The Environment and the Middle East



Pathways to Sustainability

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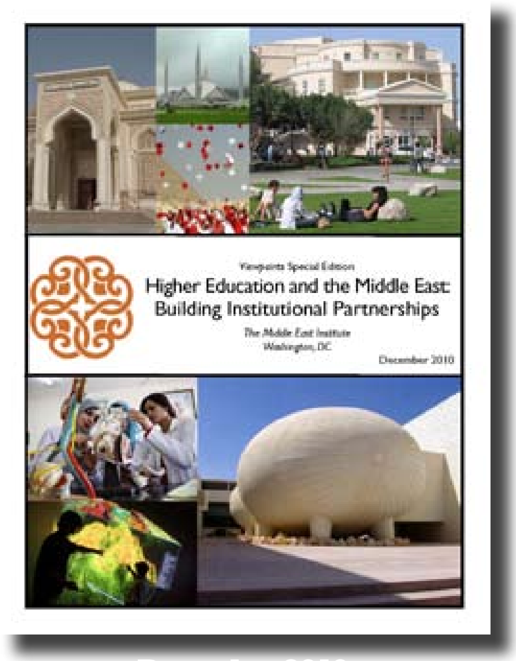

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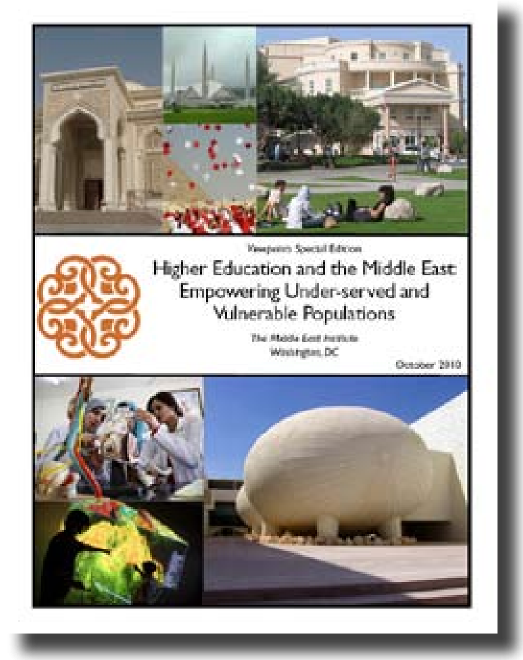

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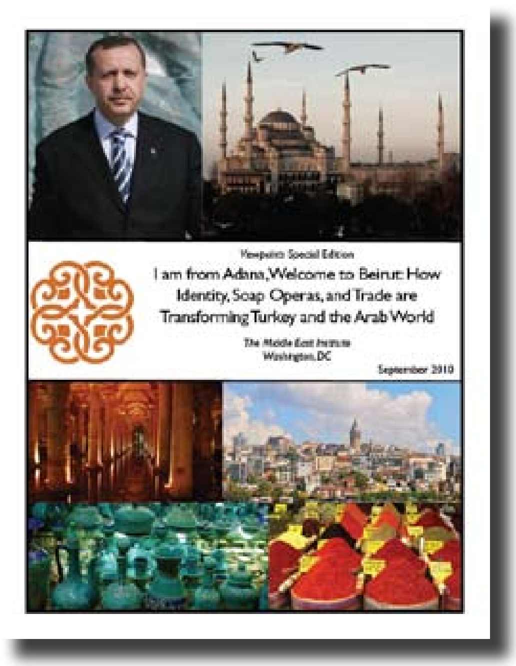

