.8
1	31° 25' 53.59''	34° 20' 36.07''	24.2	0.02	7.9	36100	56.2
2	31° 25' 54.08''	34° 20' 36.55''	23.6	0	7.66	35800	56.1
3	31° 25' 54.55''	34° 20' 37.02''	23.4	1.49	6	34500	54.5
4	31° 25' 55.04''	34° 20' 37.59''	23.2	0.1	7	35900	56.5
5	31° 25' 55.53''	34° 20' 38.12''	23.5	0	8	36100	56.7
6	31° 25' 54.08''	34° 20' 35.39''	23.7	0	7.96	36300	56.8
7	31° 25' 54.56''	34° 20' 35.83''	23.7	0.04	7.98	36200	56.7
8	31° 25' 55.01''	34° 20' 36.40''	23.7	0.14	7.95	36200	56.7
9	31° 25' 55.54''	34° 20' 36.91''	23.4	0.47	8	36100	56.5
10	31° 25' 56.07''	34° 20' 37.44''	23.4	0	7.97	36100	56.5
11	31° 25' 54.59''	34° 20' 34.71''	23.4	0	6.11	36100	56.5
12	31° 25' 55.05''	34° 20' 35.19''	23.8	1.1	7.08	34200	53.7
13	31° 25' 55.57''	34° 20' 35.65''	23.8	0.41	7.55	36000	56.2
14	31° 25' 56.03''	34° 20' 36.20''	23.6	0.7	7.6	36100	56.6
15	31° 25' 56.60''	34° 20' 36.67''	23.6	0.8	7.67	36100	56.6
16	31° 25' 60.40''	34° 20' 27.60''	23.8	0.84	7.67	36000	56.5
17	31° 25' 58.46''	34° 20' 33.43''	23.8	0.32	7.92	36100	56.9
18 (R)	31° 25' 17.44''	34° 20' 36.67''	23.8	0	5.91	36100	56.7
19	31° 25' 54.69''	34° 20' 30.19''	23.3	5.36	5.57	36200	56.6
20	31° 25' 39.72''	34° 20' 17.14''	22.9	0.4	7.97	36200	56.8

Notes :

- It should be noted that a reference point "18" in this round was in the same location of a reference point "3" which was measured on 13 June.
- Sample no. (16, 17 and 19) in the same location of sample no. (1, 2 and 3) which was measured on 28 June.
- Sample no. 20 in the same location of sample no. 4 which was measured on 28 June.

5.3.1 Temperature

Figure (5.21) illustrates the comparison between the value of Temperature measured at 19 points with the value of Temperature measured on 13 November (the third round) at point R.

Figure (5.21) illustrates that the values of temperature in the measurement points range between 22.9 to 24.3 C° in the locations examined, continued to remain within an acceptable range and that although no immediate action would be required.

Figure (5.21) shows that the maximum value of temperature was 24.2 C° at sample no. 1, but the minimum value of temperature was 22.9 C° at sample no. 20. The average temperature value was 22.9 C° in this round. The brine temperature value at a disposal point was 24.3 C°. The temperature value at a reference point R was 23.8 C° which was very close to the other points surrounding the disposal point. In general temperature of sea and ocean water surface differs from the two polar areas to the equator between 15-27° C (summer)[51].

From Figure (5.21) it can be recognized that the discharged from RO do not have an impact on increasing the temperature of the seawater since RO has no thermal pollution compared with thermal distillation technologies [31].

The temperature of the sea surface can also vary with respect to the adjacent air temperature but generally by not as much as over land. In this direction should be said that the samples were obtained during the November month so the temperature levels may be vary with the seasons.

