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A review of environmental governance and its effects on concentrate discharge from desalination plants in the Kingdom of Saudi Arabia

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ABSTRACT

The most likely environmental impact of concentrate discharges (in most instances twice the concentration of the ambient environment) leaking from desalination plants on local marine ecosystems has been controversially discussed for many years. Increasing water demand and lack of renewable natural water resources in Saudi Arabia also result in greater dependence on desalination and consequently amplify the impact on marine environment and multifactorial ecosystems in near-field areas of desalination discharges. Accurate scientific baseline data should furnish information on various factors such as intake- and outfall locality, brine (concentrate) discharge and chemical characteristics (i.e. effluent concentration, mass flow rates (flux)), local effects, and even cumulative effects of desalination activities, at least on a regional and even on a national scale. Even if such data were available, in many cases they are non-transparent and are not even accessible, or tend to be overlooked as a result of ambiguous desalination-related policies. This paper focuses on national environmental regulations in the Kingdom of Saudi Arabia (KSA) and how such regulations help control the flow of concentrate discharge into the receiving waters.

Keywords: Environmental impact assessment; Seawater desalination; Environmental regulations; Concentrate discharge; Marine ecosystems

1. Introduction

Scarcity of the available water resources coupled with an inadequate rainfall or prolonged droughts has necessitated the setting up of seawater desalination projects in several areas of the world [1]. Desalination operations however may lead to environmental impacts mainly due to the concentrate produced together with residual chemicals being discharged into the sea. This could contaminate the aquatic ecosystems and cause unfavorable impacts of a far-reaching ecological effect on the marine watery communities [2]. The more acute effects are localized closely to these rejections and cause deteriorations of local hydrography and water quality of the receiving medium. These factors in turn interfere directly with the physical processes of the biotype, such as enzymatic activity, nutrition, reproduction, breathing, and photosynthesis [3].

Although we have various methods to dispose off the concentrate, ocean brine disposal is considered to be the least expensive option [4,5]. If the concentrate were discharged directly into the sea, the density difference between the concentrate and seawater

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causes the formation of a stratified water column which can affect the previously stable salinity environments [6]. Magnitude of the impact will depend on the characteristics of the desalination plant and its reject effluent waste stream, physical and hydrogeological factors, bathymetry, waves, currents, depth of water column, etc. These factors help determine the extent of the mixing zone and therefore the amplitude of impact [3,7,8].

Even though environmental impacts on the receptors caused by concentrate discharges from desalination plants have been published in scientific literature, hardly few measured data on the characteristics of the concentrate have been published [9]. *In-situ* data of marine environmental impacts are also intermittent or are regarded as confidential information. Current environmental policies on performance standards stipulated for direct discharge (effluent standards) are generally centered on broad-based principles and do not include environmental requirements and guidelines for desalination-specific criteria, e.g. effluent- and ambient characteristics, pretreatment, intakes, outfalls, or compliance and monitoring programs.

The need for safer methodologies to handle concentrate discharge was highlighted more than two decades ago, as well as fair and pragmatic regulations on effluent- and ambient standards, for the application of desalination processes [10]. More recently, the concentrate characteristics and their possible marine impacts have been mainly discussed by the academia, the ecologists and, to some extent, by the environmental regulators. In addition, the monitoring data of dispersion and effects of the hypersaline effluents discharged by the desalination plants are very scarce [9,11]. In the majority of instances where the data are made available, it generally indicates effluent standards only, with the ambient standards entirely absent. Taking into consideration the role and importance of water for sustenance of humanity, any policy encompassing the issues of water must include a comprehensive coverage of the desalination-specific regulations [12], currently deficient in governance of the major desalination user countries.

2. Impact on the marine environment

The concentrate as a waste stream is a high saline solution that must be disposed of, mainly by discharging it back to the marine environment. Most of the impact on marine environment is a consequence of the positioning of both the intake- and discharge locations. If the operation requires submerged piping elements, the initial impact during the laying of pipes on the seabed is temporary and confined to the location of works, but even this impact—if not mitigated—may still be significant. The severity of the impact is a function of the level of disturbance to the environment and of the natural sensitivity, which in turn is dependent on the specific nature of the habitat and specific communities.