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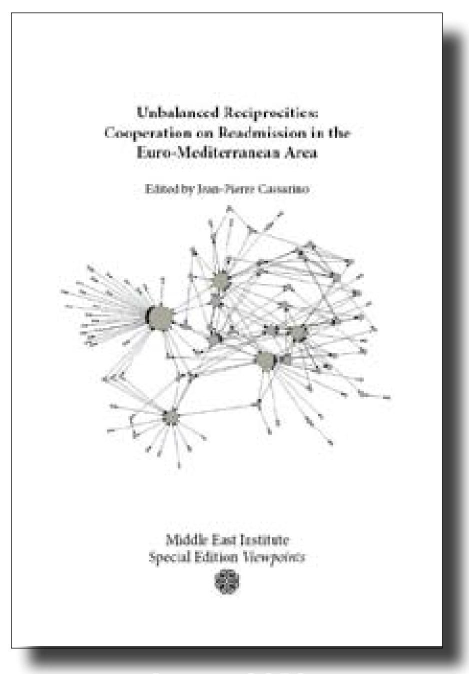

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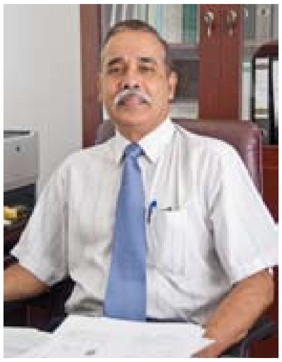
Table of Contents

About the Authors



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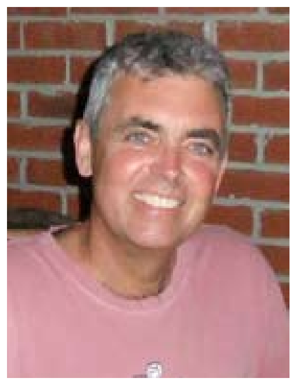

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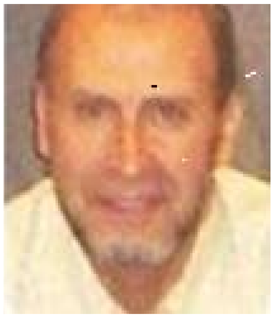

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Introduction

As this publication is being launched, Egypt enters the third week of nationwide protests. Indeed, there is evidence of political ferment throughout the Arab world, as people have taken to the streets in Tunisia, Jordan, Lebanon, and Yemen. It is these events and where they may lead the region politically that have claimed the headlines, and deservedly so. Yet, no less important than how the region's politics may be reshaped in the coming months is whether, and how, its physical environment will be preserved in the face of a multitude of challenges.

This volume is the first of several collections of essays dealing with the Environment and the Middle East. Importantly, these essays focus less on the problems themselves than on what can and should be done to address them. As the sub-title "Pathways to Sustainability" suggests, the series features some of the many examples of environmental stewardship practiced and promoted throughout the region — by scientists, teachers, non-governmental organizations, community activists, and many others. One can only hope that the current political turbulence will give rise to far-sighted leadership and a climate that embraces and supports such contributions.

Sustainable Development and the Built Environment in the Middle East: Challenges and Opportunities

Karim Elgendy

In the Western context, notions of sustainable development often refer to the need to adjust existing economic models in order to maintain better balances between economic growth and social needs, while protecting local ecologies and reducing the negative impact of growth on the global environment.

In the developing world, however, sustainable development takes on a rather different meaning. With the agendas of developing nations focused on addressing basic developmental challenges such as economic growth, water scarcity, food security, and health, other environmental and social aspects are considered secondary at best and, for the most part, a luxury that a developing nation cannot afford.

In the absence of functioning economic models in the developing world, sustainable development here is not about adjustments to maintain balances. Instead, it is about using this economical *tabula rasa* to build the foundations of a new economic model in which sustainability and the environment are integral. One of these economic foundations is the built environment.

The built environment of our cities plays a major role in shaping the way we live and work, and given its relatively long lifespan, its impact is long lasting. Our buildings determine how much energy we use to maintain thermal comfort ,while our infrastructures determine how much energy we need for transportation. It is estimated that 40% of carbon emissions worldwide are produced from the occupation of buildings, with at least a portion of transportation's 20% share being a consequence of the way our cities are planned.