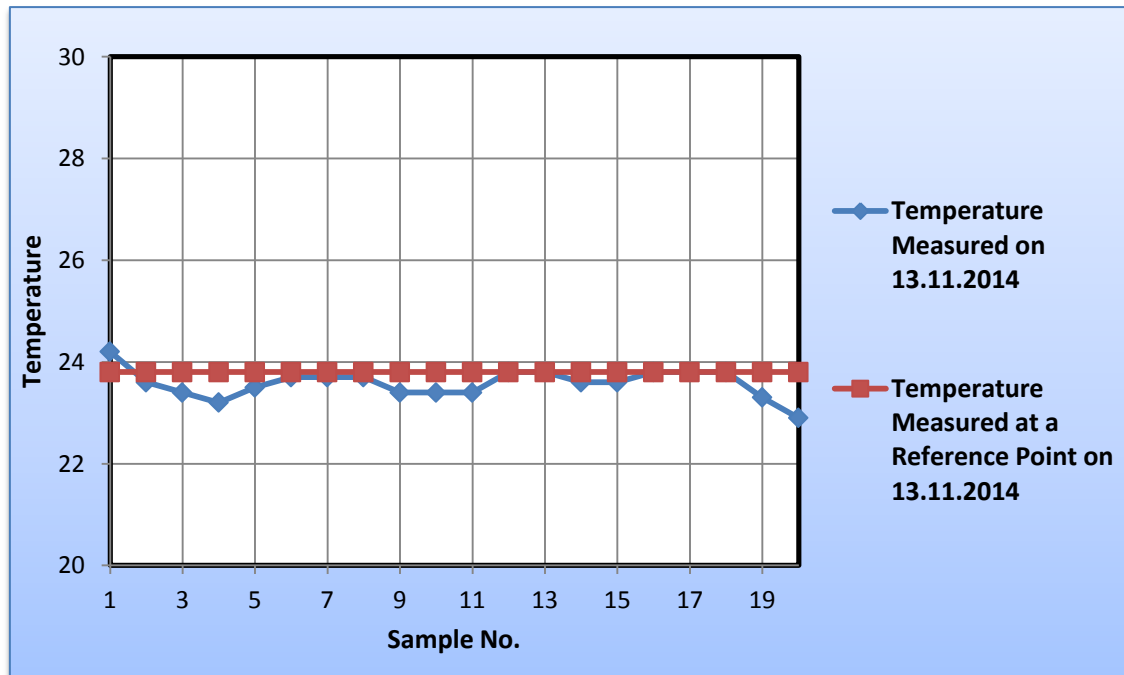


Figure (5.21): Temperature measured in the third round on 13 November, 2014

Figure (5.22) presented the map of temperature measured in the area surrounding the brine discharge point in the third round.

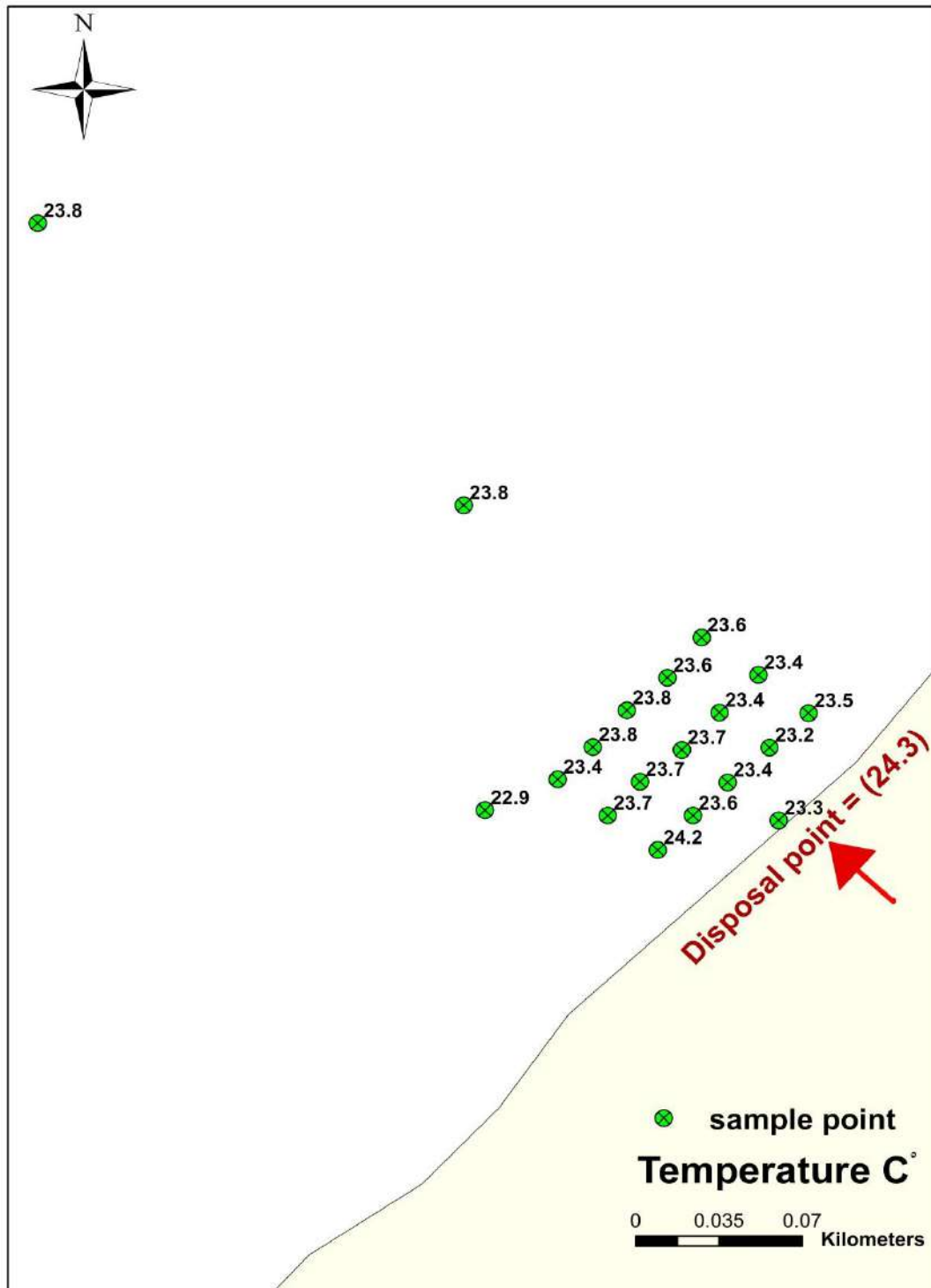


Figure (5.22): Temperature in the study area on 13 November, 2014
(Third Round)

5.3.2 Electrical Conductivity

Figure (5.23) illustrates the comparison between the value of EC measured at 19 points with the value of EC measured on 13 November (third round) at point R.

