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Environmental Risk Management and Mitigation Strategies for Offshore Gas Well Drilling Projects (Case Study: Abu Qir Bay, Egypt)

Moussa Sobh Elbisy, Ehab Abduraheem Mlybari

Civil Engineering Department, College of Engineering and Islamic Architecture, Umm Al Qura University, Makkah, Saudi Arabia

Email address:
mselbisy@uqu.edu.sa (M. S. Elbisy), eamlybari@gmail.com (E. A. Mlybari)

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Abstract: Risk evaluation for offshore gas exploration and production is a challenging task because much of the available data are highly uncertain and vague, and many of the drilling techniques are complex. The paper describes the implementation and use of environmental risk management and mitigation strategies for an offshore gas well drilling project. It includes an offshore case study from Abu-Qir Bay in the Egyptian sector of the Mediterranean. The environmental risk management study evaluated the potential impact of the operations and identified the mitigation procedures to be followed to eliminate any risk of contamination. It provides a framework for the future environmental management of the area in order to minimize the negative impacts of operations.

Keywords: Risk Assessment, Environmental Management Plan, Offshore Gas Well Project, Drilling, Safety Mitigation Measures, Maintenance

1. Introduction

Oil and gas drilling engineering cooperation is fundamental to oil and gas exploration and development. This requires systematic engineering that involves numerous investors and administrators, complicated techniques, and large investments and risks. It also encompasses several work categories and work procedures, grade separation, and continuous operations. Moreover, it is a type of concealed underground engineering. These characteristics produce many uncertainties in oil and gas drilling projects, which lead to great risks in every aspect of such projects. If effective measures are not taken, these risks can easily lead to various kinds of accidents, which will threaten the safety of operating personnel and produce environmental pollution or even a huge loss of government property [1].

The purpose of risk management is to ensure that adequate measures (responses) are taken to protect people, the environment, and assets from the harmful consequences of the activities being undertaken, as well as to balance different concerns, particularly health, environment, and safety (HES) concerns, and costs. Risk management includes measures to both avoid the occurrence of hazards and reduce their potential harm. Risk assessment is followed by risk treatment, which is a process involving the development and implementation of measures to modify risk, including measures designed to avoid, reduce ("optimize"), transfer, or retain risk. Risk management covers all coordinated activities designed to direct and control an organization with regard to risk, whereas the risk management process is the systematic application of management policies, procedures, and practices to the tasks of establishing the context for, assessing, treating, monitoring, reviewing, and communicating risks [2-3].

Oil and gas exploration and production operations have the potential for a variety of impacts on the environment, depending upon the stage of the process, the nature and sensitivity of the surrounding environment, and pollution prevention, mitigation, and control techniques. In an aquatic environment, the principal problems are linked to the presence of offshore structures and to the waste streams of the drilling fluids, cuttings, well treatment chemicals, and produced water [4-7]. The economic benefits of offshore oil and gas exploration and exploitation must be weighed against the potential for marine pollution. The greatest perceived threats of pollution associated with offshore development are spills and blowouts, but a more insidious source is the discharged effluents generated by daily drilling operations.

The potential environmental effects of offshore oil and gas development have long been recognized [8-10], including an awareness of the potential and documented hazards from oil spills associated with offshore production [11-13].

OSPAR [14] evaluated the impacts of offshore oil and gas activities on the marine environment of the OSPAR maritime area in the Northeast Atlantic to address environmental concerns through international regulatory frameworks. Their assessment was based on information from the annual OSPAR data reports on discharges, spills, emissions, and assessments. Gomiero *et al.* [15] developed a multidisciplinary, chemical–biological approach focused on changes in benthic communities and sediment chemical accumulation to assess the environmental impact of offshore gas exploitation and production activity in the Adriatic Sea. The results of this survey regarding an offshore production platform showed the importance of a multidisciplinary approach that includes both chemical and biological analyses. Elvin and Fraser [16] inadequately addressed the cumulative environmental effects from the offshore oil and gas industry in Canada in their environmental assessment process because of the complexity of the analysis required to overcome the unknowns with respect to the offshore environments. Hernández *et al.* [17] developed a regional framework for the sustainable management of marine water natural resources. The results showed a failure rate of 51–92% in controlling the marine impact of marine oil drilling and exploitation southwest of the Gulf of Mexico.

The paper describes the implementation and use of environmental risk management and mitigation strategies for an offshore gas well drilling project. The study area is located in Abu-Qir Bay (30°10′27.08"E and 31°34′27.42"N) in the Egyptian sector of the Mediterranean. It has a depth of approximately 28 m and is approximately 23.6 km from the shore. The study included a baseline environmental assessment of the site, a determination of the project's impact on the environment, an environmental impact assessment, and the development of mitigation measures, with an integrated plan for managing the identified environmental hazards and effects, and a monitoring plan.

2. Existing Environment

2.1. Abu Qir Bay

Abu Qir Bay is a semi-circular basin that lies approximately 35 km northeast of Alexandria on the northeastern Egyptian Nile delta coast, between latitudes of 31°16' and 31°28'N and longitudes of 30°4' and 30°20'E. The bay has a shoreline length of approximately 50 km. It is relatively shallow, with a depth of less than 1 m along the coast, which gradually increases away from the shore to a maximum depth of approximately 15 m. The bay is connected to Lake Edku, which is one of the coastal lagoons of the Nile Delta that lies west of the Rosetta branch. This lake is connected to the Mediterranean Sea through the Boughaz El-Meadia. Abu Qir Bay receives a substantial load of industrial polluted water from the Tabia pumping station, the brackish water of Lake Edku, and the Nile water reaching the bay through the Rosetta mouth.

2.1.1. Sediment

A preliminary estimation of the nitrates in Abu Qir Bay showed high values of 0.20–1.85 µg-at/L. The subsurface layer along the coast and the surface water offshore had higher concentrations. The sediment type distribution in the bay depends principally on the distance from the mouth of the Nile River. The hydrodynamic force and bottom topography are additional factors that tend to redistribute the surface layer of the thick sedimentary column formed by the Nile River over thousands of years. A logical analysis of the sediment of the Nile alluvium revealed that this sediment consists of 25% sand, 43% silt, and 32% clay. The dominant sediment forming minerals are feldspars, quartz, pyroxenes amphiboles, iron oxides (opaque minerals), and clay minerals. Other heavy minerals are found in minor amounts, including zircon, tourmaline, monazite, and garnet [18].

