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# A Review on the Environmental Issues in Jeddah, Saudi Arabia with Special Focus on Water Pollution

Saleh Faraj Magram
Department of Civil Engineering, Faculty of Engineering,
King Abdul Aziz University, P.O. Box 80204, Jeddah 21589, Saudi Arabia

**Abstract:** This study seeks to compile data on environmental issues in Jeddah, which is the most significant commercial city in Saudi Arabia, through a comprehensive review of the available studies. The growth of the city of Jeddah over the last fifty years and particularly in the last thirty has been rapid and diverse. Due to lack of proper care, unfortunately the development activities were accompanied by environmental degradation. Today there are many integrated management issues that relate not only to water, but also the air, land and the marine resources of Jeddah. This study systematically compiled data on environmental issues in Jeddah. Special focus was given on the water issues. It became evident through the review of the available past studies and recommendations that a significant problem in solving the environmental issues is related to the issues of integrated environmental management. Some actions that should be considered in order to resolve the high priority issues were proposed.

**Key words:** Environment, Jeddah, pollution, review Saudi Arabia, water issues

## INTRODUCTION

Jeddah is the most significant commercial city in the Kingdom (CIA, 2008). The growth of the city over the last fifty years and particularly in the last thirty has been rapid and diverse. The earliest establishment of Jeddah as a coastal settlement and transit point for eastern trade has not been dated clearly but there probably was some type of settlement 2500 years ago (Saudi Network, 2008). Figure 1 shows the location of Jeddah within Saudi Arabia. Significant changes have been taking place over the last city 50 years and particularly since the 1960's. In the development of the city, many activities took place without a strong concern about the environment.

It is notable that there although already has been certain studies to identify the extent of the environmental issues in Jeddah by different agencies, much of the work that has been done is still not comprehensive or technical enough for immediate use for engineering activities or environmental/social/economic assessments (MEPA, 1994). The results of the short projects do not present all the data required to solve the issues.

In view of the above-mentioned deficiencies, this study seeks to compile data on environmental issues in Jeddah. Through a comprehensive review of available studies done on the environment of Jeddah area the important environmental issues were identified. These were grouped according to the resource base: water, air, land and marine. The management issue was also addressed. In this study special focus was given on water pollution. Descriptions include: the present status; the trends that are occurring is it growing rapidly; the number of people affected; the severity of the issue in terms of health and safety; the severity in terms of economic costs to the community; what is known about the issue and what actions have been taken or recommended.

Fig. 1: Location of Jeddah. (a) Map of Saudi Arabia, (b) Enlarged view of location of Jeddah (Adapted from CIA, 2008)

## DEVELOPMENT AND ENVIRONMENTAL ISSUES

The past development patterns of Jeddah greatly influence the conditions that face the management of the city and the environment today. Significant changes have been taking place over the last 50 years and particularly since the 1960's. Perhaps the most notable factor that has influenced the growth of Jeddah is the increase in supply of fresh water (Haddadin, 2002), favoring population growth. Prior to 1287H (1970 G) when the first plant was installed (Kindasa), water from the natural sources of wells and cisterns was limited and expensive. This factor probably limited population and commercial growth of Jeddah.

Since, 1962 Jeddah has expanded and continues to expand at an unpredictable rate. For instance, during the development of the long range plan in 1390 H (1970 G), the Municipal Planning department predicted that the population would reach to 1.5 million people by the year 1995, while in fact it reached over 2 million people by 1994. Jeddah covered approximately 1200 $km^2$ at that time. The growth continues to date (Saudi Network, 2008).

Today there are many integrated management issues that relate not only to water, but also the air, land and the marine resources of Jeddah. Growth is also occurring outside of Jeddah that impacts on the resources of the, municipality. Water management however is still the most significant issue and the most complex (Abderrahman, 2000).

### Environmental Concerns

Concerns about the environmental quality of the city are relatively new. Unfortunately, the development activities were accompanied by environmental degradation. Jeddah has been extended in a north/south pattern with most of the residential areas in the north and the industrial areas to the south. The development has also extended out into the sea along the reef flats to utilize the attractive coastal areas for the Corniche and residential areas (Loya, 1975). The impacts of development have been to alter the natural drainage, to restrict the possibilities of the development of municipal services such as sewers and to create a pattern of travel that has a flow of people from one direction (the north) to the central business areas and the industrial areas of the south. With the greater number of people and the physical growth of the city (now 1500 $km^2$), issues of environmental quality and the relationship with the economics of managing a major urban city are being recognized .

**General Environmental Issues**

It is recognized that impacts from one activity are not independent of the impacts form other activities. Resolution of one impact or environmental issue does not always result in a complete solution. In metropolitan areas this becomes more evident due the multiplicity of issues.

In any developing city, there are other environmental management issues: solid and hazardous waste disposal; air quality deterioration; natural hazards such as flooding and coastal management. As indicated water management is perhaps the most complex of theses issues for Jeddah. There are many needs; servicing of a large population with domestic and industrial water supply; treating and disposing of sewage; draining of water from both natural and man-made sources and managing a major marine environment for commercial and recreational uses. All of this effort is done to provide people with a healthy and safe environment at a reasonable economic and social cost.

**Waste Management**

The issues of waste management are somewhat similar to the issues of water management-several interrelated issues with a core priority problem (hazardous waste). Less known about the hazardous waste issue yet the dynamic waste management activities are not in themselves seen as a major problem. The other waste issues are smaller in scope and are of lower priority. Present management activities are generally handing the problems (Dincer, 2000). Any plans of action for these other waste issues should consider the relationship to hazardous waste management.