Figure (5.23) illustrates that EC value in the measurement points ranges between 53.7 to 56.9 mS/cm and the value of TDS ranges between 34200 to 36300 mg/l in the locations examined, continued to remain within a normal range and no immediate action would be required. EC value at a reference point R was 56700 $\mu\text{S}/\text{cm}$ and the TDS value was 36100 mg/l which was very close to the other points surrounding the disposal point.

The average value of EC was 56.8 mS/cm and the average value of TDS was 36200 mg/l for all samples in this round.

The brine salinity (EC) at a disposal disposal was 26.8 mS/cm (26800 $\mu\text{S}/\text{cm}$) and the TDS value was 15750 mg/l. The brine salinity (EC) at a disposal point was much lower than brine salinity (EC) in the plant site before pumping due to the same reason mentioned in above [107]. It is clear that the salinity of brine disposal was too lower than the seawater salinity in this round.

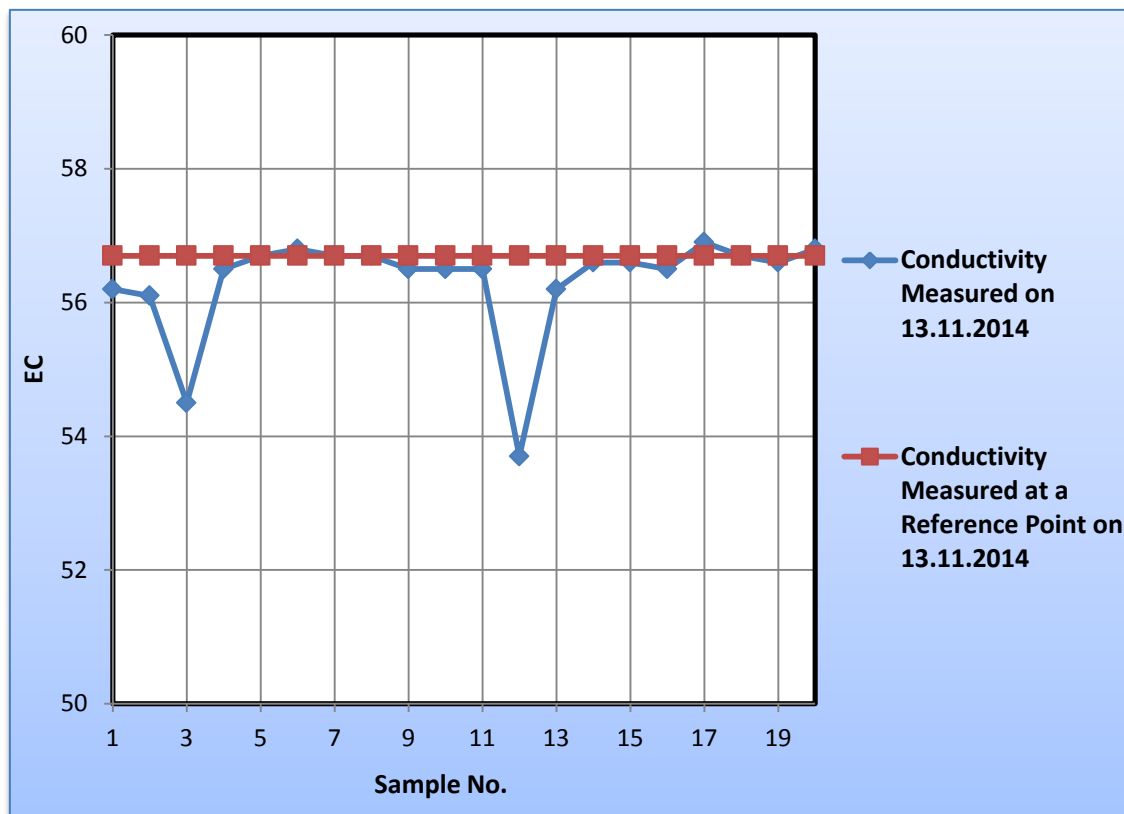
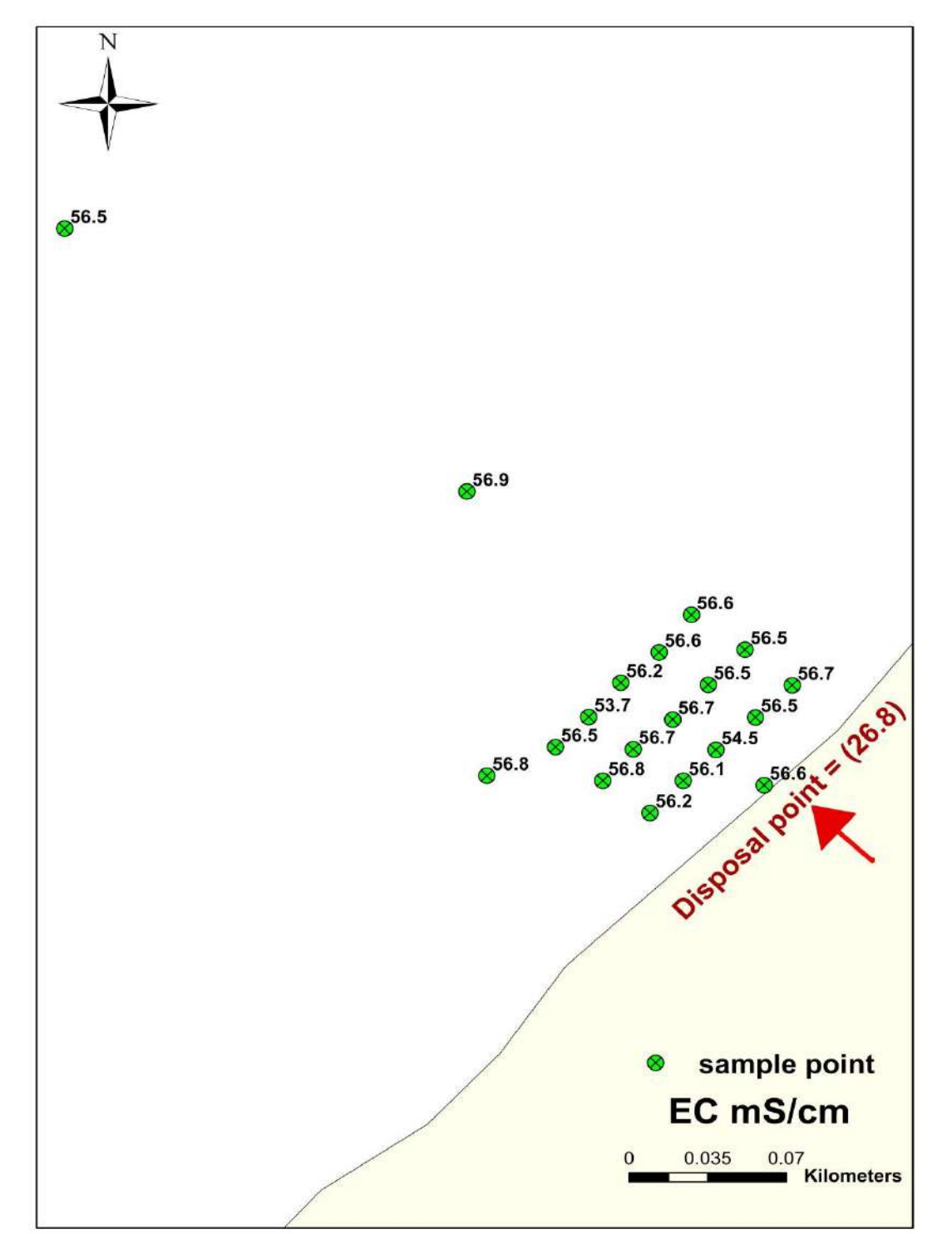