2.1.2. Major Constituents of Water

a) Salinity

The distribution of the salinity in the bay is generally affected by the three main sources of inland discharge, namely, the drainage water of Lake Edku, fresh Nile water flowing from the Rashid branch, and contaminated drainage water discarded from the El-Tabia pumping station. As a result, the salinity of the bay water was found to be subjected to wide fluctuations between 31‰ and 38‰. The lower salinity appeared around the outlets of the inland discharges previously mentioned, and it gradually increased away from the shore. The variations in the salinity of the water in the bay do not have a significant effect on the flora and fauna of Abu Qir Bay because most of these are euryhaline forms that can tolerate a wide range of salinity.

b) Total Alkalinity

The water in the western sector of the bay showed some variation in its total alkalinity, with higher values equivalent to 198 mg $CaCO_3$ recorded at the surface water east to Boughaz El-Maadiya. It gradually decreased westward to minimal values near the El-Tabia outfall. Another increase was observed in front of Abu Qir City. The subsurface water had a lower concentration and appeared to be more homogeneous in its horizontal distribution of the total alkalinity. The total alkalinity in the bay was still within the favorable limits needed for the growth of phytoplankton and benthic flora.

c) Sulphite Content

The El-labia drainage water with its load of industrial wastes represents the main source of dissolved sulphites in the adjacent coastal waters. Thus, the highest sulphite content was found near the El-Tabea pumping station, where it reached approximately 1.8 mg Na_2SO_3/L. It tended to gradually decrease away from the shore in a northeastern direction. The surface and bottom layers had mostly similar concentrations, with the same horizontal distribution pattern.

d) 2.1.2.4 Calcium (Ca ++)

Estimates of the calcium in the western sector of Abu Qir Bay indicated a lower concentration beside the El-Tabia pumping station, with an obvious gradual increase toward the northeast. This was explained by the effect of wastewater with a lower calcium content. The concentration of calcium in the surface water ranged from 0.39 to 0.68 gm/L in November and from 0.38 to 0.55 gm/L in February. Its concentration in the subsurface water did not vary in its distribution pattern from that of the surface water. However, slight increases to approximately 0.76 and 0.45 gm/L dominated the subsurface water in the vicinity of the El-Tabia outfalls during the autumn and winter, respectively.

e) Magnesium (Mg ++)

Homogenous magnesium concentrations were generally observed in Abu Qir Bay in the central regions. Concentrations ranging from 1.4 to 1.6 gm/1 were found in approximately 60% of the total area of the western section. A significant rise to 2.3 gm/L appeared in the subsurface water adjacent to the El-Tabia station in November 1982. The influence of the water flowing from Lake Edku was manifested by a sharp drop in its concentration to approximately 0.5 gm/L in front of Boughaz E1-Maadiya, and slight variations in the magnesium concentration appeared with the depth. The magnesium concentrations were nearly the same during autumn and winter.

f) Dissolved Oxygen (DO)

All of the measured values revealed that the bay, in general, is a well-oxygenated water body and tends to be saturated and sometimes over-saturated with DO (6–10 mL/L). However, in the vicinity of the El-Tabia pumping station, the DO values decreased to 0.7 mL/L in the surface water and 0.4 mg/L in the bottom water of the bay. Previous studies found higher DO values in the range of 7–11.5 mL/L in the offshore water and central part of the bay, which drastically dropped to values of 0.5–1 mL/L in the western coastal area between the Abu Qir suburb and El Tabia outfall. The great fluctuations in the dissolved organic content are probably due to the effect of several physical and biological process activities with different rates, e. g., the consumption of oxygen by the high organic load of the discharged wastewater and oxygen production through the photosynthetic activities of phytoplankton.

g) Organic Matter Represented by Biochemical Oxygen Demand and Chemical Oxygen Demand

Abu Qir Bay has much higher levels of organic matter, especially near the discharge of industrial effluents from the El Tabia outfall. The levels of chemical oxygen demand (COD) and biochemical oxygen demand (BOD) 300 m from the El Tabia drain were 53 mg/l and 20 mg/l, respectively.

h) Wind

The mean monthly wind speed is lower in summer and higher in winter because of frequent storms during the winter season. These speeds average 2 kn in summer and spring and 4 kn in winter. The maximum mean wind speed (8.5 kn) occurred in December, while the minimum (1.5 kn) was in August. Wind data revealed that the winter season is characterized by wind coming from all directions; however, northerly and northwesterly winds are still more predominant than those from the other directions. The weather is highly seasonal in nature and is strongly related to the high-pressure systems whose limits overstep the boundaries of the Mediterranean area [19]. The Nile Delta coast is subjected to an average of seventeen major storms, called Nawat, each year. In general, the storm season extends from September to July, and storms with high intensity occur from November to March. Figure 1 shows the wind rose over the study area during the period of 2005–2006 [19].

i) Waves

The Nile Delta coast is affected by a wave regime that varies with the season [20]. The average annual wave height is approximately 0.94 m, and the predominant direction of all waves is from the NW (42%), with a portion (25%) approaching from the WNW. Approximately 87% of all the wave heights are less than or equal to 1.5 m, and 13% are greater than this value. The majority of the wave period values (59%) are in the range of 5–8 s, with an annual mean period of 6.5 s. Additionally, approximately 80% of the wave periods are less than or equal to 8 s. The maximum significant wave height (4.19 m) was observed during the winter season, with a wave period of 10.7 s, and came from the NW. The predominant wave directions generate a westward-flowing longshore current. Waves approaching from the N, NNE, and NE generate reversed longshore currents toward the SW [20].