**Hazardous Waste Management**

This issue is occurring throughout the kingdom. MEPA (Meteorological and Environmental Protection Administration) is presently developing a program that will eventually lead to a national level strategy to deal with these wastes. Basic to the management of these types of waste is a comprehensive inventory of what is being produced, quantities etc. in addition the establishment of standards is needed in order to evaluate various alternative solutions. This action is presently being taken and will be applied to Jeddah. It is essential that MEPA coordinators with the municipality and the industries in this respect (MEPA, 1994).

It is not clear as to the next steps in developing solutions to the issue. The principles to follow include: the sharing of information, (using the coordination office in the municipality for example); ensuring that a process is defined that will go beyond simply doing an inventory and ensuring that the other aspects of waste management are considered i.e., the program is dealt with in framework of boarder waste management. Integral to the development of the program is the integration of the information requirements that will be needed o complete EIAs. Thus the data design and collection and the decision-making process to develop alternative means of resolving the issue, should recognize that an EIA will be required for the development of any future waste disposal sites.

**Air Quality**

Two significant sources of air pollution are impacting on the health of people and environment of the city (Osman, 1997; Stern, 2005). The stationary sources are of high priority for action. The sources include the Jeddah oil refinery, the desalinization plant, the power generation plant and several industries on the Jeddah industrial area. Other less evident and small scale activities influence neighborhoods in Jeddah. The second source is mobile including all forms of transportation. This is of lower priority for action within the context of this study but not in terms of national action (Dossing *et al*., 1994).

There have been actions taken to reduce the levels pollution from the stationary sources but the results are poor. In terms of mobile sources the issue is national in scope and is being dealt with there.

For the stationary sources, the technology is available. Compliance to standards does not take place (Ahmed, 1990). Until the industries comply the situation will not improve. Actions that will continue are monitoring of the air quality and continuing pressure on the industries. New industrial developments should be restricted to well define areas in the city and should be using the most up-to-date technology.

## WATER ISSUES

### General Situation

The water balance in the Jeddah area that is the supply, use and removal of water, has changed rapidly with the growth of Jeddah. In the early history of Jeddah water was a very scarce and expensive commodity (MEPA, 1994). The natural environment through rain and ground water could not supply the needs. Over the last years significant infrastructure has been established to provide residents throughout city with dependable water supply. Today, however, increased volumes and mixed contents of the water used in Jeddah that must be disposed of, is greater than the environment's natural ability to remediate it (Haddadin, 2002).

The supply of fresh water to the area comes from the desalinization of sea water from both the large plant and many smaller facilities and from the natural supplies of rain in the watershed east of Jeddah (Abderrahman, 2000; Magram and Azeem, 2008). The disposal of large volumes of used and often polluted water through natural drainage and man-made engineering works is difficult and expensive to mange (Hussain and Al-Saati, 1999). The local geological structures and natural channels that had in the past handled the natural runoff have been altered significantly by human settlement and filling and groundwater, the city storm water drainage and sewer systems and the marine environment. This in turn has had cumulative on the natural, social and economic environment of Jeddah.

Past and present disposal of natural and used water from domestic and industrial users has created unacceptable conditions in downtown Jeddah and along the marine areas (Gladstone *et al*., 1999). It is now expensive to fix these conditions. With continued urban expansions, future disposal plans need to be made organizing the earlier problems encountered. There must be anticipation of new environmental and socio-economic consequences of developmental decisions.

### Arbaeen Lagoon

#### Issue

The issue at Arbaeen lagoon is well known (Loya, 1975). The lagoon has been receiving large amounts of sewage for along period of time and has not been able to assimilate it naturally (Fig. 2). The lagoon is relatively closed, (more so since the bridge has been constructed) thus, there is a slow exchange of water with the sea. This situation results in low oxygen content in the water. Marine life in the Lagoon can not exist and the high potential of the area as an attractive and valuable resource is negated, in addition, this lack of oxygen does not allow any of the material entering the lagoon, sewage or other decaying matter, to biodegrade naturally (MEPA, 1994). The result has been a build up of sludge; this volume of material has further reduced the exchange of water and oxygen in the lagoon. The end result of all these circumstances is the continuous generation of odors and the creation an unhealthy environment (Jones *et al*., 1998).

Many solutions have been proposed by Gladstone *et al*. (1999). The general problem is that the resolution of this odor issue is highly related to the resolution of other water management issues particularly the sewage treatment system for entire city. Actions are being taken to eliminate present sewage dumping in the lagoon but these measures are expensive and should probably be done in the broader and longer term context of sewage treatment for the entire city.