Figure (5.23): EC measured in the third round on 13 November, 2014



5.3.3 Turbidity

Figure (5.25) illustrates the comparison between the value of Turbidity measured at 19 points with the value of Turbidity measured on 13 November (the third round) at point R.

Figure (5.25) concludes that the turbidity value in the measurement points ranges between 0 to 4.64 (NTU) which in acceptable limits. The turbidity value at a reference point R was 0.

The average turbidity value was 0.4 NTU for all samples in this round. The turbidity value at a brine disposal was 5.36 NTU. The average turbidity value at points 1, 2, 3, 4 and 5 that near a disposal point were 0.32 NTU which considered too small.

It should be noted that the samples were obtained during November, so turbidity levels may be vary with the seasons.

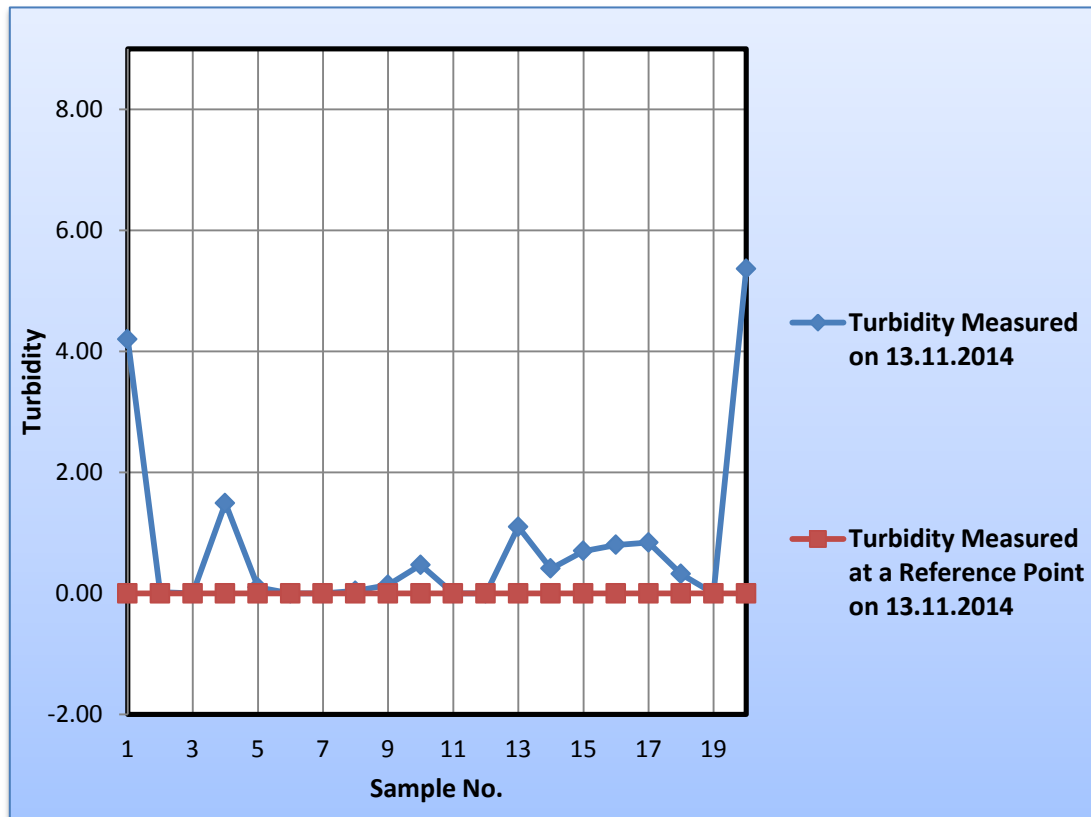


Figure (5.25): Turbidity measured in the third round on 13 November, 2014

5.3.4 pH

Figure (5.27) illustrates the comparison between the value of pH measured at 19 points with the value of EC measured on 13 November (the third round) at point R.

Figure (5.27) illustrates that the of pH value in the measurement points ranges between 5.57 to 7.37 which within a normal range. The pH value at a reference point R was lower than the points surrounding the disposal point.

The average pH value for all samples was 7.97. The brine pH value at a disposal point was 7.5 in this round. The average pH value at points 1, 2, 3, 4 and 5 that were near a disposal point was 7.31 which considered in the average range. The recommended pH range for most fish is between 6.0 and 9.0 [99,100].

The oceans generally have a higher alkalinity due to carbonate content and thus have a greater ability to buffer free hydrogen ions [102].