The increased salinity (associated with membrane and thermal desalination technologies) and temperature (associated with thermal desalination technologies only) are not "pollutants" in the classical sense, but salt concentrations and temperature values that deviate strongly from ambient levels can still be harmful to marine life. Changes in salinity, turbidity, and the presence of chemicals are vital parameters that influence the distribution of marine species. Species can typically adapt to minor deviations from these conditions and might even tolerate extreme situations temporarily, but will not withstand harsh environmental conditions in the long term. Reject streams of desalination plants with high levels of "pollutants" can be fatal to marine life and can cause a lasting change in species diversity and abundance in the discharge site. Marine organisms can be attracted or repelled by the new environmental conditions, and those more adapted to the new situation will eventually prevail in the discharge zone. This will result in a change in the biocenosis, however, will more likely be accompanied by an overall decline in biodiversity [8]. If the concentrate has a higher density than seawater, it will likely spread over the sea floor (unless it is dissipated by an adequate outfall system) where it might affect benthic habitats [13].

Consequently, adverse impacts may occur on the composition and distribution of the marine biota in the disturbed near field areas especially when high levels of concentrate discharges coincide with the sensitive ecosystems. Previous ecological monitoring studies have found variable effects ranging from no significant impacts to benthic communities, through to widespread alterations to community structure in other organisms, mainly if concentrate is released to poorly flushed environments [14]. Although environmental effects appear to be limited to close proximities of outfalls, it must be noted that a large proportion of published work provides few quantitative data that could be assessed independently. Abrupt changes in ambient water quality as a result of concentrate discharge may be an important controlling factor for the distribution of marine species, which can be normally found in marine habitats that provide favorable environmental conditions for specific ecotypes [15].

3. Environmental regulators

Currently, the total global desalination capacity is 109,646,353 m^3/d, of which 73,704,611 m^3/d is related to seawater desalination. Saudi Arabia's seawater desalination capacity accounts for 12,135,610 m^3/d, over 16% of the global seawater desalination capacity.[1] With a growing population, the Kingdom of Saudi Arabia (KSA) needs to add another 6 million m^3/day for the next 20 years. Multi-stage distillation (MSF) and reverse osmosis are the two major processes, with MSF having around 64.2% of the total installed desalination capacity [12]. Numerous desalination plants are attempting to conform to the effluent discharge regulatory standards, but are lacking monitoring programs and corresponding datasets when it comes to the effect of concentrate discharge to the receiving water (ambient standards). Additionally, many datasets are vague with respect to the sampling and statistical techniques applied. These deficient statistics and lack of supporting data are necessitating continued reports on ecological effects, mitigation measures, and appropriate monitoring systems. The impact on sensitive receptors nictitates continued emphasis and monitoring in (at least) near-field areas of concentrate discharges.

4. The Presidency of Meteorology and Environment

The principal National Environmental Regulatory body within Saudi Arabia is the Presidency of Meteorology and Environment (PME). Protection of the environment is inscribed in the Kingdom's Basic Law of Governance (issued by Royal Order No. A/91 on 1/3/1992), which is effectively KSA's constitution. Article 32 states that:

> The State shall endeavor to preserve, protect and improve the environment and prevent its pollution.

The two principal regulatory controls in relation to environmental law are as follows:

4.1. Public Environmental Law

The Public Environmental Law[2] creates a general regulatory framework for the development and enforcement of environmental rules and regulations, and assigns general responsibility for this to the PME.

4.2. General Environmental Regulations (GER) and rules for implementation

These regulations[3] were issued by the Minister of Defense and Aviation, and in addition to its responsibilities under the Public Environmental Law, the PME is made responsible for issuing or withholding its consent for projects so as to ensure compliance with the Public Environmental Law and the Implementing Regulations. Under the Implementing Regulations, any licensing authority (i.e. any other authority, other than PME, who is responsible for issuing a permit to projects that may have a negative impact on the environment) must ensure that an environmental impact assessment (EIA) is conducted by a PME registered environmental consultancy (at the expense of the client) during the feasibility study of any project that may have an adverse impact on the environment.

Projects that may have a negative impact on the environment are separated into three categories. The GER stipulate the "Fundamentals and Standards for EIA of Industry and Development Projects" under Appendix 2 of the Rules for Implementation, while Appendix 2.1 dictates the "Guidelines for Classification of Industrial and Development Projects" under the three categories. The method of assessment will depend on the classification of the project based of the level of expected impacts.