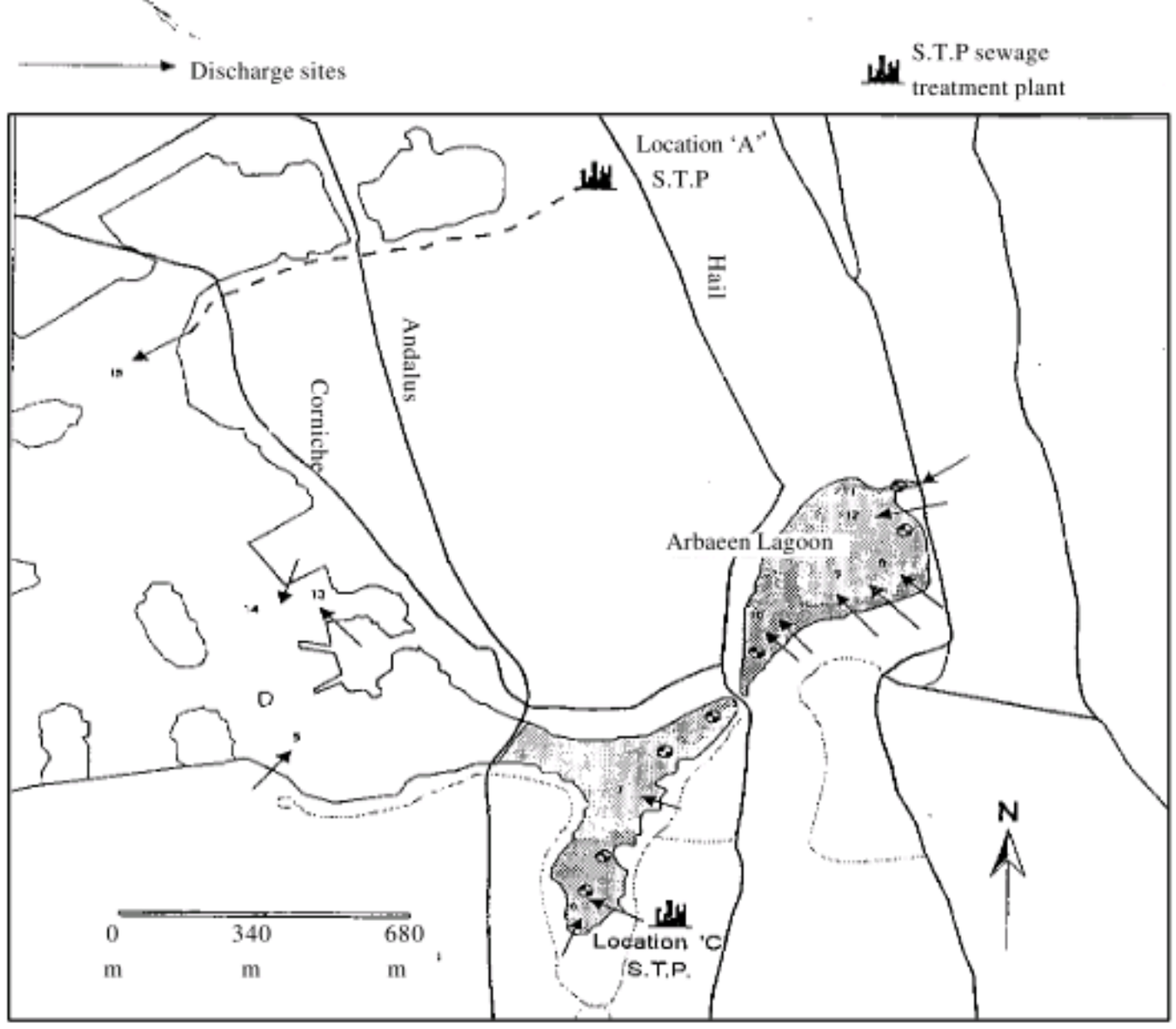


Fig. 2: Sewage discharge sites around Arbaeen Lagoon (adapted from Haddadin, 2002)

To relieve the present problem of bad odors the following measures may be taken : to eliminate the raw sewage from the present sewage discharges; to improve the water quality of the lagoon and to resolve the future problems of the sludge. In the long run it may also be desirable to increase the natural exchange of water in the lagoon improves the total value of this unique area in the center of the city.

**Sewage Treatment**

**Issue**

The existing capacity for sewage treatment, collection and disposal can not handle the present volumes (Alaboud and Magram, 2008; Azeem and Magram, 2008). Facilities are working over their design capacity (Fig. 3). Raw sewage is being dumped into areas such as Arbaeen Lagoon resulting in the unacceptable odors in the central business district. It is also suspected that other sources of sewage caused by back-ups and flooding are ending up in the storm water drainage system and eventually into the harbour area. This too may be a secondary source of odors along the Cornich and downtown areas.

New developments in the northern part of the city are not being hooked up with the sewage system so that removal by pumping to trucks and on-site disposal or treatment is the only alternatives (MEPA, 1994). In some cases for residences and commercial developments along the coast, there is direct dumping into the sea. There are continues occurrences of flooding due to backups of the sewage in turn gets into the other storm drainage system and eventually the sea. Odor problems develop in many areas of the city.

In the industrial areas, there is an industrial waste water treatment plant (Abderrahman, 2001). It was not designed to handle the types of waste generated by the many and varied industries (>400

