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Environmental impacts and impact mitigation plans for desalination facilities

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ABSTRACT

A number of sea water desalination technologies have been developed during the last several decades. Although these techniques are promising options for freshwater augmentation in coastal establishments and islands, they may have certain impacts to the environment. To safeguard a sustainable use of desalination technology, the impacts of the desalination facility should be identified and mitigated by means of an environmental impact assessment study as well as by environmental management plans (EMPs). The EMP should include tables answering questions like who is responsible from "what" and "when" and, "which" precautions will be taken and "where" these precautions should be implemented. This study aims to analyze the potential environmental impacts of desalination plants and propose measures mitigating their negative impacts. In the article, components of a desalination system, i.e. open intake, pretreatment, membrane desalination system, outfall with diffuser, and transfer pipeline, are identified as first. Waste disposal, air quality, noise, traffic, flora and fauna, water quality, and visual amenity are listed as principal issues affected from both construction works and operation. Finally, measures in order to prevent or minimize those adverse effects to acceptable levels are assessed.

Keywords: Desalination; Environmental impact assessment; Environmental management plan; Mitigation measures

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1. Introduction

Desalination processes are capable techniques to remove dissolved salts and impurities from water sources and thus suitable alternative for communities where sea water or brackish water is readily available. It has been a well-established technology since the mid-twentieth century. Until a few years ago, large-scale projects were limited to a few arid countries of the Middle East, which had the financial and natural resources and no other water supply options. Today, desalinated water has become a commodity for many other regions that require more water for socioeconomic development [1,2]. The history of desalination

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plants has been well documented by many researchers [3,4].

Although desalination techniques are promising options and have been used as a significant alternative for water-scarce countries on coastal zones, they have certain impacts on the environment. There is an increasing global interest in understanding the environmental impacts of desalination plants and their brine discharges on the marine environment [5–8]. These are mainly attributed to the concentrate and chemical discharges, which may impair sea water quality and affect marine life, air pollutant emissions, energy demand and consumption of the processes, noise generation, visual amenity, and land use. Since desalination plants may cause environmental impacts in coastal areas, it is necessary to submit plans for environmental impact assessment (EIA) in order to achieve more environmentally viable projects, effective preventive and corrective measures, and social and environmental acceptance. Most of the environmental effects can be minimized by the appropriate planning [3].

EIA is one of the major management tools and is increasingly being functional in countries. An EIA is a systematic process used to identify, evaluate, and mitigate the environmental effects of a proposed project prior to major decisions and commitments being made. However, it is noticed in many of the countries that most of the EIA practice appears to be directed at the scoping and assessment stages of EIA. The mitigation, monitoring, and management components of EIA receive less attention at formulating and implementation level. Recently, attention is being focused on the need to demonstrate that impacts can be monitored and managed. The environmental management plan (EMP) is the plan prepared during the process of EIA that provides a description of the methods and procedures for mitigating and monitoring impacts. EMP promotes the awareness and use of best practice environmental management by site operatives during construction and operative phase [9]. All those reports require comprehensive data and information related to site and its environment. In general, there should be field measurements to collect baseline data including hydrodynamic measurements such as water levels, current flow velocities and directions, and discharges to understand the flow pattern and be able to calibrate the hydrodynamic model of the area [10]. Also the water quality measurements should be carried out to evaluate the concentrations of substances such as residual chlorine, dissolved oxygen, ambient sea water temperature, salinity, pH, and ammonia that will be used for the calibration of water quality models. In addition, biological surveys are necessary in the plant vicinity. The model results should be evaluated against water quality standards, and if necessary, the configuration of the intake and outfall of the plant should be modified. For example, Areqiat and Mohamed presented their models as a case study for Taweelah Power and Desalination Plant in Abu Dhabi Emirate. Miri and Chouki studied the ecotoxicological marine impacts of thermal desalination plants [10,11]. Baalousha discussed that the effluent brines from the plants in the Gaza Strip area in Palestine are not properly disposed of and the quality of desalinated water is not monitored [12].

This study focuses the potential environmental impacts of the desalination plants particularly the reverse osmosis (RO) technology and describes a practical and achievable plan of management to mitigate the impacts of the facility. In the article, components of a desalination system, i.e. open intake, pretreatment, membrane unit (RO), outfall with diffuser, and transfer pipeline are identified as first. The potential impacts of each component are predicted for operation as well as construction stage, and measures in order to prevent or minimize adverse impacts to acceptable levels are evaluated.