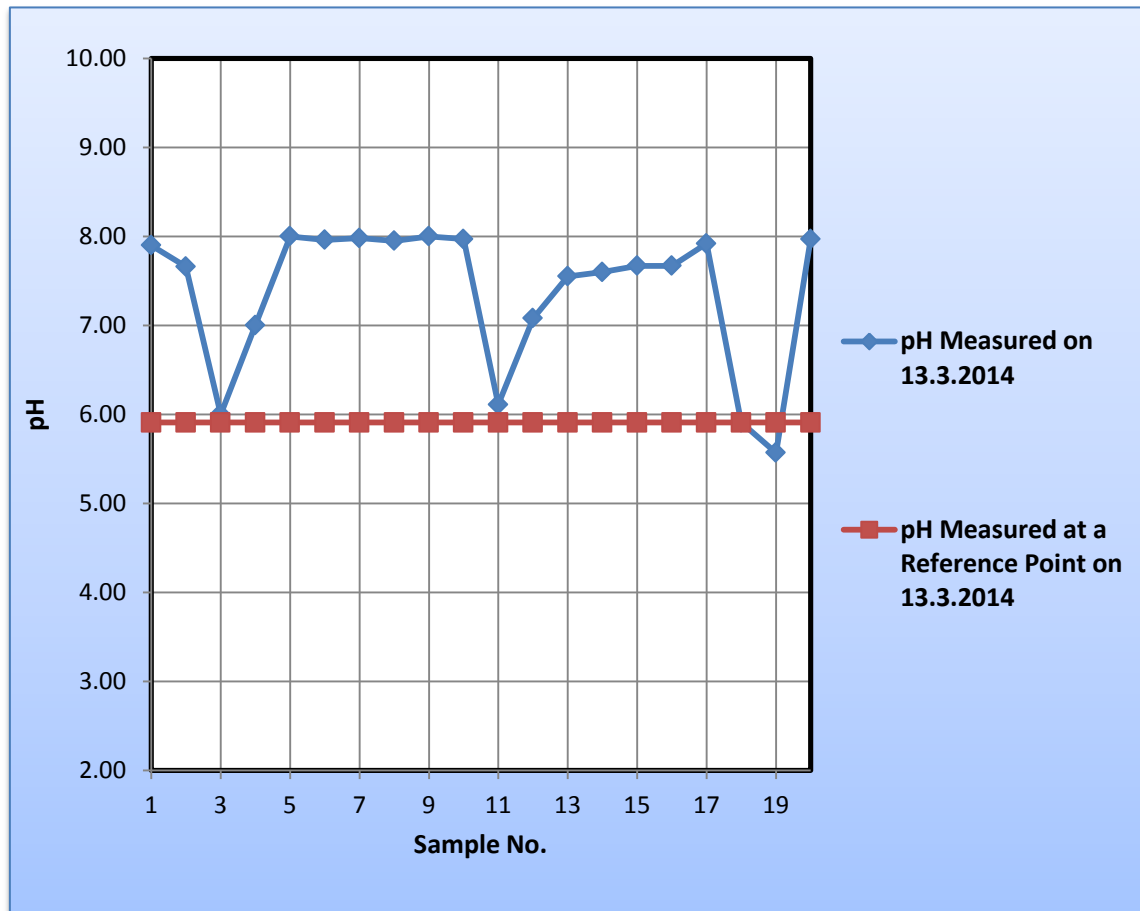


Figure (5.27): pH measured in the third round on 13 November, 2014

Figure (5.28) presented the map of pH measured in the area surrounding the brine discharge point in the third round.

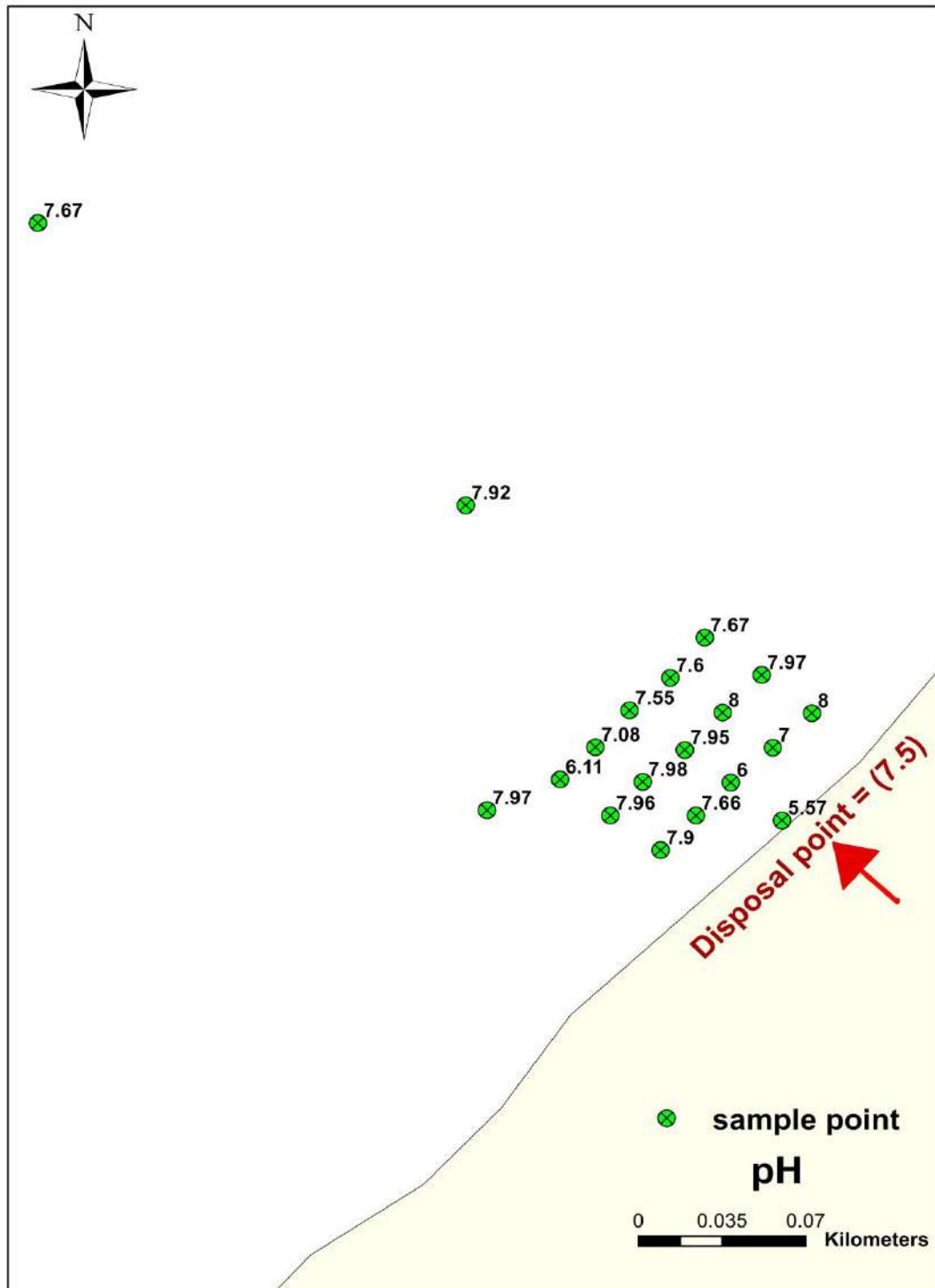


Figure (5.28): pH in the study area on 13 November, 2014
(Third Round)