Our built environment also influences our impact on the local environment as well as our collective health and wellbeing. Thus, as the cities of the developing world continue to grow, they continue to make decisions about the direction their development takes.

In the Middle East, the role of the built environment is becoming more pronounced as the region continues to experience rapid population increases and urbanization. Increased urban densities, together with the rise of consumerism, have not only led to an increase in environmental degradation locally, but they have also meant that the region's traditionally low energy use — and consequently its carbon emissions — are set to rise and play a larger role in global climate change.

But embracing sustainable development in the built environment of the Middle East faces many challenges, which prevents it from becoming part of the region's development framework and its building industry practices.

CHALLENGES TO SUSTAINABLE DEVELOPMENT

At the urban scale, sustainable development faces the lack of an urban development framework in most of the region's cities and the general lack of an encouraging regulatory environment that could stimulate a market change towards sustainable development. It also faces the scarcity of successful regional precedents in energy and water conservation as well as waste management. The latter issue is even more concerning given rising energy consumption in buildings, growing water scarcity, and the increase in waste generation that accompanies rising consumption.

At the individual building scale, sustainable development faces different — but equally difficult — challenges. Chief among which is the region's hot and arid climate. While it is common knowledge that the rapid growth of many of the region's cities was only possible with the help of the great energy resources discovered under its sands, it is perhaps a less known fact that these cities require great energy supplies to keep them habitable given the way they were planned and built.

Since the building forms that have shaped the cities of the Middle East in recent decades were mostly imported, they were not environmentally responsive to the region's climatic conditions

Since the building forms that have shaped the cities of the Middle East in recent decades were mostly imported, they were not environmentally responsive to the region's climatic conditions and relied on energy-intensive air conditioning to remain cool enough for human occupation. But given the extreme nature of the climate, for alternative building forms that are less dependent on fossil fuel to emerge and replace the existing ones, extreme design measures must be taken to reduce the energy associated with cooling in new buildings while maintaining comfort levels inside them.

Another challenge that faces sustainable development at the building scale is the region's construction industry. The general lack of enforceable energy efficiency requirements for buildings together with the lack of financial incentives and the predominant lack of sufficient sustainable design knowledge among building professionals have all created an industry that is reluctant to adopt sustainable construction. If the industry is to embrace the new designs and alternative building forms described above, it must undergo a major transformation on all of these fronts.

OPPORTUNITIES AND NATURAL POTENTIALS

With the challenges above in mind, the Middle East's urban environments also have natural potentials for sustainable development:

- The region's increasing urbanization and high population densities have a natural potential for the construction of the highly-economical neighborhood-scale energy systems;
- The region's heritage of traditional building models can also provide relevant guidance for designs that

are more energy efficient;
- The region's abundant solar and wind resources also present a potential for renewable energy systems to be effectively employed and integrated into the built environment.

In addition to these inherent potentials, recent interest in sustainable development by governments, non-governmental organizations, and professional bodies around the region presents further opportunities that can be capitalized upon. As it relates to the built environment, this interest has so far taken the form of efforts to establish sustainable development institutions and regulations.

The Moroccan government, for example, has recently announced the establishment of a national charter for sustainable development and the environment, while the governments of the United Arab Emirates (UAE), Egypt, and Jordan have started introducing energy efficiency standards for buildings. Non-governmental organizations (NGOs) and professional organizations in Jordan, Qatar, and the UAE have established green building councils in their respective countries with the goal of promoting sustainable design and developing — or importing — green building rating systems.

The governments of the Emirates and Saudi Arabia have also been engaged in commissioning sustainable design pilot projects, while others are considering providing financial incentives for energy efficient buildings and small renewable energy systems to make them commercially viable.

These positive developments and the opportunities they present indicate that the tide is turning — albeit slowly — towards more sustainable development in the Middle East. But they must be capitalized on if they are to overcome the challenges described above. The nature of the challenges faced by the region requires a commitment to sustainable development, a willingness to change the *status quo*, and a collaboration between governments, NGOs, professional bodies, and the public. The region has a lot to learn from the successful experiences of other developing countries that embraced sustainable development, but it will ultimately have to chart its own way if it is to create a sustainable future for its people.