2. Components of a desalination facility

A desalination system incorporates the following components: (i) marine structures consisting of the sea water intake and the saline concentrate outlet, (ii) desalination unit (including pretreatment), and (iii) transfer pipeline connecting the desalination unit to the water supply network. In Fig. 1, components of typical desalination facility are schematized.

The marine structures deliver sea water to the desalination unit (intake) and provide removal of the saline concentrate from the desalination process (outfall). Key elements of intake are heads, risers, tunnels or pipes, screens; and for concentrate outlet, they are tunnels or pipes, risers, and diffusers. The desalination units draw sea water via underground conduits. The sea water would then be desalinated using membrane or thermal techniques and pumped to the water supply network. The saline concentrate that is a by-product of the process would be returned to the sea. During this operation and process, certain environmental impacts take place. The potential impacts vary depending on intake type, outlet structure, methods used in pretreatment and desalination unit, and transfer pipeline as well.

2.1. Water intake

Intake structures can be classified as surface (open) and sub(non)-surface intakes. For surface intakes, the

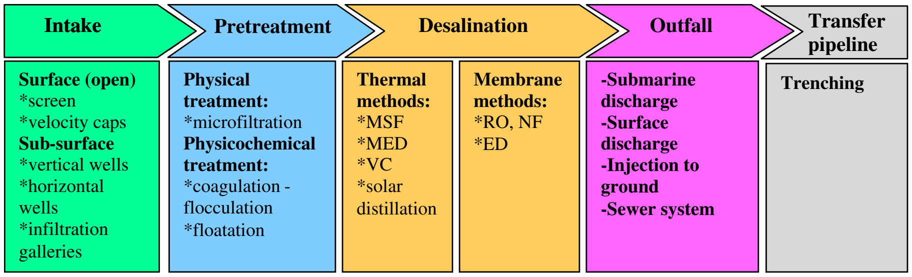

Fig. 1. Components of a typical desalination system.

inlet structure is located at the shoreline, typically near the surface or shallow water. In contrast, subsurface intakes are completely embedded in the seafloor, either in the beach sediments onshore, as vertical and radial beach wells or infiltration galleries. Impacts of intake structure are affected from type of the intake. For example, use of open intakes may result in losses of aquatic organisms when these collide with intake screens (impingement) or are drawn into the plant with the source water (entrainment). However, since subsurface infiltration gallery intake system filters the sea through the sands and gravel, it reduces the potential for entrapment and impingement problems.

2.2. Pretreatment

Prior to a desalination unit, filtration or other pretreatment methods like coagulation and flocculation or flotation should be employed to remove the finer particles and other substances that could foul the membranes. Since pretreatment processes remove suspended particles and dissolved organic molecules from sea water, waste stream due to the pretreatment processes may contain particulate matters, and dissolved and organic compounds that should be disposed of properly.

2.3. Desalination process

The desalination of salty sea water can be accomplished either by thermal or by membrane methods. The thermal methods are based on distillation process. Multi-effect desalination (MED) and multistage flash (MSF) technologies are the common thermal methods. Membrane separation processes separate the salt from the sea water by pressurizing the influent stream. The main membrane technologies used for desalination are as follows: electrodialysis (ED), nanofiltration (NF), and reverse osmosis (RO). The process of RO is the most efficient desalination process both in terms of energy and cost [13,14] so it is becoming the established and preferred process all over the world both in terms of quality of produced water and the cost of treatment [12,15]. Since both the electrical and thermal energy used for the desalination plants is usually generated from fossil energy sources, a main environmental and public health concern of desalination stem from energy generation, such as the release of air pollutants into the atmosphere, primarily as greenhouse gases. Besides pretreatment and concentrate discharges are another environmental concerns related to desalination plants. In RO processes, membranes are sensitive to particulates and fouling, thus require a great extent of pretreatment. The concentrate contains sea water with high concentrations of salt and some process chemicals and is generally being discharged to ocean. These chemicals include antiscalants, caustic soda, sodium bisulfite, hydrochloric acid, detergents, disinfectants, citric acid, ammonia, and similar.