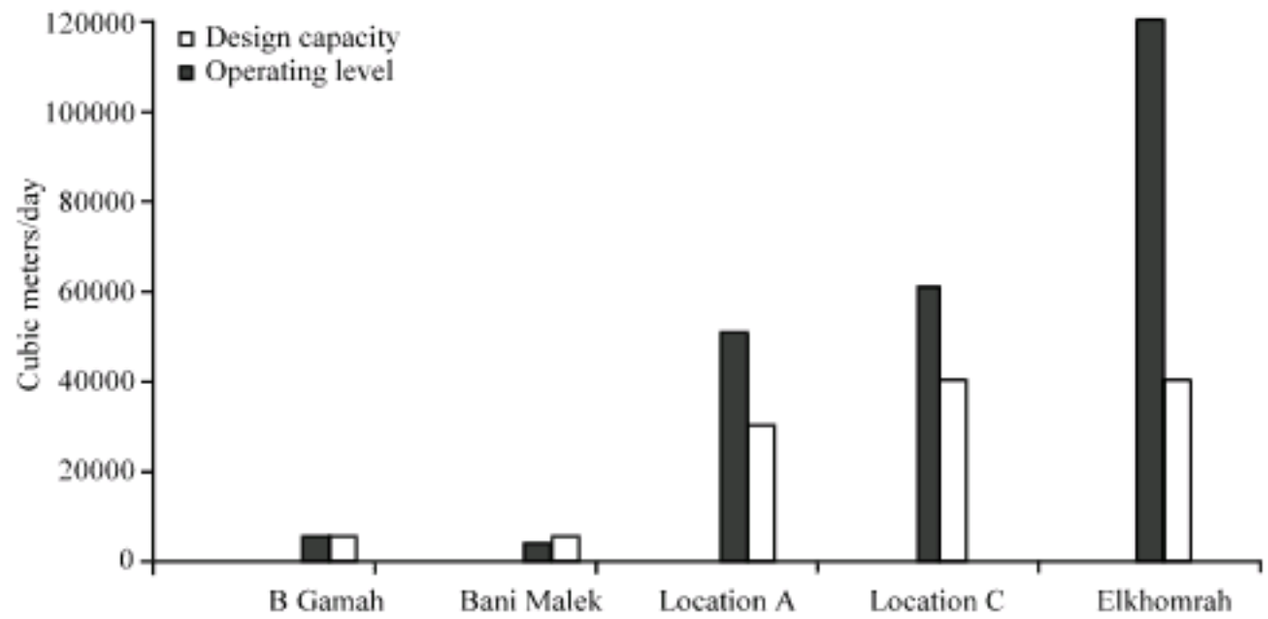


Fig. 3: Sewage treatment facilities working over their capacities (adapted from Azeem and Magram, 2008)

industries in the Jeddah industrial city). There is also a problem generated at the S.T.P.s when industrial waste is brought to these facilities. The operation of the S.T.P becomes ineffective when non-biodegradable organic compounds are disposed of through these aerobic systems.

There are also problems of developing new S.T.P facilities in the areas that need them (Alaboud and Magram, 2008). In North Jeddah, even if there was a treatment plant in place, the disposal of treated material to the sea is hindered by the intensity of shoreline development. Land owners in the area would not like to see treated sewage disposed next to their residential or commercial developments.

There have been several recommendations made to resolve the issue in Arbaeen Lagoon area. Stopping the discharge of sewage into Lagoon is the first step. Likewise for the reminder of the coast, the owners of sources of discharges are being identified and notifications to stop are being sent. It is still unknown at this time as to what are the best ways to resolve the entire issue regarding odor and water quality in the lagoon area. Plans are being developed and implement to deal with the sewage capacity problems in the city however these require time to implement and significant financial expenditures.

**Sewage Removals and On-Site Treatment**

**Issue**

A significant area (approximately 66% of Jeddah) does not have access to central sewage treatment facilities (Fig. 4, 5). Much of the area is located in the northern part of Jeddah (MEPA, 1994). Sewage is collected in on-site tanks or vaults, picked up by truck and disposed of at collection lakes to the northeast of Jeddah or simply in the desert. On site disposal occurs through deep wells, treatment through septic and leaching systems and through direct disposal in the sea. The problems that are arising include: the capacity of the present lake/disposal site has been reached and a new location is being developed near Briman; there is a rise in the level of the ground water in the area of north Jeddah believed to be the result of this supply of water and there is contamination of the ground water due to these disposal practices.

These conditions will tend to increase with population increases. It will affect the people in North Jeddah. With increase rises in the ground water, there will be salinization of the water affecting vegetation in the areas. The rise in ground water will reduce the effectiveness of any on-site septic and leaching facilities. As ground water continues to rise there is a greater potential for the problem to migrate to the central areas of Jeddah (Al-Jayyousi, 2003).