Solar Power Scale-Up in the MENA: Resolving the Associated Water Use Challenges

Adriana M. Valencia

The Middle East and North Africa (MENA) region provides excellent conditions for the development of Concentrated Solar Power (CSP),[1] notably much irradiation and unused flat land[2] in close proximity to road networks and some transmission lines. Hence, a number of initiatives are underway to scale-up several donors are jointly launching a program to scale-up CSP in the MENA to several gigawatt (GW) over the next decade.[3]

CSP deployment on this scale[4] would bring substantial advantages to participating countries, including: leveraging investments into CSP plants, thereby almost tripling current global investments in this technology; providing massive investments in MENA countries; supporting MENA countries to achieve their development energy goals; and assisting Europe to meet its greenhouse-gas emissions reduction commitments.

However, CSP scale-up is not exempt from challenges, which comprise: the readiness of Europeans to purchase produced power; affordability of the produced electricity for MENA countries versus the decision to instead purchase less climate-friendly natural gas; the readiness of transmission infrastructure; and the availability of clean water for CSP requirements, along with environmental and social impacts. This article examines the latter.

WATER AVAILABILITY AS A CENTRAL CHALLENGE

Water use presents particular challenges in the MENA due to the region's water scarcity: the region's challenges from potential water scarcity are among the greatest in the world, with only 1,110 m^3 of renewable water resources per person per year in 2007, far below the global average of 6,617 m^3 p/c.[5] Environmental problems resulting from water issues cost MENA countries between 0.5–2.5% of GDP every year.[6] Future possible problems arising from water scarcity include food security issues[7] and possible conflicts over water.[8]

This article represents the author's own viewpoints and not that of any institutions with which she is or has been affiliated. The author would like to thank Georg Caspary and Nishesh Mehta for their valuable contributions.

1. One of the most promising renewable energy technologies.
2. Both major types of CSP technologies discussed in this paper require approximately 4 ha/MW for collectors and heliostats (UN Environment Programme [UNEP], 2003).
3. Commitment investments for this development amount to nearly $5 billion at present.
4. Note that the European industry consortium, DESERTEC, intends to invest $400 billion in CSP and other renewable technologies in North Africa, making it perhaps the most ambitious climate change mitigation effort ever.
5. WRI Earthtrends Database, Water Resources and Fresh Water Ecosystems (2007).
6. World Bank, "Making the Most of Water Scarcity: Accountability for Better Water Management in the Middle East and North Africa" (2007).
7. Hang Yang and Alexander Zehnder, "Water Scarcity and Food Import: A Case Study for Southern Mediterranean Countries" (2002).
8. Conflicts over water have occurred in other countries, with a recent example leading to the death of 15 Somalians — a country where land and access to water conflicts are frequent (See *Daily News Egypt*, March 6–7, 2010). Furthermore, it has been recorded that of the 37

COMPARATIVE WATER USE: CSP VERSUS TRADITIONAL ENERGY TECHNOLOGIES

The water needs of CSP (depending on design[9]) are similar in volume to "standard" energy technologies employed in the region (notably thermal power). Yet, one of the challenges to CSP roll-out in the region is that the technology's water requirements (mainly for cooling) are nonetheless substantial.[10]

Data from CSP plants built in other parts of the world (e.g., the United States) so far suggest that parabolic trough CSP systems use ~700–800 gallons of water/MWh, compared to an average of ~500 gallons/MWh for coal and nuclear plants.

However, even though conventional power plants work at higher efficiencies (due to their ability to achieve higher temperatures and pressure), such comparisons may exaggerate their advantages in water use terms because:

- the comparisons use figures from highly efficient US-based conventional plants, versus desert located CSP plants; and
- if water use for scrubbing/ash handling in coal power plants is included in the calculations, overall their water use is similar.