2.4. Outfall–discharge

Desalination processes produce large quantities of a concentrate which contain residues of cleaning chemicals and salt (brine). Ahmet et al. pointed out that “One common aspect of all desalination plants is the production of concentrate where the amount as a percentage of the feed water varies depending on the choice of method and initial salinity of feed water” [16]. The concentrate disposal is generally made by a single port or a diffuser system at the sea bottom. Since the surface discharge of negatively buoyant plume directly at the shoreline produces very little initial mixing, Jirka claimed that better mixing efficiencies can be attained with submerged high-velocity discharges located further offshore and studied [17]. Hydraulic characteristics were studied both experimentally and numerically by researchers in order to find a correlation between the parameters of angle of bottom slope, port discharge angle, port diameter, ambient water depth at discharge, height of discharge port, discharge flowrate, etc. and the dilution amount of the flume [18–27]. Al-Barwani and Purnama simulated long-time brine plumes using a two-dimensional advection–diffusion equation considering oscillatory nature of the coastal currents [28]. Bleninger and Jirka claimed that although existing design practice favors a steep discharge angle of 60° above horizontal, model with CORMIX suggested a flatter discharge angle of about 30–45° may have design advantages [29]. All those discussions and evaluations basically aim to explain the physical phenomena taking place during the concentrate discharge eventually help the selection and determination of the mitigation measures, since the impurities and pollutants may be fatal for marine life, and cause modifications in bottom habitat and ecosystem. If the desalination plant is too far from the sea, disposal of the brine into the sea no longer exists. Ahmed et al. investigated the opportunity to use evaporation ponds for brine disposal. They are especially suitable for areas with abundance of solar energy [16].

2.5. Transfer pipeline

Water is transferred from the desalination plant to the water supply system via a pipeline, i.e. transfer pipeline. There are certain environmental risks especially associated with construction of the transfer pipeline.

3. Environmental impacts during construction

For desalination facility, construction activities can in general be subdivided into three main categories. These are the construction works at (i) sea for the intake, the outfall, and the sea water supply pipeline to the shore; (ii) land for the desalination facility; and (iii) for connecting infrastructure, e.g. product water pipelines or power transmission lines.

In general, construction works in seafloor include excavation, rock hammering, drilling and blasting, laying of pipeline depending on the ground conditions in seafloor. Land, construction generally comprises the initial earthwork activities like excavation, lying of foundations, construction of facilities, and landscaping measures (e.g. pavings, planting with trees, grass, etc.).

The magnitude of construction impacts largely depends on the design of the intake and outfall systems and the construction methods used. Different construction methods like open trench or trenchless can be used for installing the intake and outfall pipelines. Open trench techniques involving submarine excavators or jet streams for embedding the structures in the seafloor may result in a disturbance of the natural sediment layers, cause sediment compaction where machinery movements take place or where spoil is deposited, and affect the local benthic fauna. Trenchless techniques are conducted by horizontal drilling from an onshore site, e.g. by horizontal drilling of several radial drains or tunnel boring and lining the tunnel with concrete segments. In general, horizontal drilling or tunneling from the shore will minimize the disturbance of the coastal ecosystem, while underwater construction activities such as digging or the use of jet streams will generally have a larger physical impact on sediments, water, and marine life. However, noise emissions and ground-borne vibrations may be higher when drilling, blasting, or pile driving is necessary for the construction of pipes in rocky undergrounds [1].

Soil and material stockpiles, fuels, lubricants, and solid and liquid wastes stored within the active construction area may have detrimental effects on the environment without appropriate material management plans. Contaminants could be released into soils, sediments, or water bodies, or the placement of construction materials, including equipment, pipes, shoring, and spoils, could temporarily impede or redirect flows during heavy rainfall and storm water runoff. Impacts will also depend on the selection of the site and pipeline routes and the length and diameter of the pipe. Another important factor is the season in which construction activities are carried out, as species abundance and vulnerability may vary over the course of a year.

Construction activities, both in marine environment and land, result with an increase in local traffic. Marine traffic is largely due to movement of vessels to the self-elevating platforms (SEPs) from the shore. It is possible that the movement of marine vessels could disturb recreational users in the area, especially fishing activities, and affect ultimately public safety. Any disruption is expected to have a minor effect on recreational and fishing activities because the duration of the impact would be limited to the construction period. In addition to marine traffic, land traffic due to construction vehicles showed increase during construction period.