- Category 1: This included projects that are not expected to have significant environmental impacts.
- Category 2: This category covers the projects that may have significant environmental impacts (normally, impacts are restricted to the site boundary and can be fully mitigated).
- Category 3: These are projects whose construction or operation activities are likely to have significant adverse environmental impacts, which cannot be fully mitigated, will produce off-site emissions or discharges and will impact zones beyond the site boundary (the PMEs GER stipulate that desalination plants should be regarded as Category 3 projects).

Article 12 "Receiving Water Guidelines" and Article 13 "Performance Standards for Direct Discharge" under the Rules for Implementation specify the following guidelines (Tables 1 and 2) for effluent waste streams. Table 1 is applicable at the edge of the

[1]International Desalination Association (2011).

[2]Enacted by Royal Decree No. M/34 dated 28/7/1422 Hejri (corresponding to 16 October 2001) and was published in the Official Gazette No 3868 dated 24/8/1422 Hejri (corresponding to 9 November 2001).

[3]Resolution No. 1/1/4/5/1/924 dated 03/08/1424 Hejri corresponding to 30 September 2003 (the "Implementing Regulations") and published in the Official Gazette No. 3964 on 28/08/1424 Hejri (corresponding to 25 October 2003).

Table 1
Receiving water guidelines (ambient standards)

Pollutant	
Physiochemical pollutants	*Guidelines at the edge of mixing zone*
(a) Floatables	None
(b) pH	0.1 pH units (maximum variation from typical local baseline conditions)
(c) Total suspended solids (TSS)	5%[a]
(d) Temperature	1°C (maximum variation from typical baseline conditions)
(e) Oil and grease	Management measures required[b]
(f) DO	5%[a]
(g) Turbidity	5%[a]
Organic pollutants	*Guidelines at the edge of mixing zone*
(a) Chemical oxygen demand (COD)	5%[a]
(b) Total organic carbon (TOC)	5%[a]
(c) Total Kjeldahl Nitrogen (TKN)	5%[a]
(d) Chlorinated hydrocarbons	5%[a]
(e) Oil and grease	5%[a]
(f) Phenols	5%[a]
Inorganic pollutants	*Guidelines at the edge of mixing zone*
(a) Ammonia	5%[a]
(b) Arsenic	5%[a]
(c) Cadmium	5%[a]
(d) Chloride	5%[a]
(e) Residual chlorine	5%[a]
(f) Total chromium	5%[a]
(g) Copper	5%[a]
(h) Total cyanide	5%[a]
(i) Lead	5%[a]
(j) Mercury	5%[a]
(k) Nickel	5%[a]
(l) Total phosphate	5%[a]
(m) Zinc	5%[a]
(n) DO	5%[a]
Biological pollutants	*Guidelines at the edge of mixing zone*
(a) Total coliform	70 (most probable number (MPN) per 100 ml) (30-day average)

[a]Percentages (%) referred to in the table indicate the maximum allowable variations in comparison with local baseline conditions (unless otherwise stated, each interim guideline refers to a thirty [30-day average]).
[b]Facilities using, transferring, or storing oil and petroleum hydrocarbons are required to prepare, maintain, and update a spill prevention, control, and cleanup emergency response plan.

mixing zone and beyond for the discharge from any facility to coastal waters, while Table 2 shows the performance standards for direct discharge. These performance standards currently apply to wastewater at the end of the outfall, but before discharge into a marine environment.

5. The Royal Commission for Jubail and Yanbu

The Royal Commission for Jubail and Yanbu (RCJY) has a special status in the environmental legislative system of KSA. It is responsible for the planning, development, construction, operation, and maintenance of the various infrastructure and services of Jubail and Yanbu industrial cities, and, in particular, the encouragement of downstream industries that utilize Saudi Arabia's natural resources to produce value-added products for local use and export. These ever-expanding industrial complexes and their industries require huge amounts of process water, in almost all instances acquired from the adjacent marine environment (Arabian Gulf and the Red Sea, respectively).