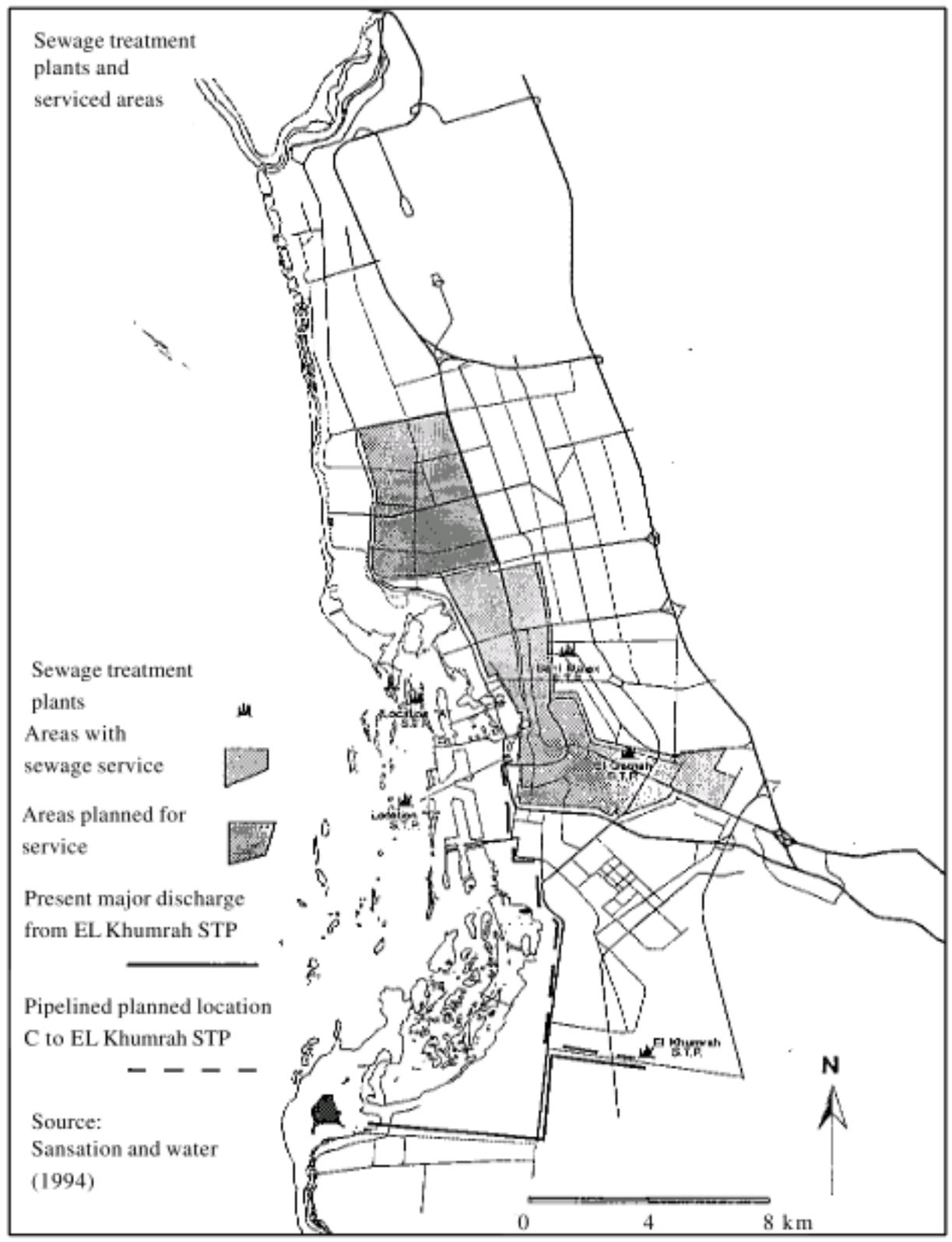


Fig. 4: Sewage treatment plants and serviced areas (adapted from MEPA, 1994)

**Desalinization Plants**

**Issue**

The desalinization of water creates several environmental issues. In terms of water issues, two main impacts are of concern, the impact on the marine ecosystems due to thermal pollution and the elevated levels of salt and chlorine in the return waters (Beaumont, 2000); these impacts vary with the volumes of water and the location where the discharge takes place, for example in shallow or deep water.

In Jeddah several desalinization plants are serving the general population and specific facilities (Abderrahman, 2000). The total volume of water produced and the actual locations of all the plants is not known but for example the Port Authority and Airport produce in total approximately 11 million gallons per day. The Jeddah Sea Water Conversion Company (SWCC-desalinization plant) supplies the largest volume of water, 384.000 cubic meters per day. The present consumption of water per capita in Jeddah is less than in Riyadh. It might be expected that with further diversification of