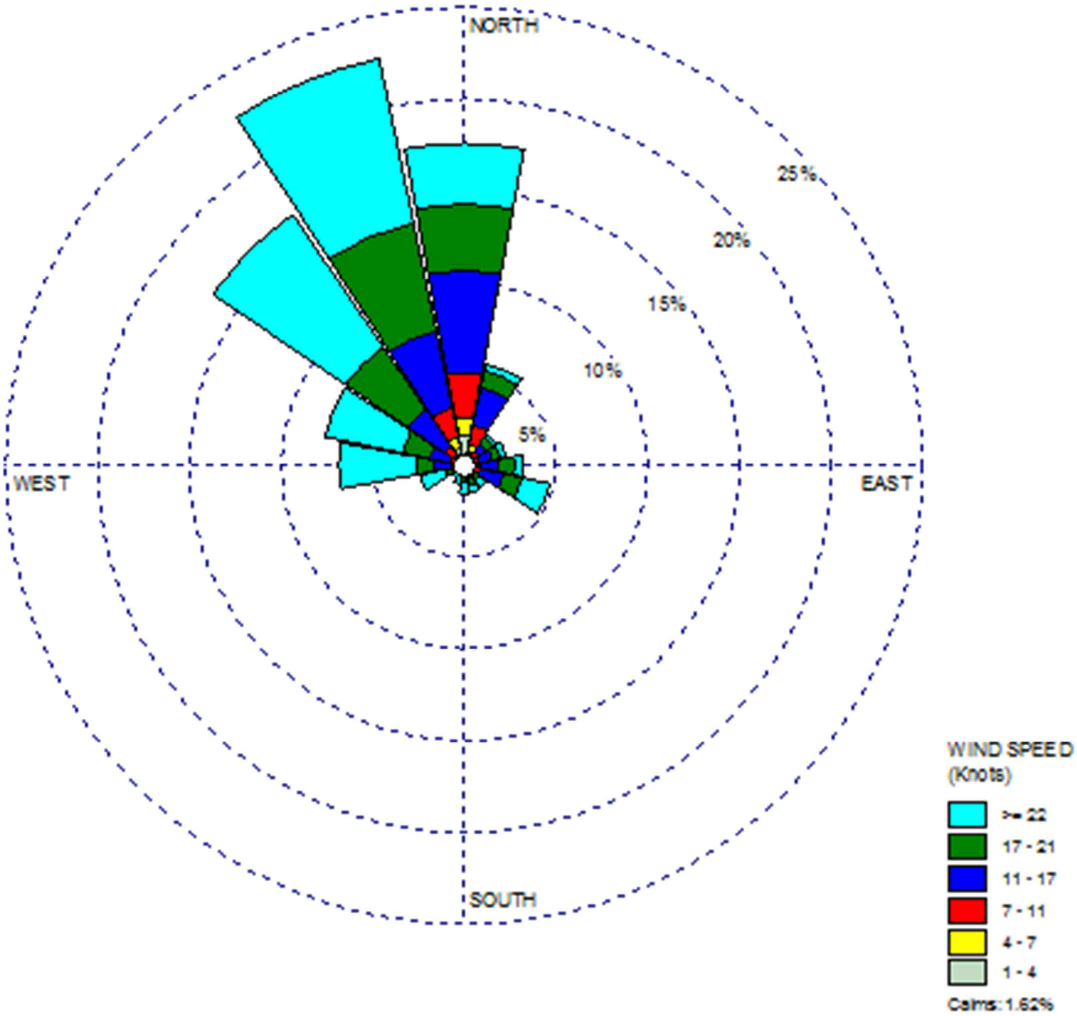

Figure 1. *Wind rose over study area during period of 2005–2006 [19].*

2.2. Study Area

The study area was located in Abu-Qir Bay (30°10′27.08"E and 31°34′27.42"N). It had a depth of approximately 28 m and was approximately 23.6 km from the shore (Figure 2).

The offshore development well (N. A/Q P-II#2) will be drilled to 11000 ft TVDSS (Abu-Qir Bay in Mediterranean Sea) using the Ocean Spur rig offshore development well, which is proposed to be a vertical well, because the surface and target geographical locations are the same (31°36’46.83’’N, 30°05’52.39’’E).

The water depth at the proposed well location is ±93 ft. The drilling operations are proposed to be finalized within 70 days of the starting date. In the drilling process, a considerable amount of drilling mud will be used to lubricate the drill string, cool the rotary drill bit, carry the rock cuttings/fines from the well bore to the surface, inhibit the entrance of undesirable formation fluids into the well bore, and control excessive pressure in the well bore to prevent blowouts.

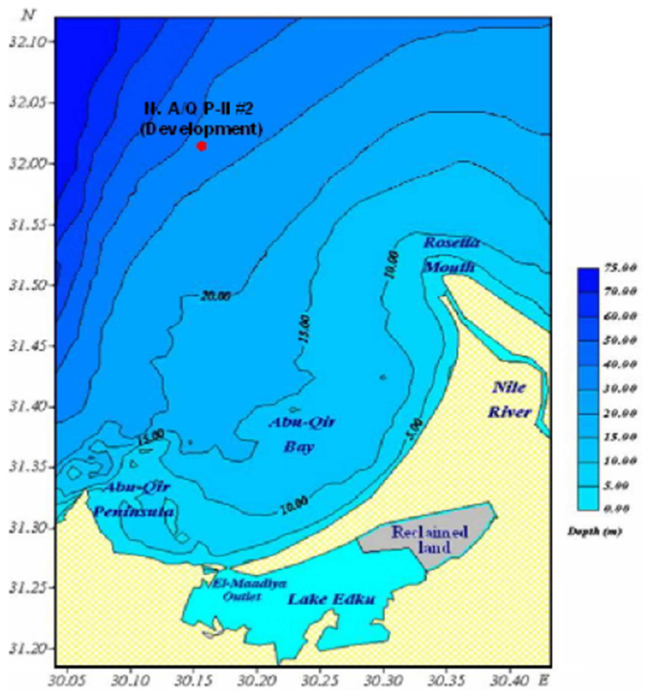

Figure 2. *Location of study area and bathymetric map of Abu-Qir Bay.*

2.2.1. Measured Water Quality Parameters

The total dissolved solids (TDS) were measured after filtering a known volume of a well-mixed sample using glass fiber filter paper (0.045 mm), which was transferred to a weighed evaporating dish, evaporated to dryness in a drying oven at 180°C, and cooled in a desiccator to the balance temperature before calculating the TDS. The BOD was determined using the 5 day method, and the COD was determined using the potassium dichromate method. The water alkalinity was determined using phenolphthalein and methyl orange indicators. The chlorisity was measured using Mohr's method. The sulphide was determined using the iodometeric method. The total hardness was determined through a complexometric method by direct titration using EDTA solution. The ammonia was determined using the phenate method. The nitrate as determined using the reduction method, as described by Mullin and Riley [21]. The orthophosphate was determined using the stannous chloride and acid molybdate method. The measured water quality parameters are represented in Table 1.