Furthermore, conventional plants have very serious non-water environmental issues: local and global pollution (coal); scarcity (gas); or waste storage issues (nuclear). CSP arguably has less serious non-water environmental impacts, mostly from the risk of toxic fluid leakage — which hardly compare to the risks mentioned for coal or nuclear.

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actual military water conflicts since 1950, 32 took place in the Middle East (30 of which involved Israel and its Arab neighbors in conflicts over the Jordan River and its tributaries, which supply millions of people with water for drinking, bathing, and farming. See "National Parting the Waters," *National Geographic* (April 2010), http://ngm.nationalgeographic.com/2010/04/parting-the-waters/belt-text/1. See also Joyce Starr, "Water Wars," *Foreign Policy*, No. 82 (Spring 1991), pp. 17–36.

9. The key types of CSP design considered in this report (and being used in MENA) are parabolic trough and power tower. Power tower systems are one of the three types of concentrating solar power (CSP) technologies in use today. Some power towers use water/steam as the heat-transfer fluid. Other advanced designs are experimenting with molten nitrate salt because of its superior heat-transfer and energy-storage capabilities. Power towers also offer good longer-term prospects because of the high solar-to-electrical conversion efficiency (see US Department of Energy [USDOE] website, 2010). Parabolic troughs are a type of linear concentrator and the most commercially available technology (e.g. they have been performing reliably at a commercial scale in the US for more than 15 years). In such a system, the receiver tube is positioned along the focal line of each parabola-shaped reflector. The tube is fixed to the mirror structure and the heated fluid — either a heat-transfer fluid or water/steam — flows through and out of the field of solar mirrors to where it is used to create steam (or, for the case of a water/steam receiver, it is sent directly to the turbine) and drives a generator to produce electricity (USDOE website, 2010). Note that another type of CSP is dish/engine systems, which use the Stirling thermodynamic cycle to directly produce electricity and therefore are air-cooled and only require water for mirror washing. These systems use sunlight to power a small engine at the focal point and the engines typically use hydrogen as the working fluid. These are not widely used yet and are currently designed to provide electricity only when the sun is shining (low possibilities for thermal storage) (USDOE, 2008). Since this is a disadvantage to utility scale production and when the peak load period lasts past sunset, this technology is not discussed in this paper.

10. A smaller portion is for cleaning of mirrors, while a certain amount of water is also needed for steam generation, if this is the chosen method of heat transfer.

Table 1: Impacts from CSP as they Possibly Relate to Water Issues and Mitigation Options

Impacts	Mitigation options
Water availability concerns	Use of air cooling where use of wet cooling would result in water shortage. Water conservation practices.
Routine/accidental release of chemicals: e.g., anti-freeze or rust inhibitors in coolant liquids. Heat transfer fluids with harmful chemicals.	Safety measures against such release through relevant components being leak-proof, regularly maintained, cleaned, and periodically replaced by appropriately trained staff.
Thermal and/or chemical pollution of local water ways from cooling water/other waste water.	Effluent treatment techniques to remove/reduce concentrations of contaminants. Monitoring of discharge water (e.g. eutrophication, oxygen content, temperature). Compliance with regulated pollutant emission levels of liquid effluents (e.g. local and/or national regulations, or international standards as default).

Sources used to create this table include: Tsoutos et al. 2005; Biswas et al. 1992; Downing 1996; UNEP 2003, WB project documentation on existing CSP projects; and conversations with WB environmental safeguards staff.

WATER IMPACTS FROM CSP

The construction and operation of CSP projects lead to a variety of environmental and social impacts that need to be identified, assessed, monitored, and mitigated. This environmental due diligence is site-specific[11] and important at all stages of the project.[12] Table 1, below, shows the key possible CSP impacts related to water.