5.4 Comparison between the brine of Deir El-Balah Desalination Plant and Askelon Seawater Desalination Plant

Table (5.4) shows the comparison between the brine of Deir El-Balah Desalination Plant and Askelon Seawater Desalination Plant Discharge Quality Standards (DQS)

Table 5.4): Comparison between brine of Deir El-Balah Desalination

Parameters	Units	Brine of Deir El-Ballah Desalination Plant (avg. for all conditions)	Discharge Quality Standards [107, 136]
Turbidity	NTU	0.03- 0.494	10
pH		7.97- 8.32	9>pH>6.5
Temperature of brine	C ^o	22.9- 29	4 above ambient seawater

5.4.1 Turbidity

The average value of brine turbidity as shown in Table 5.4 was measured from 0.03 to 0.494 NTU. According to Askelon Seawater Desalination Plant Discharge Quality Standards (DQS), the turbidity should be lower than 10 NTU as shown in Table 5.4.

By the comparing between the brine of Deir El-Balah Desalination Plant and Askelon Seawater Desalination Plant Discharge Quality Standards for the turbidity, as shown in Table 5.4, it was found that the brine has too small value of turbidity.

5.4.2 pH

The average value of brine pH as shown in Table (5.4) was measured as 7.5 NTU. According to Askelon Seawater Desalination Plant Discharge Quality Standards (DQS), the pH value should be in the range of 6.5 to 9 as shown in Table (5.4)

By the comparing between the brine of Deir El-Balah Desalination Plant and for pH value, as shown in Table 5.4, it was found the brine is in the acceptable range.

5.4.3 Temperature

As shown in Table 5.4, the average value of brine temperature was measured from 22.9 to 29 C^o on the temperature scale. It should be noted the brine temperature value at all conditions was lower than or the same of the seawater temperature. According to (DQS) the brine temperature must not raise the seawater temperature above 4 degrees.

By the comparing between the brine of Deir El-Balah Desalination Plant and (DQS) for temperature value, it was found the brine temperature in the acceptable range.

5.5 Results Discussion

Table (5.5) shows the comparison between the average of the measurements in the three rounds with the measurement of Mediterranean Sea carried out by Universal Group and Arterlia Consultants, 2013.

Table (5.5): Comparison between Round results and UG results

Item	Unit	1 st Round	2 nd Round	3 rd Round	UG, June, 2013
Temperature	C°	27.00	29	22.9	24.5
pH		-	8.32	7.97	8.05
EC	µs/cm	59200	60000	56800	57700
TDS	mg/l	39640	39800	36200	41000
Turbidity	NTU	0.494	0.03	0.4	-
Dissolved Oxygen	mg/l	8.56	7.98	-	-

5.5.1 Temperature

As shown in Table (5.5), the temperature in Round1 and 2 is higher than in Round 3. This due that the measurement in Round3 was in November as in UG measurement that was taken in same month, where in Round 1 and 2 was in June. A study of seawater properties conducted in the same month by UG confirmed this trend regardless of brine effect.

It is clearly noticeable in Table (5.5) that the temperature ranges between (22.9- 29) C° in the locations examined, continued to remain within an acceptable range. It should be remembered that the water bodies will naturally show changes in temperature seasonally and daily. Many sea will exhibit vertical temperature gradients (thermal stratification) as the sun warms the upper water during the day while deeper water will remain cooler. Through these results it can be seen that alteration of temperature basically depends on the type of the treatment plants.

5.5.2 pH

According to several studies, the majority of aquatic creatures prefer a pH range of 6.5-9.0, though some can live in water with pH levels outside of this range.

As shown in Table (5.5), the pH value in Round 2 is slightly higher than in Round 3. The pH values in Rounds 1 and 2 were close to the value of UG and also all of these values were fallen within acceptable ranges.

Natural variations in the pH values in Rounds 1 and 2 may be occur due to photosynthesis. Hydrogen molecules are used in this process when plants convert light into energy, this decreases the concentration of hydrogen ions and therefore the pH increases. For this reason, pH may be higher during daylight hours and during the growing season, when photosynthesis is at a maximum.

Although the pH scale goes from 0-14, the pH of natural water is generally around 6- 9. Based on the above, it is obviously that seawater is a slightly alkaline (from 7.97 to 8.32).

There is also limited literature available, which explores the impact of total alkalinity on marine life. However, the current desalination seawater plant has not the ability to increase the total alkalinity level of the brine discharge and to the seawater in the area of discharge afterwards.

5.5.3 Salinity

EC values in Rounds 1 and 2 are very close and they are higher than the value in Round 3 and the value carried out by UG. This due to the fact that the measurement of EC carried out in different lab than the measurement in Round1 and 2. However, the value of 1, 2 and 3 rounds are very close to that carried out by UG which is the normal value of EC in Mediterranean Sea. According to several studies salinity of sea and ocean water worldwide varies between 30-37 ppt (part per thousand) [34].