2.2.2. Heavy Metals in Water

Five milliliters of concentrated HNO_3 was added to each 1 L sample to preserve it, after which it was stored in a refrigerator at approximately 4°C for later analyses. To determine the concentrations of various elements (Fe, Mn, Cu, Zn, Cd, and Pb) 20 mL of nitric acid was added to 500 mL of a well-mixed sample in a beaker. Slow boiling and evaporation on a hot plate were carried out until a reduced volume was reached (before dryness occurred) and the digestion was complete. The beaker walls were washed down with distilled water, and the sample was transferred to a 100 mL volumetric flask, cooled, diluted to mark, and mixed thoroughly. The samples were analyzed using a Perkin Elmer atomic adsorption spectroscope with a graphite furnace. The concentrations of these elements were determined using standard calibration curves from a series of different standard concentrations for each element. A blank sample was prepared using de-ionized distilled water acidified by concentrated nitric acid and treated like the previous samples. The concentrations of the heavy metals in the water samples are listed in Table 2.

Table 1. *Measured water quality parameters.*

Parameters	**TDS (g/L)**	**Salinity (‰)**	**EC (mS/cm)**	**TSS (mg/L)**	**COD (mg/L)**	**Calcium (mg/L)**	**Magnesium (mg/L)**	**Chloride (g/L)**
Concentration	40.9	39.1	57	526	12.5	725	1210	21.3
Parameters	Nitrate (µg/L)	Ammonia (µg/L)	Silica (mg/L)	Nitrite (µg/L)	Sulfate (g/L)	pH	Orthophosphate (µg/L)	
Concentration	45	325	1.25	5.5	3.5	8.15	57.5	

Table 2. *Concentrations of heavy metals in water samples.*

Parameters	**Cadmium µg/L**	**Copper µg/L**	**Manganese µg/L**	**Lead µg/L**	**Iron µg/L**	**Zincc µg/L**
Concentration	1.91	7.5	51.6	12.6	255	95.6

2.2.3. Organic Pollutants

The total polyaromatic hydrocarbons were measured using the UNEP analysis method (1984). The pollution analysis of the total petroleum hydrocarbons (TPH) showed a value of 55 mg/L.

2.2.4. Meio Fauna

It was found that the benthic community at this site consisted of three phyla: Annelida, Arthropoda, and Mollusca. Numerically, Annelida and Arthropoda had the same percentages (36.36%) of the total benthic community at this site, followed by Mollusca (27.27%).

Regarding the biomass, the collected species contributed a total of 15.084 GFW/m², with Mollusca having the largest weight, constituting 95.03% of the total weight, followed by Annelida (4.47%) and Arthropoda (0.51%).

2.2.5 Fisheries

Fisheries are important sources of income in the study area. In the Idku district, approximately 10% of the population depends on marine and freshwater fisheries. In the town of Meadia and its surrounding villages, the proportion is 50%. Marine fishing is very important in Meadia. There are more than 270 boats registered in the Meadia fishing port. Fish catches rose from 1,500 tons in 1984 to approximately 11,500 tons in 1996. Fishing in various forms occurs extensively in the area of the proposed export pipeline route. The fishing activity appears to involve a variety of methods, including trawling, purse seiners, gill nets, and surface long liners. The type that poses the greatest hazard to the pipeline is trawling, because this is carried out using a sac-like net with two clump weights attached close to the ends of the net, which is dragged along the seabed. The other types are associated with mid-depth and surface fishing and will not influence the pipeline.

2.3. Process Description

The proposed offshore development well will be drilled to 11000 ft TVDSS. In the drilling process, a considerable amount of drilling mud (water-based mud) will be used to lubricate the drill string, cool the rotary drill bit, carry the rock cuttings/fines from the well bore to the surface, inhibit the entrance of undesirable formation fluids into the well bore, and control excessive pressure in the well bore to prevent blowouts. The cuttings will be transferred by boat in isolated boxes from the rig to an onshore base and then by a truck to a contractor's base, where they will be processed by the contractor's treatment facilities to make them environmentally safe. Water for preparing the mud and fresh water for drinking and accommodations will be supplied from a well base by workboats.

3. Environmental Impacts

The significance of the impacts will be determined to ascertain whether they are acceptable, require mitigation, or are unacceptable to the community. The significance of an impact is determined by considering its characteristics and the values attached to them. The significance can be determined based on ecological importance, social importance, and environmental standards. The significance of the impact from any of the activities is based on the following factors:

i. The possibility of environmental damage (certain, probable, uncertain), and
ii. The scope of the impact (minor or no impact), the possibility of rehabilitating the environment after the occurrence of the damage, and the continuity of an impact (temporary, permanent).

These factors can be used to assess the impact in a scientific manner, with the result showing one of two possibilities: no impact or minor impact.

3.1. Air Quality

There are numerous emission sources affecting the offshore atmosphere as a result of the project activities, including marine vessels, the machinery and equipment of the rig (e. g., generators, cranes, and compressors), and well testing. Atmospheric emissions from these sources comprise carbon dioxide (CO_2), methane (CH_4), nitrogen oxides (NO_X), sulphur dioxide (SO_2), carbon monoxide (CO), and volatile organic compounds (VOCs). Table 3 lists the environmental impacts of these emissions.

The emissions from marine vessels are expected to be relatively low, notably because the emission sources are mobile, and the durations of these emissions are relatively short. It is believed that these emissions would be readily dispersed over a wide area. Hence, the significance of the impact associated with emissions from marine vessels is considered to be low.

The emissions from the machinery and equipment of the rig (e. g., generators, cranes, and compressors) are also expected to be relatively low considering the periodic maintenance of this equipment and machinery, and these emissions would be readily dispersed over a wide area. Hence, the significance of the impact associated with emissions from machinery and equipment is considered to be low.

The flow testing technique for well testing is associated with the generation of significant volumes of well fluid. The fluids produced will be flared using a low-emission burner boom with auxiliary air injection. These flares are installed on cantilevers, and seawater spray systems are used to reduce the heat radiation effects on the rig. The key advantages of using these burners are their smoke free and fallout free operation, which has minimal environmental impact, and their ability to efficiently burn all types of oils, including heavy crude oils. The main sensitive receptors that could be potentially affected by the atmospheric emissions associated with the proposed drilling activities include: sensitive human resources, air quailaty in and around the proposed drilling sitr, and air quality in the coastal zone.