Table 2
Performance standards for direct discharge (effluent standards)

Pollutant	
Physiochemical pollutants	*Allowable effluent levels*
(a) Floatables	None
(b) pH	6–9 pH units
(c) TSS	15 mg/l (maximum limit)
(d) Temperature	PME will determine the thermal properties of the discharge water to fit the properties of the receiving water on a case-to-case basis
(e) Turbidity	75 NTU (maximum)
Organic pollutants	*Allowable effluent levels (30-day average)*
(a) Biological Oxygen Demand (BOD)	25 mg/l
(b) COD	150 mg/l
(c) TOC	50 mg/l
(d) TKN	5 mg/l
(e) Total chlorinated hydrocarbons	0.1 mg/l
(f) Oil and grease	8.0 mg/l (not to exceed 15 mg in any individual discharge)
(g) Phenols	0.1 mg/l
Inorganic pollutants	*Allowable effluent levels (30-day average)*
(a) Ammonia (as Nitrogen)	1.0 mg/l
(b) Arsenic	0.1 mg/l
(c) Cadmium	0.02 mg/l
(d) Chlorine (residual)	0.5 mg/l
(e) Total chromium	0.1 mg/l
(f) Copper	0.2 mg/l
(g) Cyanide	0.05 mg/l
(h) Lead	0.1 mg/l
(i) Mercury	0.001 mg/l
(j) Nickel	0.2 mg/l
(k) Phosphate (total as phosphorus)	1.0 mg/l
(l) Zinc	1.0 mg/l
Biological pollutants	*Allowable effluent levels*
(a) Total coliform	70 (MPN per 100 ml) (30-day average)

Notes: The performance standards for direct discharge are intended to require wastewater source to adopt the best practical controls. Wastewater streams of different characteristics must be segregated to the maximum extend possible.

Established in 1975 the Commission is responsible for providing the complete infrastructure, both physical and societal, needed to construct and operate the huge industrial developments at Jubail and Yanbu. The Royal Commission is in charge of community and human resources development, environmental protection, and the development of private-sector investments in these two cities. They have developed and adopted regulations, standards, and guidelines to control substances emitted, discharged, or deposited, and noise generated within the industrial cities. The environmental regulations, standards, and guidelines are specific to both Jubail and Yanbu Industrial Cities. These are intended to clearly state the environmental protection regulations and to formally define the requirements for adherence to them. They are solely responsible for overseeing and controlling pollution associated with the development and operation of both the industrial complexes.

An optimistic objective of the RCJY has been industrialization coupled with environmental protection. Since inception, the Royal Commission has been determined that Jubail and Yanbu would be models of environmental planning and management in addition to being productive manufacturing complexes. The RCJY realize that there must be a close cooperation between industries and environmental management personnel to achieve this goal. The RCJY has issued the Royal Commission Environmental Regulations (RCER) to be adopted by industries both in Jubail and Yanbu. Any facility operating or planning to operate on the Royal Commission property will be

Table 3
Ambient water quality criteria for coastal waters (RCER-2010, Volume I, Regulations and Standards)

Variable	Units	Limits (Red Sea and Arabian Gulf)	Limits (monthly average [Red Sea])
Physical			
Floating particles[a]	mg/l	1	0.5
Temperature[b]	Δ°C	2.2[c]	<1
TSS	mg/l	5	1.5
Turbidity	NTU[d]	5	1.5
Chemical			
Aluminum	mg/l	0.05	0.001
Ammonia free (as N)[e]	mg/l	1.2	0.008
Arsenic	mg/l	0.05	0.001
Barium	mg/l	1	0.05
Cadmium	mg/l	0.005	0.0005
Chlorinated Hydrocarbons	mg/l	0.01	–
Chlorine residual	mg/l	0.05	0.01
Chromium	mg/l	0.1	0.002
Cobalt	mg/l	0.05	0.001
Copper	mg/l	0.015	0.001
Cyanide	mg/l	0.1	0.1
Fluoride	mg/l	1.5	1.4
Iron	mg/l	1	0.001
Lead	mg/l	0.01	0.002
Manganese	mg/l	0.05	0.0005
Mercury	mg/l	0.0,001	0.0001
Nickel	mg/l	0.1	0.002
Nitrate as N	mg/l	1	0.008
Oil and grease	mg/l	5	2
Oxygen (dissolved)	mg/l	5 (minimum)	5 (minimum)
pH	pH units	7.8–8.5[f]	8–8.3[f]
Phenols	mg/l	0.12	0.1
Phosphate (total)	mg/l	0.025	0.02
Salinity (above ambient)	ppt	1.4	1
Sulfide	mg/l	0.4	0.4
TKN	mg/l	–	0.02
TOC	mg/l	10	2
Zinc	mg/l	0.1	0.001
Bacteriological			
Fecal coliform	MPN/100 ml	–	2
Total coliform	MPN/100 ml	–	70

[a]Waters shall be free of all floating particles which may be attributed to wastewater or other discharges.
[b]Temperature differential with respect to the water temperature at cooling water canal intake.
[c]For Yanbu only (refers to the maximum temperature at the edge of the mixing zone (approximately 600 m from the Port Barrier Reef)).
[d]NTU: nephalometric turbidity unit.
[e]Non-ionized concentration (pH and temperature dependent).
[f]Inclusive range.

required to comply with these regulations[4]. They demonstrate their own environmental regulations under their Environmental Control Department which monitors the industrial cities ambient air quality and emissions, water resources as well as sea water monitoring, with particular focus on the cooling water discharge areas. In addition, the Royal Commission

[4]Royal Commission Environmental Regulations (RCER-2010, Volume I, Regulations and Standards).