Construction activities are expected to affect the visual amenity of the local area, as the project may interrupt the quality of coastal views in some areas. Any effect from construction would be restricted to a small section of the coast and would only occur for the temporary construction period. Since the desalination plant site is very vital for the design, financing, construction, and operation, Tsiourtis proposed a flow chart for site selection process [30]. The process for site selection is composed of 10 steps

Table 1
Impacts of construction works

Waste Disposal	Deposition of excavated material
	Hazardous waste (waste oil from vehicles, batteries, and accumulators, antifreeze, and other chemical substances)
	Solid waste and wastewater from workers
	Accidental spills
	Spoil generated from tunneling and drilling
Air Quality	Site grading and trenching.
	Exhaust generated by construction equipment, trucks, and worker vehicles
Noise	Construction activities at seafloor (excavation, rock hammering, pile driving, drilling, blasting, etc.) for seabed clearing
	Construction activities at land (excavation, rock hammering, etc.)
Traffic	Marine vessels for intake and outfall construction
	Land traffic for construction vehicles
Flora and fauna	Seabed clearing—destruction of benthic habitat
	Laying of pipelines—destruction of benthic habitat
	Resuspension of sediments—increasing in turbidity, light penetration, etc.
Sea water quality	Resuspension of sediments (temporarily increased turbidity in the vicinity of the construction site)
	Accidental spills (accidental spills or leakages)
	Chemicals and hydrocarbons from vessels (intake and outfall construction)
Visual amenity	Visual annoyance during the construction activities (stockpiling of soils, movement of construction machinery, etc.)
	Interrupting the quality of coastal view

beginning by setting up a special committee, preparation of site selection criteria, defining the potential sites to finally selection of the final site by client and local authority. The author also defined the criteria for selecting a site so that the plant site should be away from populated areas close to good quality sea water source, close to suitable brine discharge area, electric power supply lines, water supply system and a high level road network [30].

Considering the construction works, potential impacts mentioned above are categorized as waste disposal, air quality, noise, traffic, flora and fauna, sea water quality, and visual amenity and presented in Table 1.

4. Environmental impacts during operation

The potentially significant environmental risks associated with operation of the desalination system are identified as follows:

(1) Effects of the intake on marine flora and fauna.
(2) Effects of the discharge stream on marine flora and fauna and water quality.
(3) Noise generation from desalination unit and intake structure.
(4) Waste generation and disposal.
(5) Energy consumption.
(6) Visual impacts of the desalination unit.

The intake structure draws sea water via a head structure that could be screened with coarse screen. The intake may affect individual organisms through entrainment, entrapment, and impingement mechanisms. Each of these mechanisms may result in the removal of some individuals. The sea water intake may cause another impact as extinction of aquatic organisms by impingement and entrainment mechanisms on the intake structure. The extent of damage depends on the ecological characteristics of the intake piping location, the intake velocity, and the overall volume of intake water.

The concentrate released to the marine environment via diffusers (outfall structure) contains concentrated sea water and trace chemical residuals from the desalination process. Mandil and Bushnak observed that the environmental impact of brine discharge is related to the physical, chemical, and biological characteristics of the receiving marine environment [31]. Khordagui stated that the amount and nature of salts discharged with brine are identical to the salt content of the sea, with concentration factor increasing by no more than two [32]. Fard claimed that in plants of RO, the discharge concentration is 30–70%, or 1.3–1.7 times that of the original sea water [33]. Brine is a hypersaline effluent of desalination plant and thus is denser than the sea water [3]. Therefore, it sinks to the bottom of the sea and affects the benthic ecosystems and water quality [34]. Process chemicals include antiscalants, chemicals for cleaning of membranes e.g. caustic soda, sodium bisulfite, hydrochloric acid, detergents, disinfectants, citric acid, ammonia. Hence, the impacts of the concentrated waste discharge (brine) may be considered as the major environmental and aquatic concern for marine life.

Potential impact of brine disposal operations on coastal and marine environment can be determined by modeling. After their modeling study, Purnama et al. concluded that in Oman, the increase in salinity in coastal water will intensify the critical problems of sea water intrusion into coastal groundwater aquifer and proposed to build longer sea outfalls to alleviate this problem [35]. CORMIX, Visual Plumes, Visjet, MEDVSA, Hydrotam are introduced as well-known models or software for brine discharges [36]. These models can be used to estimate the impacts, for submerged single-port and multiport diffusers as well as surface discharge sources [37]. Among them, CORMIX is not only able to simulate the dispersion of heated brine effluent in the marine environment but also to conduct sensitivity analysis to identify most influencing input parameters on simulation results [38].

Desalination plants can produce significant noise emissions. Major sources of noise during operation include intake pumps, the RO high-pressure pumps, and the energy recovery systems, and other pumps and equipment, such as the different pumps and equipment of the pretreatment and cleaning systems.