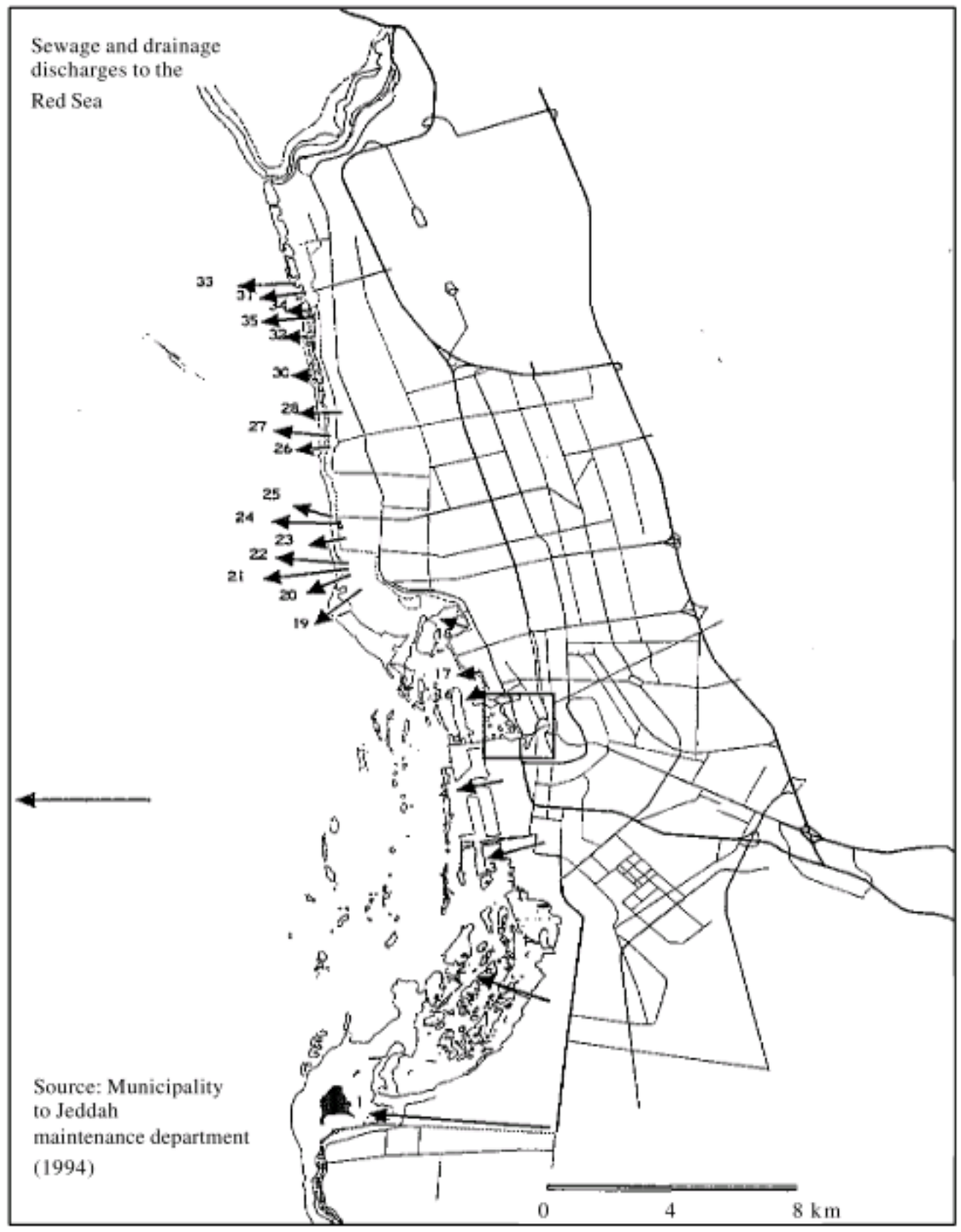


Fig. 5: Sewage and drainage discharges to the Red sea (adapted from MEPA, 1994)

industry in the Jeddah area increases in per capita growth will also increase the total consumption of water. This growth will result increased production needs from the plants and therefore may increase the impacts on the marine environment. Some initial work has been done on determining the impacts on the marine environment. Some initial work has been done on determining the impacts of thermal pollution but no conclusions were made (MEPA, 1994).

**Flooding and Storm Drainage**

**Issues**

Flooding due to the intensive thunderstorms in the region is a concern for both human safety and also economic coasts due to damage caused to private and public property and infrastructure. Food and drainage problem areas limit development or increase the coasts to develop and service. There will be a trend to develop more housing and industrial activities in these areas, such as Wadi Fatima, as demands for land in the city increase (MEPA, 1994).

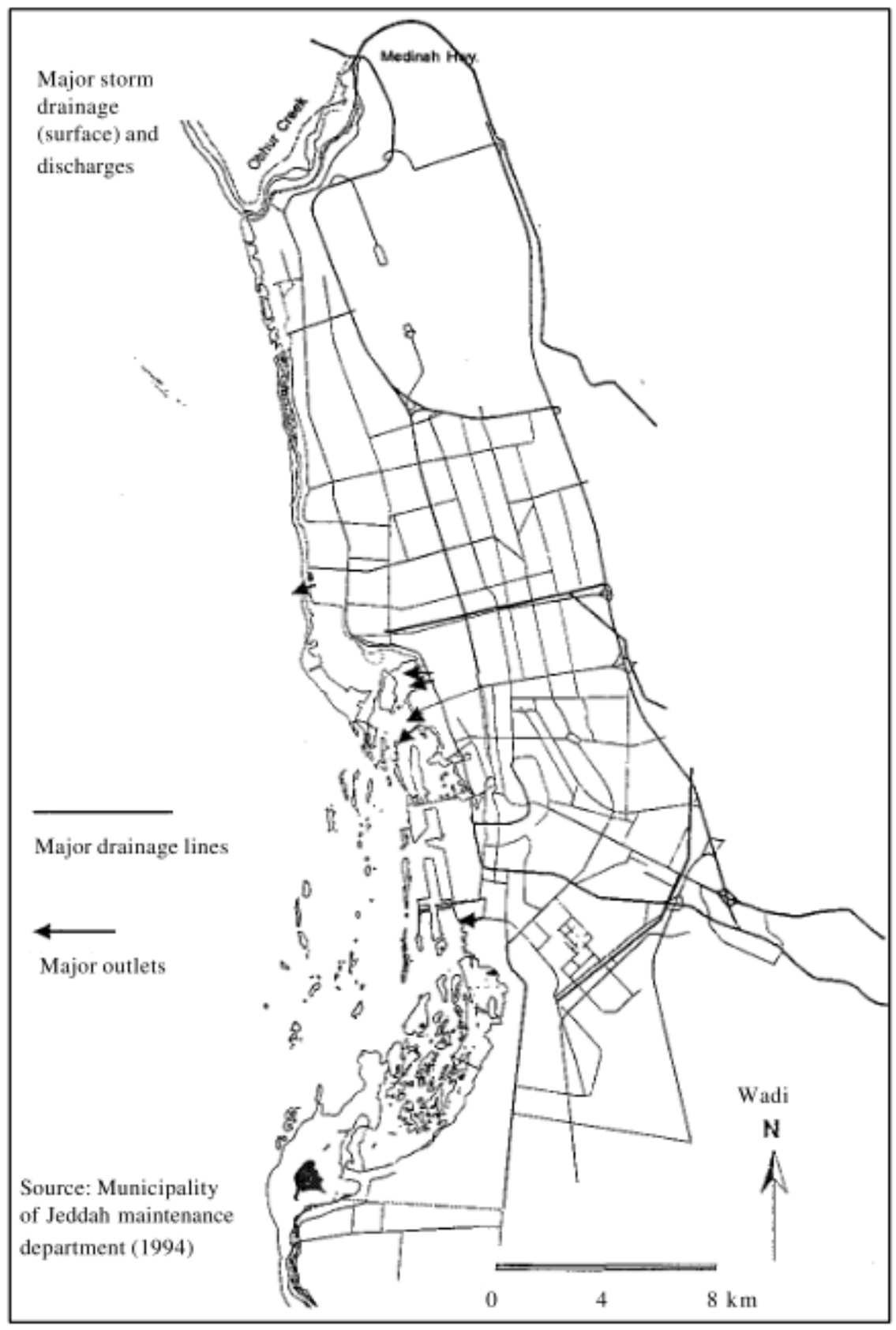


Fig. 6: Major storm drainage and discharges (adapted from MEPA, 1994)