Table 4
Water quality standards for direct discharge to coastal waters (including treated effluent,[a] discharge to the seawater cooling return canal, variance streams,[b] and surface drainage ditches[c])

Parameter[d]	Units	Maximum allowable	Monthly average
Physical			
Floating particles	Mg/m^2	NIL	NIL
Temperature[e]	Δ°C	10[f]	10[f]
Temperature (Yanbu)	Δ°C	Case-by-case basis	Case-by-case basis
TSS	mg/l	40	25
Turbidity (Jubail)	NTU	75[g]	50[g]
Turbidity (Yanbu)	NTU	15	8
Chemical			
Aluminum	mg/l	25	15
Ammonia (total as N)	mg/l	3	1
Arsenic	mg/l	0.5	0.1
Barium	mg/l	2	1
BOD_5	mg/l	25	15
Cadmium	mg/l	0.05	0.01
COD	mg/l	150	75
Chlorinated Hydrocarbons	mg/l	0.5	0.1
Chlorine residual[h]	mg/l	0.3	0.2
Chromium (total)	mg/l	0.5	0.1
Chromium (hexavalent)	mg/l	0.1	0.05
Cobalt	mg/l	2	0.1
Copper	mg/l	0.5	0.2
Cyanide	mg/l	0.1	0.05
Fluoride	mg/l	25	15
Iron	mg/l	10	5
Lead	mg/l	0.5	0.1
Manganese	mg/l	1	0.2
Mercury	mg/l	0.005	0.001
Nickel	mg/l	0.5	0.2
Nitrate as N	mg/l	10	1
Oil and grease	mg/l	15	8
Oxygen (dissolved)	mg/l	2[i]	5[i]
PAH[j]	mg/l	0.01	–
pH	pH units	6–9[k]	6–9[k]
Phenols	mg/l	1	0.1
Phosphorus (total as P)	mg/l	2	1
Salinity (Yanbu)	Δ ppt	2	1
Sulfide	mg/l	0.1	0.05
TKN	mg/l	10	5
TOC	mg/l	75	–
Zinc	mg/l	5	2
Biological			
Total coliform	MPN/100 ml	2,400	1,000

[a]Treated effluent discharge standards apply in Yanbu Industrial City to wastewater at the end of an outfall pipe and before discharge into the Red Sea.

[b]Permission to discharge variance streams is subject to Section 3.5.3. Standards are applicable to variance stream discharges before dilution with the main non-contact cooling water flow.

[c]Applicable to storm water discharges only, unless permission to discharge wastewater is granted under Section 3.4.10a.

[d]For any parameters not identified, specific standards will be determined on a case-to-case basis.

[e]Temperature standard does not apply to variance stream discharges.
[f]Differential temperature standard between seawater cooling intake and seawater cooling discharge.
[g]Differential standard between seawater cooling intake and seawater cooling discharge for non-contact cooling water, absolute standard for all other discharges.
[h]Chlorine residual is after 30 minutes contact and is total residual chlorine.
[i]Dissolved oxygen requirement is a minimum concentration requirement.
[j]PAH: polycyclic aromatic hydrocarbons.
[k]Allowable range.

expects operators in the Industrial Cities to utilize the Best Available Technologies (BAT) for environmental control. BAT must as a minimum achieve emission or discharge standards in RCJY Regulations taking into account energy, environmental and economic impacts. BAT assessment is conducted for new, reconstructed, and modified facilities. If an operator is not in compliance with the RCER, the operator of a facility must provide an assessment of BAT to address environmental issues that were identified by the Royal Commission as posing a direct detrimental environmental or public health impact.