Energy use is a major factor in the environmental assessment of desalination projects. The energy used for the desalination of sea water is usually produced from fossil energy sources. A main environmental concern associated with the energy demand of desalination processes is therefore the release of air pollutants into the atmosphere, including greenhouse gas (CO_2), acid rain gases (NOx, SOx), or fine particulate matter. Green energy should be an alternative, whereas Ma and Lu discussed the technological problems in wind utilization and presented potential counter measures for the intermittent characteristics and direct utilization of wind energy [39].

Considering the operation, potential impacts mentioned above are categorized as groundwater and sea water quality deterioration, marine flora and fauna, air quality and climate, noise, hazardous materials, and waste disposal and presented in Table 2.

5. Environmental mitigation plans

Mitigation plan for a desalination facility is necessary to anticipate the effects of the plant failure and identify suitable procedures for mitigating those effects. Mitigation plans are documented as EMPs which define the details of who, what, where, and when environmental management is to be implemented throughout the life of a project [40]. The precautionary approach such as "better save than sorry" or "look before you leap" should be an essential issue when implementing and creating new environmental regulations [41]. Mitigation plans for construction and operation stages are evaluated separately and presented.

5.1. Mitigation measures for construction phase

5.1.1. Waste disposal

Wastes are produced from construction works, i.e. excavation, rock hammering, drilling and blasting, tunneling, etc., anthropogenic facilities (domestic wastewater and solid wastes), and accidental spills. For mitigation, construction material should be piled next to the trench until they are reused as backfilling. This material should not be stored for more than a specified period and should be kept in temporary storage containers. Domestic and hazardous wastes should not be disposed in these temporary containers. Containers filled with waste should be collected and transported to storage or recycling facilities by municipality or authorized companies. Hazardous wastes as waste oils originating from machinery and vehicles should be stored in impervious tanks and containers that would be situated on impervious foundation in accordance with the relevant regulation. Tanks and containers should be equipped with apparatus that would prevent over filling and should be filled till the designated level mark. Used batteries from construction site and accumulators from vehicles should be disposed in compliance with the consumer responsibilities. Accordingly, used batteries should be collected separately (from municipal wastes) and transferred to the designated collection sites. All other hazardous materials should be disposed in accordance with the relevant regulation. If waste is defined to be as hazardous material, records will be kept and waste will later be transferred to licensed waste recycling or disposal facilities by proper packaging and labeling procedures that comply with this regulation. Hazardous wastes should be stored at the construction site away from buildings in impermeable and safe containers placed on concrete ground that are produced according to regulation. Those wastes should be transported by contractors licensed to handle these materials. Finally, wastes should be sent to hazardous waste landfill site to be disposed at the special area reserved for hazardous waste. Solid waste in construction site

Table 2
Impacts of operation

Sea water quality deterioration	Increase in salinity due to RO reject discharge Influence on density stratification Chlorine and chlorination by-products Increase in turbidity due to filter backwash water Antiscalants Decrease in dissolved oxygen levels due to sodium bisulfite used for dechlorination Accidentally spilled chemicals The intake of large quantities of sea water may affect water circulation
Groundwater quality deterioration	Salt water intrusion for below ground intakes Leakage from pipes may result in penetration of salt water threatening the aquifer.
Marine flora and fauna	Loss of marine organisms by entrainment, entrapment, and impingement Increased salinity, temperature can be harmful and even lethal Decreased oxygen levels may be harmful Chlorine and chlorination by-products may be harmful Metals may be assimilated by marine organisms, with the risk of bioaccumulation Accidental spills into the ground or surface water bodies or into sea may affect the local fauna and flora.
Noise emissions	From intake pumps, the RO high-pressure pumps and the energy recovery systems, and other pumps and equipment
Air quality and climate	Release of air pollutants into the atmosphere, including greenhouse gas (CO_2), acid rain gases (NOx, SOx), or fine particulate matter due to high energy consumption
Hazardous materials	From routine transport, storage and handling of hazardous materials.
Waste disposal	Screening from intake screens and solid waste produced during the pretreatment process
Visual amenity	Impair landscape properties due to buildings on coast and land use

should be collected and stored in containers and should be transported daily to the landfill site. Domestic wastewater in construction site should be properly collected. In this scope, if possible, connection to the existing sewer system via a manhole may be provided. If not, wastewater will be collected in constructed impervious septic tanks in or next to the construction site. The tanks should be emptied by sewage trucks when it is filled and should either be disposed to the sewer system from a predetermined point or directly be transferred to the inlet of the municipal wastewater treatment plant [42].