The highest concentrations of emissions at and near the rig would be expected during hydrocarbon flaring events after well testing, and minor localized reductions in air quality could be expected. It is expected that wind and natural atmospheric circulation would rapidly disperse these emissions. Because of the short-lived nature (24–36 h) of these flaring activities and the rapid/comprehensive dispersion of the emissions, adverse effects on the health of the rig and vessel personnel in the area are not anticipated. Marine fauna are not expected to be at risk from the atmospheric emissions generated, and it is expected that the sea level concentrations at the drilling site would be below harmful levels. The considerable distance of the offshore drilling operations from the sensitive receptors on the shore/coastline means that no deterioration in onshore/coastal air quality is expected. Overall, because the atmospheric emissions would be readily dispersed, the significance of the impacts on the offshore atmosphere resulting from the release of emissions during these activities is considered to be "low."

Table 3. *Environmental impact assessment of emissions.*

Emission	Environmental Impact
Carbon dioxide (CO_2)	A green house gas that contributes to climate change.
Methane (CH_4)	Contributes directly to climate change by enhancing low level ozone production. Poisonous at high concentrations and can potentially enhance photochemical smog formation.
Carbon Monoxide (CO)	Contributes indirectly to climate change by enhancing low level ozone production. Highly toxic to human health at concentrations of several percent and can augment photochemical smog formation.
Nitrogen Oxides (NOX)	NO_2 is a toxic gas, even at relatively low concentrations. NOx also contributes to the formation of acidic species, which can be deposited by wet and dry processes. Acidic species may impact both freshwater and terrestrial ecosystems. NOx augments the formation of ozone at ground level when mixed with VOCs in the sunlight atmosphere. NO is a relatively innocuous species, but is of interest as a precursor of NO_2.
Sulphur Dioxide (SO_2)	SO_2 is a toxic gas, and is known to contribute to acid deposition (wet and dry), which may impact both freshwater and terrestrial ecosystems. It has direct health effects that potentially cause respiratory illness.
Volatile Organic Compounds (VOCs)	The non-methane VOCs associated with the proposed development are anticipated to be predominately hydrocarbons, which play an important role in the formation of photochemical oxidants such as tropospheric ozone. Many are also known or suspected carcinogens.

3.2. Water Quality

Numerous drilling activities have been assessed as having potential environmental impacts on seawater and seawater biology (i. e., plankton, fish, marine flora, marine mammals, and seabirds). The categories/impacts considered in the seawater and seawater impact assessment included aqueous discharges to the sea of drill cuttings and drilling fluids; and water-based mud drill stem tests**.**

Discharges of sewage effluents can result in localized organic enrichment near the discharge point, which may result in oxygen depletion in the discharge plume, resulting in some minor disturbance to the marine ecosystem close to the point of the discharge. If properly operated, it is expected that the anaerobic digestion of the effluents carried out on the offshore rig marine sanitation units would reduce the BOD. Water currents would also assist in the dilution and dispersion of the discharged material, and would eventually restore the oxygen and nutrient levels to the background conditions. The impacts on marine water quality and marine organisms are therefore considered to be of “low” significance.

Because of the small volumes of cement discharged to the environment from the proposed activities and the low toxicity of the mixed cement materials, the environmental impact of cement usage and discharge has been assessed to be of “low” significance.

If the bilge and drainage water (from both the drilling rig and vessels) has been treated properly, this discharge would therefore contain very low levels of oil and would be readily dispersed after its discharge. In this case, the impacts on marine water quality and marine organisms from bilge and drainage water are considered to be of “low” significance.

The flaring of hydrocarbon products is a very rapid process with test flaring expected to last for approximately 24–36 h. Hydrocarbons would be burned using a “low emission burner,” which is a proven high efficiency burner. Given these factors and the short-term nature of the above testing process, it is expected that a very small amount of dropout will be associated with the well-testing process, especially with the proper implementation of an effective maintenance program. Consequently, the associated impact is expected to be of “low” significance.

The impacts of the cutting discharge from the drilling rig would be minimized because of the relatively high water depth in the drilling area (i. e., 98 ft). The main factors that affect phytoplankton production are light and nutrient availability. The presence of a turbid plume in association with the mud and cutting discharge process, which would reduce light penetration into the primary production zone, could result in a reduction in phytoplankton production. This in turn would lead to a reduction in nutrient uptake. The reduction in phytoplankton production rates would only persist as long as a turbid plume was present and would only be observed where the turbidity was the greatest; that is, close to the point of discharge. Because unused nutrients would remain in the water column and would still be available after plume dilution, the production rates would be expected to eventually return to normal.

The acute toxic effects of drilling fluids on marine organisms are mainly found at high concentrations. The toxic effects on water column biota would normally be present within a few tens of meters from the point of discharge and only for a short period after discharge. Discharged drilling fluid and cuttings contain concentrations of metals that have been the subject of extensive bioaccumulation and toxicity studies. These have reliably established that the metals in drilling mud have a limited bioavailability to marine organisms because of their composition and fixation in the matrix of the minerals present. A limited food chain transfer of the metal barium may occur, but this transfer is so small that a biomagnification of barium in the marine food chain is unlikely and has not been recorded. Zooplankton is likely to be physically affected by increased turbidity as a result of the cutting discharge. However, the plume is expected to disperse quite rapidly because of the high water depth at the proposed area. Fish could also be affected in the vicinity of the plume by the large quantity of sediment, which may cause irritation by abrading their protective mucous coating and thereby increasing their susceptibility to parasites, bacteria, and fungal infections. Suspended sediment may also reduce their visual acuity, and hence feeding behavior, and may reduce their respiration efficiency as a result of blocking their gills. Other species (e. g., marine mammals) would be expected to exhibit avoidance behavior in response to increased turbidity. In general, the impacts on the seawater quality and seawater biology resulting from the discharge of drill cuttings and fluids are therefore considered to be of “medium” significance.

Oil spills may occur during prospect testing, prospect blowouts, periodic equipment maintenance, generator fueling, etc…. Any oil spills or discharge of oily wastes without treatment will have short- and long-term effects on the existing marine ecosystems. Moreover, wind and surface currents can move the contaminants to distant areas. No sensitive areas will be affected by a limited spill. In the case of a large spill, the ecosystem in an area of approximately 3 km^2 will be affected.

3.3. Marine Life

There is a potential for impacts on the benthic flora and fauna as a result of the physical disturbance of the benthic habitats and deterioration in water quality (increased turbidity).