ESTIMATING WATER NEEDS OF CSP IN THE MENA WITH DIFFERENT COOLING TECHNOLOGIES

Generally, decision makers must choose between wet/evaporative cooling, air cooling, or hybrid cooling technologies for each prospective CSP project:[13]

1. Wet/evaporative cooling: efficient at moderate investment costs but high water consumption (approximately 574 gal/MWh or between 2–3 m^3/MWh).

11. The regional nature of this program may well necessitate a Strategic Impact Assessment for both environmental and social effects.
12. Three main stages may be defined as follows (based on UNEP, 2003): (1) environmental regulatory framework for the project; (2) environmental appraisal of the project; and (3) monitoring of environmental aspects during operation.
13. There is also a cooling option in which water is drawn from a body of water and then returned to that source. Termed once-through cooling, this option is not discussed here as it is now highly disregarded as an alternative due to its impacts on aquatic life. The losses from evaporation can also be significant and the option requires an average of 25,000 gal/MWh or 94.6 m^3/MWh (USDOE 2008).

2. Air/dry cooling: less efficient[14] and more expensive than wet cooling but less than 10% of the water consumption compared to wet cooling (between <0.04–0.3 m^3/MWh). Air cooling is restricted as an option if there are frequent overlaps of necessary highest plant output with highest ambient air temperature or "hot days" (above 37.7°C).[15]
3. Hybrid cooling: combination of wet and air cooling technologies. Air cooling with water during times of peak ambient temperatures. It is less efficient and more expensive than wet cooling but limits water consumption and is generally less expensive than air cooling. Water savings over the wet system can be 50% on average (ranging between 0–95%) since the system can be used in any combination depending on the design and actual usage of the cooling devices. Hybrid systems are especially useful in regions with many "hot days."[16]

Initial data suggest that the water savings to be achieved with hybrid and dry cooling are substantial (up to 97% when switching from wet to dry cooling[17]), even though they carry performance and cost penalties (of 1–5% for hybrid cooling, and 5–9% for dry cooling). Performance and costs will likely be further impacted by the number of "hot days." Thus, water availability, best technology choice, levelized electricity cost (LEC), and "hot days" issues all will require further study with data from the specific project areas.[18]

Based on cost, performance, and water use information, the author obtained data on the capacity and technology of each of the proposed CSP projects in the MENA and established the likely annual generation of each of these projects from average annual generation figures of CSP projects of that capacity level. Subsequently, two data sets were obtained (one from the Clinton Climate Initiative and one from the US Department of Energy) of general figures of estimated water needs for different CSP cooling options at various generation output levels. Project-level water needs were calculated for each project, which confirmed that water savings from air and hybrid cooling systems *vis-à-vis* wet cooling in CSP are considerable.

The calculations suggest that:

- for air cooling and for the lower end range of estimates of hybrid cooling, water use is only 9–18% of the water used for wet cooling.
- for hybrid cooling's higher end range of the estimates, water use is 33–56% of the water used for wet cooling.

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14. Water cooling has higher thermal efficiency and maintains consistent efficiency year round (USDOE, 2008).
15. This would be exacerbated if it coincided with highest electricity demand and revenues. Juergen Dersch and Christoph Richter, "Water-Saving Heat Rejection for Solar Thermal Power Plants," Institute of Technical Thermodynamics (2007).
16. During hot days the performance of air-cooled systems has been shown to drop significantly. In such cases, the hybrid cooling system's wet unit can reduce the load of the air unit and thus bring the condensing steam temperature closer to the design condenser temperature.
17. According to the German Institute for Thermodynamics.
18. Initial data from the German Institute for Thermodynamics give insight on the impact of local water costs on LEC in CSP projects in Spain and California, focusing on a comparison between wet and air cooling. The results indicate that wet cooling is only preferable to air cooling at very low water cost levels.