5.1.2. Air quality

Air quality is affected from dust formation during construction works and exhaust generation by construction equipment, trucks, and worker vehicles. In order to minimize adverse impacts, the top layers of the excavated material should be wetted to prevent dust formation especially in dry and windy weathers. Protection barriers should be used in construction sites depending on wind conditions. Trucks, carrying excavated material, should be covered and their bodies should be controlled against spill, scatter, etc. In case of scattering to road surfaces, the surface should be cleaned as soon as possible. In dry weather, roads with heavy traffic should be wetted frequently per day. Routine control and maintenance of vehicles used in transportation activities should be conducted regularly (daily and periodically). Daily maintenance should be carried out in each shift; and working time of each vehicle should be registered by the operator in order to follow the total working hours for periodic maintenances. Periodic maintenances should be conducted and maintenance forms should be filled regularly. All vehicles used in transportation activities should be issued an emission control stamp which is renewed every year by measuring the emissions from the exhausts. Speed limits must be strictly obeyed for all vehicles used in transportation activities.

5.1.3. Noise

Construction activities at seafloor (excavation, rock hammering, pile driving, drilling, blasting, etc.) for seabed clearing and land produce noise. For land-based noise, noise barriers may be installed around the construction site for excavations in land. To determine the effects of noise to marine life, a noise modeling study should be performed for excavation works in sea. Besides, routine maintenance of all vehicles and equipment used for excavation, construction, pipe installation, and asphalting should be done regularly. For the maintenance of transportation vehicles (e.g. trucks) the “distance” is the key factor for maintenance scheduling. A specific working time could be suggested for work vehicles as excavator, forklift. Construction works should be performed between predetermined hours. Both the land and marine traffic should be carried out at times during the population is the least. Nevertheless, the EMPs should schedule the most disruptive work at the least sensitive times’ construction work that generates very loud, sharp noise.

5.1.4. Traffic

As it stated before, marine traffic is largely due to movement of vessels to the SEPs from the shore. Since duration of the impacts would be limited to the construction period, any disruption from the movement of marine vessels is expected to have a minor effect. For the influence of construction activities on local traffic, public should be informed about the details of work (duration, diversion of traffic, etc.) before construction starts.

5.1.5. Flora and fauna

Seabed clearing and pipeline lying are the potential dangers for benthic habitat. The turbidity may increase due to the resuspension of sediments and cause a decrease in illumination. All environmental risks should be identified for the ecological communities of plants and the species of animals. The number of endangered ecological communities should be listed. EMP should include the monitoring plans for all zones for specific periods by taking photographs, surveying, population counts, etc., during the construction phase.

5.1.6. Sea water quality

The sea water quality can be affected from the resuspension of sediments, accidental spills, or leakages. The durations of pipe laying and construction works should be specified for resuspended sediments to be fell down and consequently help to decrease the turbidity. Sampling and online monitoring of the turbidity during the construction should be performed. The action plans for accidents should be included.

5.1.7. Visual amenity/esthetic impacts

Any effect from construction occurs for the temporary construction period and should be restricted to a small section of the coast. Barriers may be used in order to prevent visual annoyance during the construction works. Placement of barriers and separators around the construction site may provide mitigation to esthetic pollution. Destructed green spaces should be replanted and uprooted trees may be implanted at different sites by cooperating with relevant institutions.

5.2. Mitigation measures for operation phase

The mitigation measures to be comprised by the EMPs during the operation phase are explained in this section. In any case, a pilot plant will be helpful in determining the necessary precautions and during the preparation of EMPs of operation.

5.2.1. Groundwater quality deterioration

Below ground intakes are completely embedded in the seafloor, either in the beach sediments onshore, such as vertical and radial beach wells or infiltration galleries. Depending on the plant capacity, salt water intrusion problem may arise and cause the quality deterioration in groundwater. In certain cases, plants may be located farther inland instead of shoreline to minimize the land use at the shoreline. This may introduce the problem of using pipes for transporting large amounts of sea water and brine, with the danger of pollution to the underlying aquifer from potential leakage [3]. So, in that case the route of the pipelines should be planned considering this danger. At intake locations, observation wells should be drilled and samples should be gathered periodically to monitor the water quality through the operation period.