The main source of the impacts on benthic fauna will be the direct physical disturbance resulting from drilling activities. The benthic habitats and species associated with the seabed at the proposed well site will be directly affected by the drilling activities. In addition, the seabed will be affected by the deposition of suspended sediment, but the loss of or damage to benthic species will depend on the rate and degree of this deposition. The loss of benthic biomass may have a secondary effect on animals that feed on these species (birds, mammals, fish, etc). The direct impacts on the benthic community will affect localized individuals within the population of benthic species found in the study area. The loss of individuals will be caused by the direct physical disturbance. Therefore, the impacts are not likely to affect more than one generation (i. e., the disturbed areas will be recognized by other individuals). Therefore, the impacts are considered to be minor.

3.4. Noise

Noise will be generated during the equipment mobilization and primary installation activities. Higher levels of noise may continue during the initial phases of the drilling activities and abandonment of the well. The sound and vibration generated during drilling may lead to the repulsion of some fish species and other aquatic forms from the immediate vicinity of the drilling area, as well as affecting the workers.

Noise has an unavoidable impact because of the nature of the drilling. However, the impact on the environment would be limited because of the short period of the drilling activities. If the drilling proves to be successful, much lower sound levels will be encountered. Consequently, the fish and aquatic fauna will restock the area again, and workers will usually wear hearing protection.

3.5. Drilling Fluids

Water-based mud will be used as a drilling fluid, which will be dumped with its cuttings into the sea. Water-based mud is considered to be environmental friendly for offshore drilling, because it has a minor impact on the surrounding environment.

3.6. Collision Risk

The drilling rig is equipped with warning lights, foghorns, and other identification equipment, as approved by the Egyptian ports and lights authority. An up-to-date radio room is located on the drilling unit, with various marine radios, which monitor the international distress frequency 24 h per day for possible collisions. A radar unit is also provided. This unit is manned 24 h per day and tracks ships approaching within 12 nautical miles (nm) of the rig. Ships entering an area with a 5 nautical mile radius and appearing to be on a collision course are contacted by marine radio and asked to maintain a safe distance from the rig. If radio contact cannot be established, one of the two supply vessels will be dispatched to the scene to attract the attention of the vessel using a fire hose, ship horn, etc. This supply boat will try to establish radio contact with the approaching ship to divert it from its course and/or determine if the ship has mechanical difficulty. If no contact can be established and/or it has mechanical difficulty (engine/steering failure), the rig personnel will be ready to abandon operations and evacuate.

3.7. Socioeconomic Impacts

The main socioeconomic impacts considered in this study include the potential interference with fishing activities, potential interference with marine traffic, and employment.

The proposed drilling activities may result in a short-term site-to-local-area and low-magnitude impact on offshore fishing operations. The location of the proposed well is within the oil and gas concession area, which has limited importance for fishing activities. The impact on fishing activities associated with the proposed drilling activities is expected to be of “low” significance.

The offshore drilling activities will result in short-term, local, and low impacts on marine traffic activities associated with the presence and movement of the drilling rig, supply boats, etc. The impact on marine traffic activities associated with the proposed drilling activities is expected to be of “low” significance.

Usually, drilling activities employ a group of workers from the nearest areas. The presence of these work groups mandate extra manpower to satisfy their human needs such as food supplies, medical care and supplies, fuel, linen service, dry cleaning, sewage removal, and garbage hauling. There will be added job opportunities for such service contractors. These types of activities will create extra jobs, leading to an improvement in the socioeconomic status of the area.

4. Mitigation Measures

Mitigation measures will be adopted to minimize the potential negative environmental impacts from the different project stages. The detailed mitigation measures are presented in Table 4.

Table 4. *Mitigation measures.*

Mitigation measures		
	During construction	**During operation**
Air quality	Employ dust suppression measures. Prohibit waste burning on the site. All machines must be maintained and operated under the manufacturer's standards to ensure operational efficiency.	No routine venting will take place during the operations.
Water quality	The contaminated drainage must be treated with an oil/water separator. Waste from sewage/grey water must be treated to reduce the concentration of organic material prior to discharge. All solid wastes will be transported to shore for waste disposal. All vessels must comply with all of the requirements of MARPOL (the International Convention for the Prevention of Pollution from Ships). Prompt containment using floating booms and other means of recovery will be performed as a quick response to oil spills. Predictive mathematical models will be used to predict the direction of an oil slick based on the wind strength and direction, along with the surface water currents.	Produced water must be treated prior to discharge. Cuttings must be transported to shore. Solid wastes must be transported to shore for proper treatment and disposal. Flaring during testing will cease if an oil sheen appears on the sea surface. Small oil spills and leaks must be cleaned up using routine cleanup equipment. Prompt containment using floating booms and other means of recovery will be performed as a quick response to an oil spill.

Mitigation measures		
	During construction	**During operation**
		Predictive mathematical models will be used to predict the direction of an oil slick based on the wind strength and direction, along with the surface water currents
Marine life	Use the same mitigation measures as for water quality. Use the type of dredging machine that reduces the volume of suspended sediments produced. Use hoses for the disposal of dredged soils close to the seabed to reduce the generation of suspended sediments.	No need for specific mitigation measures
Noise	Use equipment and procedures that minimize noise.	No need for specific mitigation measures
Drilling fluids	The use of chromium lignosulfate and asbestos in drilling fluids will be avoided. Barite with a very lowest concentration of heavy metals will be used to confirm that mud waste is environmentally safe. Closed circulation system for the drilling mud.	No need for specific mitigation measures
Socioeconomic	Create an exclusion zone around the platforms. Adhere to international maritime regulations to reduce risks of interference and collisions with other vessels. Save the facility and use safe working systems. Use equipment and procedures that minimize noise.	Make an exclusion zone around the platforms. Adhere to international maritime regulations to reduce risks of interference and collisions with other vessels. Vessel trips must be limited to maintenance operations only. Save the facility and use safe working systems.

5. Environmental Risk Assessment

The risks associated with the mobilization and installation of the rig and its operational support facilities will be addressed to minimize these adverse impacts on both the surrounding environment and the working staff. The environmental profile for the site indicates that vulnerable natural resource sites are located near the shore and not likely to be directly impacted by the drilling activities under consideration. However, the hazards from spills are covered by Abu Qir's formulated oil spill contingency plan. The general strategy that has been adopted to minimize any adverse impact on the marine environment is as follows:

i. Minimal use of hazardous materials in the drilling fluids,
ii. Near zero discharge of effluent from the drilling operation,
iii. Safety measures against accidental discharge, and
iv. Monitoring activities to ensure that no contamination occurs.