There is a conflict between the natural drainage system through the municipal area and the pattern of urban development (Al-A'ama and Nakhla, 1995). As a result considerable canalization has had to be carried out of direct flood waters from developed areas and the transportation corridors (Fig. 6). There are interrelated problems with high ground water and sewage disposal, particularly with the deep wells, holding tanks and septic fields.

There are still areas that are regularly flooded in the developed areas of the city and in areas that could be developed if and when drainage projects are completed. Maintenance of the drainage systems is expensive and requires continuous operations. This is well defined in the reports prepared by the Municipal Engineering Department. There are some areas where development has occurred such that additional drainage works can not be provided. There are also developments that are occurring on flood prone areas. Filling flood plains and adding development may restrict flood water flows and can cause

problems in the upper water courses (For example a potential problem may develop at Obhur Creek and Medina Highway). Alterations of natural draining can also change fresh water and nutrient regimes in the marine, salt marsh and mangrove areas (Gladstone *et al*., 1999).

### Ground Water

#### Issue

The level of ground water in many parts of Jeddah is rising rapidly. In places it is less that a meter from the surface. The trend for high ground water is increasing with the development of the city and the increased amounts of water used (Haddadin, 2002). About 100,000 cubic meters per day of sewage is presently dumped in the northeast part of Jeddah and is making its way into the area of north Jeddah with no means of escape to the sea. The soil conditions in the region are such that drainage is not good. As rains occur and drain through these areas, there is no extra capacity for the ground to absorb the runoff.

The impacts of ground water rising include (Abderrahman, 2000): damage to cement due to chemical content of the water; damage to drainage and transportation infrastructure; interference with sewage infrastructure and major hazards to people and property. It increases the construction and maintenance costs of all developments. It reduce the effectiveness of on-site sewage treatment and can potential cause health problems if sewage enters this water.

There also have been concerns raised about the quality of the ground water that might be drained into the sea. The salinity is very high (2 times that of sea water) as is the hardness. This was initially through to be a problem if the discharge of ground water was to occur near the intakes for the desalinization plant (SWCC).

With increased development in areas requiring sewage pumping (and thus increased dumping of swage), cesspools, increase irrigation and the natural conditions of intense rainfall occurrences, there will be a trend for increased problems related to a high ground water table.

Studies at the university sponsored by the department of sanitation and water have been continuing on the problems of ground water.

### Corniche Lakes

#### Issue

The small lakes/lagoons found along the Corniche do not have adequate or any access to the sea and therefore are not refreshed regularly (Beaumont, 2002). Conditions in these areas do not support any water contact activities or marine life. The areas are attractive and are a major part of the entire Corniche design. The water in the area can become stagnant and develop unsightly conditions and odors thus negating the attractiveness of the area. Over a long period these locations may become a larger problem as nutrient rich water used for the maintenance of the vegetation around the lakes increases the rate of eutrophication (MEPA, 1994).

The full scope of the water issues is not known due the complexity of the relationship of water supply, water and sewage disposal, drainage, geological and soil structures and growing development demands.

## PROPOSED ACTIONS

This section summarizes the issues of the study and presents in total the actions that should be considered in order to resolve the high priority issue.

It is evident from the review of past studies that most issues impact on several resources and that they also cross over many operational programs. This emphasizes the need for coordination to ensure the environmental quality of the city is maintained or improved. It is also evident that with a

regular coordination mechanism in place, implementation of decisions could be monitored assist in any joint coordination actions.

There are however some fundamental problems facing the management agencies responsible for alleviating the problem. In addition, there are problems of enforcement of approved environmental standards and controls. In some cases, there is a complex interrelationship between agencies dealing with issues: e.g., ground water, drainage, sewage treatment and urban development. There are cases where interrelationships between activities are not understood or there is an obvious lack of base information to make decisions. Some limitations as follows may be identified:

- Lack of basic information and or the sharing of information that is already available
- Lack of comprehensive city wide research to determine the alternative technical approaches to solve the problems
- Lack of clear responsibility to resolve the issue and implement decisions
- Lack of a forum to resolve conflicts or to assist in interdisciplinary decisions
- Lack of enforcement capability including laws, regulations, training, standards and management guidelines
- The problem of the allocation of limited funds to deal with the problems

**Management**

It became evident over the review of past studies and recommendations that a significant problem in solving the environmental issues related to issues of integrated environmental management.

Environment is seen by many as simply clean water, clean air and having wastes removed from their own backyard. The environment management issues go beyond the already complex take of delivering all the municipal services of a major urban center. Issues of health, public safety, economic development, sustaining resources for the future, social benefits of recreation, public education etc. are all involved in environmental management. This is a complex problem facing many institutions. Each has other primary responsibilities to deliver public services to department and program had their normal problems in implementation. These problems can not independently be identified as the major weakness in proving sound environmental management for the city.