5.2.2. Sea water quality deterioration

There are several approaches to mitigate the environmental effects of the waste discharges. To avoid impacts from high salinity, the desalination plant reject stream can be pre-diluted with other waste streams where applicable, such as power plant cooling water. Mixing and dispersal of the discharge plume should be enhanced by installing a diffuser system, and by locating the discharge in a favorable oceanographic site which dissipates the salinity load quickly [43].

Alameddine and El-Fadel outlined the advantages and disadvantages of brine disposal options such as direct surface water discharge, discharge to a sewage treatment plant, deep well disposal [38].

Negative impacts from chemicals can be minimized by treatment before discharge, by substitution of hazardous substances, and by implementing alternative treatment options. In particular, biocides such as chlorine, which may acutely affect organisms in the discharge site, should be replaced or treated prior to discharge. Chlorine can be effectively removed by different chemicals, such as sodium bisulfite as practiced in RO plants, while sulfur dioxide and hydrogen peroxide have been suggested to treat thermal plant reject streams [44]. Filter backwash waters should be treated by sedimentation, dewatering, and land deposition, while cleaning solutions should be treated on-site in special treatment facilities or discharged to a sanitary sewer system.

Besides, measurements of oceanographic conditions and physical model simulations of the dispersion of the sea water concentrate should be performed. Mathematical models are effective tool to predict the extent and intensity of brine discharge plumes in receiving waters and in the optimization of outfall design; therefore, data gathering from oceanographic studies and physical model studies should be used for the validation of results and for the prediction of the impacts on biota and sea water quality. However, in practice, data gathering from dispersed plume are very scarce. Fernandez-Torquemada et al. presented the data from brine discharge originated by the Alicante sea water RO desalination plant in southeastern part of Spain [45] throughout one year after operation. They proposed a prior dilution of the brine with sea water that has been proved useful in other plants [46,47].

5.2.3. Marine flora and fauna

The EMPs prepared for operation phase should indicate the methods to determine the impacts on marine ecology from the sea water intake during operation. The precautions should be designated so that the potential for marine biota to become entrained in the intake should be minimized. In order to mitigate the impacts of open intakes, a combination of differently meshed screens and a low intake velocity should be considered. This can minimize the impingement and entrainment of larger organisms, while the entrainment of smaller plankton organisms, eggs, and larvae can be minimized by locating intakes away from productive areas, e.g. into deeper waters, offshore, or underground (e.g. by using beachwells) [48].

Determination of the properties of the marine organisms that may be entrained within the sea water intake and monitoring plans to obtain the number, size, and type of these organisms during the operation should be explained briefly. In this framework, Höpner and Winderbergs offered to make sensitivity assessment of sub-ecosystems in the sequence from the lowest to the highest sensitivity [49]. The monitoring plans should also be carried out before and after the plant commences operation so that a comparison to determine any detectable effects of the plant could be specified. During the operation, the plume tracer studies should be undertaken to directly measure the concentration in the near and far mixing zone of the plume. The locations and frequencies of the sea water samples to be taken and afterward the necessary experiments to obtain the critical chemical ingredients and their concentration should be declared in the management plans. The population estimates of the species written in the reports should be compared with the ones obtained at side during construction and operation is a way of monitoring the flora and fauna. The reports prepared by the experts particularly academicians from universities and their recommendations should be included in reports. The plans should encourage animals to remain in their current locations. The plans should identify the level of tolerations of the species living neighboring to the site and strictly monitor the responses of species to operational noise and put in place the mitigation measures if required such as sound modeling [50].

5.2.4. Hazards and hazardous materials

The risks of the hazardous materials should be determined, and the necessary activation plans should be explained in the management plan in detail. The person, who is responsible for the storage and handling of hazardous materials, should also be determined and included.

5.2.5. Noise emissions

Noise should be kept minimal as most noisy equipment is housed in buildings and truck movements to and from the plant, which may be limited to daytime, are the main activities related to operation and maintenance. Noise insulation may be provided at high-pressure pumping stations. This could be achieved by installing insulation materials in the inner walls of the stations or noisy pumps could be placed in acoustic cabins. All mechanical equipments that generate noise should be maintained and the oil levels, silencers, etc., should be controlled and renewed periodically. Trees could be planted in the vicinity of pumping stations to provide a natural noise barrier in long term.

High-pressure pumps and energy recovery systems, such as turbines or similar, produce significant level of noise over 90 dB(A). Therefore, they should be located far away from populated areas and equipped with appropriate acoustic technology to reduce noise level.