However, to make these calculations more accurate, it is important to know the number of "hot days."[19] This data is currently unavailable (for one full year) but is expected to become available by the end of 2011.[20]

MEETING CSP COOLING AND MENA WATER NEEDS: POTENTIAL DOUBLE-DIVIDENDS FROM DESALINATION

Given the existing and growing water scarcity problems in the MENA, CSP scale-up should be done in a way that contributes to solving the problems by: serving as a stable electricity source for desalination through processes such as reverse osmosis (and thus partly meeting water needs of the region); and meeting the water needs of the CSP plants.

Since CSP plants are in essence thermal power plants, they can be used for combined heat and power. Thus, they can be coupled with desalination technologies that use both heat and water such as Multi-Stage Flash (MSF) and Multi-Effect Desalination (MED).[21]

While a long implementation time frame should be expected ... CSP desalination has the highest potential to supply the most economic ... and sustainable water to the region.

An advantage of CSP-powered desalination is that a CSP plant can deliver more stable and constant power capacity than wind or photovoltaic due to its thermal energy storage capacity (the variability found in wind and solar may lead to system inefficiencies).

While a long implementation time frame should be expected (CSP desalination may need some 10–15 years from today in order to reach a significant share in the MENA water supply), CSP desalination has the highest potential to supply the most economic (<€0.3/m^3) and sustainable water to the region. Given the dearth of alternatives to secure the region's water supply (e.g., with subsurface water withdrawal having reached over 1,000% of the safe limit in some countries), this option will become increasingly important.

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19. According to the US Department of Energy data, the performance of air cooled systems is reduced up to 5% for air-cooled trough systems during hot (above 37.7°C) summer days when compared to wet cooling.
20. As mentioned earlier, if high temperatures coincide with the highest electricity demand and possibly highest revenues, air cooling may become a less or the least attractive option. Data available: Egypt (Cairo Airport station — the Kureymat plant is 90km south): 22 hot days/yr on average; Morocco (Ouarzazate, project site): 50 hot days/yr on average; Algeria Hassir Mel: 6 hot days/yr on average. However, it has been indicated that providing mean air temperatures for the day is not enough and that hourly temperatures may be more necessary. It should also be noted that: 1) the performance drop is not instantaneous at a certain temperature value but it is continuous; 2) during "hot days" only few hours tend to be above 37.7°C; and 3) the actual extent of the performance decrease depends on the design of the heat rejection system. Furthermore, some of these "hot hours" are even in the late afternoon when the DNI is decreasing and thus the plant may run in part load, which means that the performance penalty from high ambient temperature might be reduced by the performance gain of the air-cooled system running in part load (Dersch 2010 Personal Communication); and that 2) increasing the solar field can allow for higher steam production to offset the higher backpressure during high ambient temperature periods (according to a study performed in California, USDOE 2008).
21. German Aerospace Center 2007, "Concentrating Solar Power for Seawater Desalination," http://www.dlr.de/tt/Portaldata/41/Resources/dokumente/institut/system/projects/aqua-csp/AQUA-CSP-Full-Report-Final.pdf. There are two broad categories of desalination technologies: thermal technologies and membrane technologies. Thermal technologies have been commonly used for seawater desalination in the MENA region. These involve heating the saline water and collecting condensed vapour to produce pure water.

Given the assumptions of water requirement of 2.8–3.4 m^3/MWh and capital costs of \$1,500–2,000/m^3/d for MSF desalination and \$900–1700/m^3/d for MED, the additional capital costs required for the desalination equipment come to ~\$33-37/kW. For the CSP scale-up plan of 1,000MW, this amounts to an additional \$33 million, assuming that each plant reaches the economies of scale required for these costs. Since desalination is a mature technology in the region, these costs can be stated with a reasonable degree of accuracy. The additional solar field required would be in the order of 1–3%.

Initial figures researched on the level of water and electricity needed in a combined CSP and desalination scenario suggest that for a 1,000 MW initial configuration of the plan (assumed to run for an average of seven hours a day), the water requirements of the combined plants would be about 19,600 m^3/day. Providing all of the needed water for the operation of such 1,000 MW CPS scale-up capacity through desalination would require 0.5–2.8% of the electricity output of the CSP plants, depending on the kind of technology utilized.