According to (UG) [88], the quality of raw water from Mediterranean Sea is approximately 41,000 mg/L as total dissolved solids (TDS), but electrical conductivity (EC) is approximately 57700 as shown in Table (5.5).

5.5.4 Turbidity

As shown in Table (5.5) the turbidity values in Round 2 and 3 are lower than in Round1. It is clearly noticeable Table (5.5) that the turbidity ranges between (0.03-0.49) NTU in the locations examined, continued to remain within an acceptable range.

It should be remembered that the water bodies will naturally show changes in turbidity seasonally and daily. Through these results, it can be seen that alteration of sea water turbidity basically depends on the type of the treatment plants.

Since turbidity of seawater shows the round that degree of optical clearness of seawater is affected by the existence of dissolved matters and suspended particles so it can be said deservedly these results are considered the index for clean maps of seawater.

5.5.5 Dissolved Oxygen

As shown Table (5.5), DO value in round 1 is higher than in Round 2. It is clearly noticeable in Table (5.5) that the average DO is (7.98- 8.56) mg/l in the locations examined, continued to remain within an acceptable range and much greater than 2 mg/l that required to marine life. Dissolved Oxygen levels are fluctuated with temperature, salinity and pressure changes [92, 93].

A direct relationship can be clarified between the water temperature and dissolved oxygen concentration; the colder the water, the more oxygen can be dissolved in it. For instance the dissolved oxygen value was 8.56 mg/l when temperature value was 27.00 C°, but the dissolved oxygen value was 7.98 mg/l when temperature value was 29 C°.

Therefore, in reverse osmosis processes, temperature is not varied much so major changes in dissolve oxygen due to heating is very unlikely. As it is mentioned earlier DO of fresh water at sea level will range from 15 mg/l at 0 C° to 8mg/l at 25 C°, so it was not required to measure dissolved oxygen in third condition [92, 93].

Through these results it can be seen that alteration of seawater turbidity basically depends on the type of the treatment plants.

While water equilibrates toward 100% air saturation, dissolved oxygen levels will also fluctuate with temperature, salinity and pressure changes. As such, dissolved oxygen levels can range from less than 1 mg/L to more than 20 mg/L depending on how all of these factors interact. In freshwater systems such as lakes, rivers and streams, dissolved oxygen concentrations will vary by season, location and water depth [93].

Chapter 6 : Conclusions and Recommendations

6.1 Conclusions

Through this research three rounds were carried near the disposal area of Deir El-Balah desalination plant and other area which was far away approximately 1600 m to verify and understand the environmental impact of brine disposal on the sea by measuring the marine indicators after and before brine disposal.

After conducting the sampling laboratory analysis and data analysis and presentation, the followings can be concluded:

- Desalinated seawater holds the key for a new fresh water resource in Gaza Strip.
- It was found that the average values from the three rounds of DO, pH, Turbidity, temperature and EC are (8.27, 8.145, 0.308, 26.3, 58.67) (mg/l, -, NTU, C°,mS/cm) respectively.
- It was found that the impact of brine discharge on the water quality and marine life is low when compared with the high physical and chemical changes to the seawater. It can be concluded that the brine of Deir El-Balah Desalination Plant can be safely disposed to the sea.

6.2 Recommendations

Based on the executed experimental programs and the obtained results, the following recommendation may be stated. The recommendations can be summarized as follows:

1. Long term monitoring of the rounds proposed in relation to temperature, salinity and alkalinity at the site of the desalination discharge outlet vicinity during the desalination process is recommended to determine the possible harm and the negative impacts they could cause to the environment.
2. Modeling the plume of the brine discharge will be desirable in order to illustrate the diffusion area. This would allow the verification of the appropriate distribution of the discharge plume into the seawater and the impact of the above factors on the aquatic organisms could be better understood. A manual water sampling program needs to be undertaken in the area of the desalination outfall discharge. It is needed to prove that desalination plants are not just a great source of fresh potable water but, that this process is economical and environmental friendly.
3. It is obvious that no modeling results have been used to identify proper location of brine disposal due to a recurring interruption of electricity for Deir El-Balah desalination plant which was operated only 8 hours every two days. Modeling the plume of brine is recommended to demonstrate the dispersion area. Water quality test of the concentrated brine is essential with respect to the different factors like-temperature, salinity, dissolved oxygen, alkalinity etc. to validate the damage these could cause to the marine environment.
4. For environmental as well as other reasons, it is recommended to discharge the brine water into sea by onshore outfall, which guarantees maximum dilution and minimal effect on the marine environment. This is because of high mixing process that dilutes the salinity quickly. The near shore current due to wave breaking, the mixing process

would accelerate and decrease the dilution time for the near shore outfall. Mix with less saline waste streams before ultimate discharge (e.g. brine can be directed to existing power plant or sewer treatment plant to dilute with municipal wastewater prior to discharge). This option can be used for larger plants.

5. The brine discharge system should be placed in areas of high turbulence, where ambient currents and waves facilitate brine dilution into the receiving water body.
6. Selection of suitable location of the outfall point and its shape. This plays an important role on the quick mixing with the seawater and the dilution and diffusion of the salt to the larger mass body.

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