Researches indicated that much of the decision making carried out at the municipal level could be described as incremental/ incrementalism means anon-comprehensive analysis made prior to actions. The research was done in connection with the development of the Corniche.

**Coordination**

**Issue**

There is no single agency with a mandate to manage the environment in Jeddah-nor is there any group that coordinates or facilitates environmental management in the city. However, it is equally evident that there is no case where an organization does not have concern and activities that are directed at operating in an environmentally responsible manner.

**Implementation**

**Issue**

In many cases the technical answers to solve the environmental problems are known or can be developed/designed. Implementing solution is more difficult due to several factors:

- A lack of a common information base on the extent and impacts of development activities on the entire environment
- A lack of knowledge about the interrelationships amongst various department and private sector development and management activities

- A lack of knowledge about how various activates impact on environment and particularly cumulative impacts
- A lack of communication amongst organizations about relevant programs, projects and information
- Unclear common priorities to deal with environmental issues
- Inadequate and or uncoordinated budgets allocations
- A lack of defined enforcement responsibility or the means of enforcing existing standards
- A lack of effective monitoring of compliance with plans and standards
- Lack of training of enough staff to effectively identify and address the problems
- The public (including the development sector) are not informed about their roles and responsibilities environmental management in the city

## CONCLUSIONS

In the development of the city, many activities took place without a strong concern about the environment. Through a comprehensive review of available studies done on the environment of Jeddah area, the important environmental issues were identified in this review study. This study is prepared as an initial step in a longer process to resolve environmental issues. There are some issues that have yet to be identified. There are probably reports that have not yet been reviewed that have relevant data and recommendations. There are already actions taking place by the appropriate agencies to remedy some of these issues and others. This present inventory of issues and the resulting action plans; need to be updated by a broader group of managers to make it more comprehensive before major costly actions are made.

## REFERENCES

Abderrahman, W.A., 2000. Urban water management in developing arid countries. Int. J. Water Resour. D, 16: 7-20.

Abderrahman, W.A., 2001. Energy and water in arid developing countries: Saudi Arabia, a case-study. Int. J. Water Resour. Dev., 17: 247-255.

Ahmed, A.F.M., 1990. $SO_2$ and $NO_x$ emissions due to fossil fuel consumption in Saudi Arabia. A preliminary inventory. Atmos. Environ., 24A: 2917-2926.

Al-A'ama, M.S. and G.F. Nakhla, 1995. Wastewater reuse in Jubail, Saudi Arabia. Water Res., 29: 1579-1584.

Al-Jayyousi, O.R., 2003. Greywater reuse: Towards sustainable water management. Desalnation, 156: 181-192.

Alaboud, T.M. and S.F. Magram, 2008. A discourse on feasibility of the membrane bioreactor technology for wastewater reuse in Saudi Arabia. Res. J. Environ. Sci., 2: 445-455.

Azeem, M. and S.F. Magram, 2008. Efficiency of anaerobic digestion of low-strength sludge under different thermophilic conditions. Asian J. Scientific Res., 1: 510-517.

Beaumont, P., 2000. The quest for water efficiency-restructuring of water use in the Middle East. Water Air Soil Pollution, 123: 551-564.

Beaumont, P., 2002. Water policies for the Middle East in the 21st century: The new economic realities. Int. J. Water Resour. Dev., 18: 315-334.

CIA-The World Fact Book, 2008. Saudi Arabia. https://www.cia.gov/library/publications/the-world-factbook/geos/sa.html.

Dincer, I., 2000. Renewable energy and sustainable development: A crucial review. Renewable Sustainable Energy Rev., 4: 157-175.

Dossing, M., J. Khan and F. Al-Rabiah, 1994. Risk factors for chronic obstructive lung disease in Saudi Arabia. Respir. Med., 88: 519-522.

Gladstone, W., N. Tawfiq, D. Nasr, I. Andersen and C. Cheung *et al*., 1999. Sustainable use of renewable resources and conservation in the Red Sea and Gulf of Aden: Issues, needs and strategic actions. Ocean Coastal Manage., 42: 671-697.

Haddadin, M.J., 2002. Water issues in the Middle East challenges and opportunities. Water Policy, 4: 205-222.

Hussain, G. and A.J. Al-Saati, 1999. Wastewater quality and its reuse in agriculture in Saudi Arabia. Desalination, 123: 241-251.

Jones, D.A., J. Plaza, I. Watt and M. Al-Sanei, 1998. Long-term (1991-1995) monitoring of the intertidal biota of Saudi Arabia after the 1991 gulf war oil spill. Mar. Pollution Bull., 36: 472-489.

Loya, Y., 1975. Possible effects of water pollution on the community structure of Red Sea corals. Mar. Biol., 29: 177-185.

Magram, S.F. and M. Azeem, 2008. Evaluation of the performance of dynamic sand filtration under real working conditions. Res. J. Environ. Sci., 2: 52-57.

MEPA (Meteorology and Environmental Protection Administration), 1994. Jeddah environmental study. Report No. B-2-04-9403.

Osman, Y., 1997. Environmental surveys conducted in the gulf region following the gulf war to identify possible neurobehavioral consequences. Environ. Res., 73: 207-210.

Saudi Network, 2008. Jeddah. http://www.the-saudi.net/saudi-arabia/jeddah/index.htm.

Stern, D.I., 2005. Global sulfur emissions from 1850 to 2000. Chemosphere, 58: 163-175.