RCER states that the Royal Commission reserves the right to enter and access the facility, upon reasonable prior notice of at least 24 h, for the purpose of regular surveillance, monitoring, and inspection to verify compliance with Royal Commission Regulations. The operator must also facilitate the Royal Commission, upon reasonable request, to review all environmental-related records, methods, and procedures to verify compliance with their Regulations. Based on merit, this is the major dissimilarity between the RCER and the PME's GER.

Table 3 indicates the coastal receiving water criteria for the Red Sea and Arabian Gulf, while Table 4 signifies the water quality standards for direct discharge to coastal waters (including treated effluent, discharge to the seawater cooling return canals, variance streams, and surface drainage ditches).

6. The Ministry of Petroleum and Mineral Resources

The Ministry of Petroleum and Mineral Resources (MinPet) was established in 1960 to execute the general policy related to oil, gas, and minerals within the KSA. The MinPets is responsible for the administration, development, and exploitation of the Kingdom's oil, gas, and mineral resources. All oil, gas, and petrochemical related EIAs are dealt with and approved or disapproved by the Ministry (including such projects within the RCJY's jurisdiction).

All the remaining sectors' (outside of jurisdiction of RCJY) impact assessments are sent to the PME for approval. In addition, the Ministry supervises its affiliate companies working in the fields of petroleum and minerals by observing and monitoring exploration, development, production, refining, transportation, and distribution activities related to petroleum and petroleum products. The Ministry monitors the activities of Saudi Aramco, Saudi Texaco, Aramco Gulf Operation (AGOC), the Saudi Arabian Mining Company (Ma'aden), and also oversees the Saudi Geological Survey.

7. The current status of the regulatory framework

The GER has to some extent standardized the EIA process, when compared to assessments prior to the release of these regulations. Although the GER consequently standardized the EIA process under the PME regulations, the standard however does not provide guidance on the depth of the assessment, which is a major issue of concern when it comes to the quality and scientific significance of the findings of the EIA. A major inadequacy in the Kingdom's environmental governance is—although legal requirements have been enacted—they are not enforced. The enforcement of environmental policies and procedures requires the availability of independent bodies with adequate power. The environmental legislative system in the KSA would benefit from the establishment of an independent regulatory body, which is equipped with sufficient staff and trained personnel as well as institutional rights to enforce the various environmental policies and procedures. Although the PME and Ministry of Petroleum and Minerals are accepted as competent authorities for EIA and environmental acceptability, their role and responsibilities could further be strengthened.

The major shortcoming however is the non-existence of tailored desalination-specific regulations (this is also true for the majority of the major desalination user countries). Innovative scientifically desalination focused regulations must be generated and adopted. Consequently, the existing receiving water guidelines (ambient standards) and performance standards for direct discharge (effluent standards) might be in serious need of revision (or existing up-to-date regulations must be rigorously enforced), mainly due to the growing desalination capacities and an increasing awareness of the possible environmental problems associated with concentrate discharge. In addition to these deficiencies, there is also a lack of robust up-to-date scientific baseline data to support reports on ecological effects, mitigation measures, and appropriate monitoring systems.

8. Recommendations

8.1. Attaining sound environmental data

- Data, which are currently scattered among numerous government and private sector institutions should be pooled in a central database to improve collaboration and assessment.
- The national focal point should be provided with full access to data that are required for national assessment and reporting.
- Data should be available to all agencies and shared among major stakeholders.
- Facilities should be required to cooperate to allow for the assessment of cumulative effects in sea areas with high desalination densities.
- Resources (financial, trained personnel, etc.) of the environmental regulatory system should be improved.

8.2. Strengthening the assessment system

- Capability of the technical guidelines, responsibilities, EIA report content, and data control must be improved.
- Explicit desalination regulation must be generated, adopted, and enforced.
- Implementation of perpetual monitoring systems at desalination intake and discharge locations.
- Follow coherent legal requirements and the actual implementation thereof.
- There must be a holistic coverage of the environmental impacts on receptors as part of the decision-making process for locating and building new desalination plants, or expanding existing facilities.
- The establishment of a national task force can also improve environmental standards for desalination plants.

The responsibility belongs to the environmental regulatory bodies (PME and RCJY), desalination operators as well as academia, to be active participants in the process by collecting and maintaining data which are transparent and available for all to share. Research centers (e.g. KAUST WDRC) play a very important role in providing scientific data in minimizing the impacts of desalination plants, not only regionally, but also globally. It is a big challenge to develop and implement cost-effective techniques with minimum adverse impact on water quality and environment. It is recognized that implementation of increased environmental measures will have an *impact on the cost*, which is a consequential consideration. These costs should be evaluated with respect to long-term costs associated with a 'doing nothing' approach, particularly with regard to adopting appropriate environmental measures whether in the construction of new "greenfield" plants or retrofitting "brownfield" plants currently in operation.