Table 5. *Environmental management plan.*

Activities	Environmental management
Drilling fluids and drilled cuttings	Minimizing environmental hazards related to residual chemical additives in discharged cuttings by the careful selection of the fluid system. Careful selection of fluid additives, taking into account their concentration, toxicity, bioavailability, and bioaccumulation potential. Use of high-efficiency solid control equipment to reduce the need for fluid change out and minimize the amount of residual fluid on drilled cuttings. Use of slim-hole multilateral wells and coiled tubing drilling techniques, when feasible, to reduce the amount of fluids and cuttings.
Chemicals and mud	Use of chemical hazard assessment and risk management techniques to evaluate chemicals and their effects. Selected chemicals should previously have been tested for environmental hazards. Eliminate all unused chemicals or abandoned containers and do not dispose of them by dumping them into the sea. It is recommended that they be shipped to shore and disposed of in an environmentally safe way at the nearest specialized site or returned to the supplier; Reuse water-based mud while drilling and finally dispose of the mud with dispersants at the end of the job. A supply boat will be made available to immediately haul all hazardous chemicals, containers for the different chemical used, and domestic solid waste. The nearest onshore solid dumpsite can be used for domestic organic waste disposal.
Drilling operations	Provide safe residential facilities. Monitor the noise and vibration levels and maintain them below 80 dB. Monitor the bottom subsidence and take corrective measures for it during the planning, operation, and phase-out stages. Move the large equipment over the main roads used by different government authorities and according to the traffic regulations. Provide the best available technical safety for the equipment operators. Train the working staff on environmental obligations. Contractors should have the necessary contingency plans to address the recognized potential hazards associated with the project in order to minimize the risks to their staff before initiating drilling operations.
Spills	Conduct a spill risk assessment for the rig facilities and supply boats. Design the process, utility, and drilling systems to reduce the risk of major uncontained spills. Review the maintenance and monitoring programs for the rig facilities to ensure the integrity of the equipment. Provide adequate personnel training in oil spill prevention, containment, and response. Ensure that spill response and containment equipment is deployed or available as necessary. Develop a spill response plan, along with the capability to implement the plan. This spill response plan should address potential oil, chemical, and fuel spills from offshore rig facilities and supply boats.

6. Environmental Management Plan

An environmental management plan (EMP) is an implementation plan to mitigate and offset the adverse environmental impacts of the project and to protect and, where possible, enhance the environment. The EMP provides general guidance for implementing an environmental management program/plan for the proposed drilling activities. Drilling activities produce a variety of solid and liquid wastes. Some of these wastes are attributable to exploration and production activities (drilling wastes, produced water, and treatment and workover fluids), while others are due to either the human presence (sanitary wastes and food wastes) or generic industrial operations (wastepaper, scrap metal, used paints, and solvents). There is increasing international concern that wastes be properly managed in order to minimize their potential to cause harm to health or the environment. The environmental management procedures are presented in Table 5.

Table 6. *Monitoring program [19].*

Item	Phase	Monitored parameters	Frequency of monitoring
Gas produced	Operation phase	Quantity Carbon content NO_2 content CO_2 content	Daily
Gas vented	Operation phase	Quantity Carbon content NO_2 content CO_2 content	Daily
Gas flared	Operation phase	Quantity	Continuous
Sediment transport	Construction phase Operation phase	Rate Direction	Continuous
Solid waste	Construction phase Operation phase	Quantities and types of wastes generated. Final disposal for wastes	Continuous
Accidental hydrocarbon spills	Construction phase Operation phase	Amount of spilled material Type of material spilled	At each spill incident
Health and safety incidents	Construction phase Operation phase	Type of incident Reason for incident Mitigation measures taken to prevent similar incidents in the future	At each incident

7. Monitoring Plan

Environmental monitoring is essential and should be undertaken during the construction and operation phases of the project. Given the current (international and national) environmental regulations, the application of environmental monitoring tools is required to avoid, minimize, and mitigate the potential impacts arising from exploration and the production of oil and gas [2]. Environmental performance monitoring will be undertaken to ensure that mitigation measures are implemented and have the intended result. Additional remedial measures may be undertaken if mitigation measures are inadequate or the impacts have been underestimated, particularly where the project would be in breach of permits or Egyptian standards. The monitoring program is presented in Table 6.

8. Conclusions

Gas exploration and production operations have the potential for a variety of impacts on the environment. Thus, this paper discussed the nature and sensitivity of the surrounding environment, and pollution prevention, mitigation, and control techniques. With regard to the aquatic environment, the principal risks were linked to the presence of the offshore gas well and to the waste streams of drilling fluids, cuttings, well treatment chemicals, and produced water.

The case study involved a well located in Abu-Qir Bay (30°10′27.08"E and 31°34′27.42"N) in the Egyptian sector of the Mediterranean. It has a depth of about 28 m, and is approximately 23.6 km from shore. An environmental risk management study was conducted in compliance with the Egyptian Environmental Regulations (law 4 of 1994) and the executive regulations (no. 338 of 1995) amended by Prime Minister Decree no. 9/2009, along with the requirements of the Egyptian Environmental Affairs Agency EIA guidelines.

The study was designed specifically to support the future environmental management of the area and serve as a reference document for the life of the project. This assessment described the project operations and facilities, the current and proposed Egyptian environmental legislation, and the existing environmental features around the offshore well area. It evaluated the potential impact of the operations and identified the mitigation procedures to be followed in order to eliminate any risk of contamination. It provided a framework for the future environmental management of the area in order to minimize the negative impacts of operations. The findings from this study are as follows.

A. The positive impacts of the proposed well can be summarized as follows.
   1. It will add to the Egyptian oil reserves if it is a successful exploration well.
   2. It will provide employment opportunities.

B. Most of the predicted negative environmental impacts have low to negligible significance. The main adverse impacts are as follows.