5.2.6. *Air quality and climate*

As both the electrical and thermal energy used for the desalination of sea water are usually produced from fossil energy sources, a main environmental and public health concern of desalination is the release of air pollutants into the atmosphere, primarily greenhouse gas (CO_2), acid rain gases (NOX; SO_2), and fine particulate matter. In order to reduce the energy consumption in desalination plants, using of energy recovery equipment or variable frequency pumps in RO plants is recommended. Furthermore, the potential for renewable energy use (solar, wind, geothermal, biomass) should be investigated to minimize impacts on air quality and climate. Although it cannot provide all the energy needed for the process, it can partially compensate. There should be a commitment to the plant being powered by a specific (in percentage) renewable energy. In order to track electricity use, a recording system may be used.

5.2.7. *Waste disposal*

Screening from intake screens are required to temporarily store on shore while waiting for a truck to remove them from site to landfill. The solid waste produced during the pretreatment process and the domestic waste could be taken to landfill. The recycling possibilities of waste material from maintenance works such as membranes should be evaluated, and remaining waste materials should be sent to landfill site. All hazardous wastes should be disposed in accordance with the regulations. In this context, the characteristics of waste generated should first be determined by accredited laboratories. If waste is defined to be as hazardous material, records should be kept and waste will later be transferred to licensed waste recycling or disposal facilities proper packaging and labeling procedures that comply with the regulation. In this scope, hazardous waste (paint, waste oil, etc.) should be stored temporarily in an area thought fit. Waste oils should be stored in leak-proof tanks and containers located on impervious ground in accordance with the regulation. Liquid level measuring device (transparent tube) should be mounted to the outside of the tanks and containers to prevent overfilling. Tanks and containers should have red color and be labeled as "waste oil." After the temporary storage, those wastes should be sent to hazardous waste landfill site in containers having license to transport these wastes. Used batteries and accumulators should be collected separately and disposed in compliance with the consumer responsibilities specified in regulations. Accordingly, used batteries should be collected by licensed contractors separately and transferred to collection sites.

6. Results and conclusion

Desalination plants provide an extra source of water that does not rely on rain. An important issue in a desalination project is to keep the environmental impacts to minimum both on land and marine environment [40]. Therefore, in the planning phase, an EIA studies should be performed. Plus incorporation of those studies with EMPs is highly required [1,11].

The EMP prepared for a facility consists mainly of mitigation measure, monitoring plan, and recommendations. Monitoring programs contain information regarding to parameter that will be measured (what), method used in measurement (how), sampling point (where), sampling frequency (when), responsible (who), and cost estimates. Monitoring programs are prepared to monitor the impacts of the project on water quality and marine ecosystems, to validate and calibrate modeling. The monitoring program should be performed at design, construction, and operation stages to identify impacts and to evaluate the mitigation measures. The possible environmental changes due to the construction, implementation, and operation should be determined by starting monitoring the original environment few years before, at least during the planning phase. Obtaining the required levels and frequencies of sampling, it is necessary to understand the natural variations of the parameters to be measured. Data gathering and monitoring program should continue after the implementation and during the operation of the facility in order to compare before and after situation, clarify the human induced change to the environment, and deduce the environmental impacts, trying to keep them to minimum as declared in the EMPs [50].

In this study, the environmental impacts and the mitigation measures are summarized for specifically RO desalination plants both in construction and operation phases and mitigation measures and control plans were highlighted. Concerning the EMPs, the objective for desalination plants is the identification of potential impacts resulting from the construction and operation facilities. Construction works including excavation of intake and outfall pipeline at sea and land preparation of desalination plant are expected to create various environmental impacts including dust formation, noise pollution, traffic problems as well as problems with public health and occupational safety and waste disposal. Besides, the construction activities can temporarily impair the esthetic landscape properties and the natural scenery in the construction site and nearby areas within visual and acoustic range. The operation of a desalination plant may also result in undesirable environment effects, i.e. waste discharge, noise pollution, air emissions, impingement and entrainment of the aquatic organisms, and problems with public health and occupational safety. Thus, in order to maintain the sustainable use of desalination technology, it is essential to determine the impacts, their quantification methods, the sensitive threshold levels of the parameters, start monitoring these parameters before commissioning and continue during the operation of the plans so as to get the impact level at both construction and operation phase. The EMPs should include tables answering questions as who is responsible from what, when, and which precautions will be taken and where these precautions should be implemented.

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