A national task force could also initiate a dialog and seek cooperation with neighboring countries in order to develop regional standards for desalination plants to safeguard the environmental protection of the shared marine water bodies of the Arabian Gulf and the Red Sea. For example, the Water and Power Research Center of Abu Dhabi Water and Electricity Authority [15] has set up procedures to be followed on the study of environmental feasibility of building or extending the capacity of desalination plants. Sharing this information among the riparian states of the Arabian Gulf and the Red Sea could be a first step in developing regional guidelines. A summary of Abu Dhabi's procedures follows:

8.3. Baseline data collection and record keeping

Baseline field measurements should (at least) consist of:

- Hydrodynamic field measurements should be carried out in the plant vicinity and should include water levels, current flow velocities, and directions of flow discharges. The hydrodynamic measurements must be used in understanding the flow pattern in the discharge vicinity and in the calibration of the hydrodynamic model of the area.
- Water quality measurements should be carried out to evaluate the concentrations of the substances (residual chlorine, dissolved oxygen (DO), ambient seawater temperature, salinity, pH, ammonia, etc.) to the water quality and marine species.
- A biological survey should be carried out at the intake and discharge locations to evaluate the ecosystem in the area. A detailed sampling protocol (grid) should be generated and the area thoroughly surveyed. Divers, utilizing adequate underwater cameras, should record the photographs and videos

on the grid. These data should provide a detailed description of local habitats and species.

8.4. Development of numerical flow- and water quality models

Flow velocity and flow pattern are the main transport and dispersion mechanism of the concentrate from the discharge point. A numerical flow model[5] simulates the flow pattern and assists in the configuration of the intake and outfall of the plant. Additionally, a numerical water quality model should also be developed. The goal of water quality modeling is to simulate the water quality of the waters around the discharge. The flow pattern from the hydrodynamic model will be used as an input for the water quality model as it is the main transport mechanism of the substances.

8.5. Habitat evaluation procedures

The effect of water quality change owing to concentrate discharge must be evaluated against the nature of the habitat in the discharge vicinity. This can be done by comparing the concentrations of the substances with the species thresholds. If the study shows that the plant discharge will affect receptors, measures should be taken to minimize the impact, e.g. changing discharge configurations to redistribute the substances in the concentrate in such a way as to reduce their concentrations to an acceptable level.

9. Conclusions

Current deficient statistics and lack of supporting data are necessitating continued reports on the ecological effects, mitigation measures, and appropriate monitoring systems. Regulators must impose stricter policies on ongoing marine- and effluent water quality monitoring programs at existing and new desalination facilities. The desalination process has a vital role in meeting the ever-increasing demand for water by various sectors in Saudi Arabia and also in the wider Middle Eastern region, where the use of conventional water resources has reached critical limits. The environmental agencies (PME, the Ministry of Petroleum and Minerals, RCJY as well as Saudi Aramco as de facto regulator) are in theory ultimately responsible for setting environmental regulations and standards. These responsibilities are in practice fragmented, creating institutional overlaps and contradictory interpretations on environmental protection practices, implementation, and enforcement. The existing environmental policies with regard to performance standards for direct discharge (effluent standards) are generally centered on broad-based principles and do not include environmental requirements and guidelines for desalination-specific criteria, e.g. effluent- and ambient characteristics, pretreatment, intakes, outfalls, or compliance and monitoring programs. There remains an inescapable need to strengthen environmental legislation and regulatory framework within the Kingdom. This could be addressed through the establishment of a task force (for the improvement and consistency of national practices, regulations, and to initiate adoption and implementation of cross-border desalination regulations.

[5]Deep submerged discharges are generally preferred. Numerous design practices favor a steep discharge angle of 60° above horizontal. (However, examination of more recent laboratory data and the parametric application of CorJet, a jet integral model within the Cornell Mixing Zone Expert System, suggests that flatter discharge angles of about 30°–45° above horizontal may have considerable design advantages (preliminary) [16]. These relate to better dilution levels at the impingement location, especially if the bottom slope on port height is taken into account, better transport of mixing effluent during weak ambient current conditions, and the ability to locate in shallower waters).

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