1. The expected impacts of emissions from marine vessels, machinery, and equipment are considered to be relatively low.
2. Offshore airborne noise may disturb birds and marine mammals. However, upon the completion of the drilling activities, it is likely that birds and marine mammals would re-colonize back to their normal habitats.
3. The expected impacts of discharges of sewage effluents, cement usage, and bilge on the marine water quality and marine organisms are considered to be of "low" significance.
4. The main impacts on marine fauna and flora are the deteriorating seawater quality due to seabed sediment during the construction and the discharge of produced water during the operation. These impacts will be mitigated through a set of measures.
5. It was predicted that the impacts on the marine biology resulting from the discharge of drill cuttings and fluids would be of "low" significance if only water-based mud were used.
6. All of the garbage (paper, other burnable trash, food remains, and wet garbage) will be collected and transported to shore for disposal.
7. The main adverse socioeconomic impact is the interference with fishing activities during the construction phase.

C. The mitigation measures used to prevent and minimize the negative impacts of the project were presented.

D. Environmental performance monitoring will be undertaken to ensure that the mitigation measures are implemented and have the intended result.

References

[1] Zhenhai, X., and Longwei, W., (2002). "Index system study of risk investment project evaluation" *Journal of Zhongyuan University of Technology*, Vol. 1, pp. 44-47.

[2] Maggi, C., Trabucco, B., Mannozzi, M., Manfra, L., Gabellini, M., Di Mento, R., Nonnis, O., Virno Lamberti, C., and Cicero, A. M. (2007). "A methodology approach to study the environmental impact of oil and gas offshore platforms." Rapport de la Commission Internationale pour l'Exploration Scientifique de la Mer Méditerranée 38, 688.

[3] Badiru, A. B., and Osisanya, S. O., (2016) Project Management for the Oil and Gas Industry., CRC Press.

[4] Cicero, A. M., Di Mento, R., Gabellini, M., Maggi, C., Trabucco, B., Astori, M., and Ferraro, M. (2003). "Monitoring of environmental impact resulting from offshore oil and gas installations in the Adriatic Sea: preliminary evaluation." *Annali di Chimica*, *Journal of Analytical Environmental and Cultural Heritage Chemistry,* Vol. 93, No. 7-8, pp. 701- 705.

[5] Trabucco, B., Maggi, C., Virno Lamberti, C., Bacci, T., Marusso, V., Vani, D., Gabellini M., and Cicero, A. M. (2006). "Marine benthic assemblages around a gas platform (Central Adriatic sea)." Coastal Innovations and Initiatives - Proceedings Littoral, pp. 39-46.

[6] Terlizzi, A., Bevilacqua, S., Scuderi, D., Fiorentino, D., Guranieri, G., Giangrande, A., Licciano, M., Felline, S., and Fraschetti, S. (2008). "Effects of offshore platforms on softbottom macro-benthic assemblages: a case study in a Mediterranean gas field." *Marine Pollution Bulletin*, Vol. 56, pp. 1303-1309.

[7] Manoukian, S., Spagnolo, A., Scarcella, G., Punzo, E., Angelini, R., and Fabi, G. (2010). "Effects of two offshore gas platforms on soft-bottom benthic communities (northwestern Adriatic Sea, Italy)." *Marine Environmental Research*, Vol. 70, No. 5, pp. 402-410.

[8] Boesch, D. F. and Rabalais, N. N. (1987). Long-Term Environmental Effects of Offshore oil and Gas Development, Elsevier Applied Science, London, UK.

[9] Middleditch, B. S. (1981). Environmental Effects of Offshore Oil Production: The Buccaneer Gas and Oil Field Study, Marine Science, Plenum Press, New York, USA.

[10] Patin, S. (1999). Environmental Impact of The Offshore Oil and Gas Industry, Elena Cascio (Translator). East North Port, NY: EcoMonitor Publishing.

[11] McCrary, M. D., Panzer, D. E., and Pierson, M. O. (2003). "Oil and gas operations offshore California: status, risks, and safety." *Marine. Ornithology*, Vol. 31, pp. 43-49.

[12] Milne, A. R., and Smiley, B. D. (1978). Offshore Drilling in Lancaster Sound: Possible Environmental Hazards, Department of Fisheries and Oceans, Sidney, BC.

[13] Hansen, A. M., Olesen, P., Mortensen, L., Hristova, K., and Welsch, K. (2017). Why cumulative impacts assessments of hydrocarbon activities in the Arctic fail to meet their purpose. *Regional Environmental Change*, Vol. 17, No. 3, pp 725–737.

[14] OSPAR (2009). "Assessment of Impacts of Offshore Oil and Gas Activities in the North-East Atlantic." OSPAR Commission, London. Publication number 453/2009.

[15] Gomiero, A., Spagnolo, A., Biasi, A. De, Kozinkova, L., Polidori, P., Punzo, E., Santelli, A., Strafella, P., Girasole, M., Dinarelli, S., Viarengo, A., Negri, A., Nasci, C., and Fabi, G. (2013). "Development of an integrated chemical, biological and ecological approach for impact assessment of Mediterranean offshore gas platforms." *Chemistry and Ecology*, Vol. 29, No. 7, pp. 620-634.

[16] Elvin, S. E., and Fraser, G. S. (2012). "Advancing a national strategic environmental assessment for the Canadian offshore oil and gas industry with special emphasis on cumulative effects." *Journal of Environmental Assessment Policy and Management*, Vol. 14, No. 3, pp. 1-37.

[17] Hernández, L. E. V., Romero, I. P., Soto, L. A., and Arriaga, E. R. (2012). "Legal framework for the offshore operations of the Mexican Oil Industry from a systemic environmental perspective." *Ocean & Coastal Management,* Vol. 58, pp. 9-16.

[18] Emelyanov, E. M., Lisitzin, A. P., Shimkus, K. M., Trimonis, E. S., Lukashev, E. S., Lukashin, V. N., Mitropolskiy, A. Yu., and Philipchuk, M. F. (1978). "Geochemistry of Late Cenozoic sediments of the Black Sea", Leg 428. in: Initial Reports of the Deep Sea Drilling Pro-ject, 42, Part 2, 543-605.

[19] Elbisy, M. S. (2016). "Environmental Management of Offshore Gas Platforms in Abu Qir Bay, Egypt." *KSCE Journal of Civil Engineering*, Vol. 20, No. 4, pp. 1228-1241.

[20] Fanos, A. M. (1996). "Wave Climate along the Mediterranean Egyptian coast." Technical Progress Report No W1. Coastal Research Institute, Egypt.

[21] Mullin, J. B., and Riley, J. B. (1955). "The spectrophotomctric determination of nitrate in natural waters with particular refrence to seawater." *Anal. Chim. Acta.,* Vol. 12, pp. 464-480.