CONCLUSIONS

CSP scale-up may lead to a number of specific social and environmental issues, though few of these "CSP-specific" issues have so far arisen in actual CSP projects. For the most part, CSP projects are likely to give rise to the "standard" safeguards issues of an infrastructure project of the relevant size; however, special care needs to be taken to avoid replacement of agricultural water use or contamination of water bodies.

CSP scale-up throughout the MENA region may require vast amounts of water depending on the selected cooling option. While water availability for CSP is, at the moment, only a side issue in CSP development in the MENA (as CSP is still a technology with a limited geographical scale), a large-scale roll-out of the technology (e.g., as proposed under the DESERTEC initiative) would imply taking a close look at water availability/scarcity and should bring the issue to the forefront of CSP planning.

Combining CSP electricity generation with desalination technology can circumvent the problem of water availability

This article described that the water savings to be had from hybrid cooling systems and air cooling systems *vis-à-vis* wet cooling are considerable. This is of special importance, given the water scarcity in the MENA region. Additional water savings generated by air cooling over hybrid cooling (at least at the upper end of the estimates range) generally outweigh the rather marginal additional performance and cost penalty associated with air and hybrid cooling. Nonetheless, the decision on the cooling technology ought to be made in each instance taking into account local conditions.[22]

22. E.g., water availability/cost, hourly ambient temperature, electricity costs, topography, population density, as well as the quality of water output needed.

The article also discussed the possible impact on performance during "hot days" (air temperatures above 37.7°C degrees), and based on outside studies, indicated that as long as these "hot days" do not coincide with high plant output/peak demand and high revenues, the performance and costs impact may not be significant. However, to be able to perform a true assessment of the possible performance penalties associated with high temperatures, more data is required on hourly temperatures throughout the year and more information is also needed on the expected loads in the countries under consideration.

Combining CSP electricity generation with desalination technology can circumvent the problem of water availability since the desalination plant can strike a symbiotic relationship where it supplies the requisite cooling water to the CSP plants in return for electricity/heat needed to purify water for various purposes. This is of particular significance for the MENA, where desalination is already a mature technology and CSP has a very high power generation potential.

Impacts of Water Scarcity on the Social Welfare of Citizens in the Middle East

Muawya Ahmed Hussein

Over the past century, the Middle East and North Africa (MENA) has undergone huge changes. According to 2007 estimates, its population has risen from less than 50 million a century ago to over 331 million, and is expected to reach some 385 million people by 2015. During this same period, the environment has deteriorated and natural resources have dwindled due to development patterns which were largely unsustainable. In most cases, policies were overwhelmingly sets of provisional short-term measures, meant to tackle momentary challenges rather than engage in long-term planning. Some parts of the region have seen unprecedented growth, bringing both economic and social prosperity to millions of Arabs, thanks largely to income from oil. Has this economic development, however, come at a cost? Can the patterns of development which some Arab countries are experiencing continue while sustaining livelihood and quality of life for future generations?

The Middle East's physical environment stands at a pivotal juncture, threatened by numerous current and imminent problems. At the same time, awareness of the issues, as well as signs of political and social willingness to act, provide hope for timely intervention.

The growth of cities and towns poses particular challenges. Accelerating urbanization is straining already-overstretched infrastructure and creating overcrowded, unhealthy, and insecure living conditions in many cities. In 1970, 38% of the Arab population was urban. By 2005, this figure had grown to 55%, and is likely to surpass 60% by 2020.[1]

The two major environmental threats in the region are those related to water scarcity and desertification and land degradation. Although the MENA has 5% of the world's population, it has less than 1% of the world's available water supply. Meanwhile, the rate of water consumption is straining this supply. Per capita water use in the United Arab Emirates (UAE), for example, is about four times that of Europe; consumption in Abu Dhabi is 550 liters of water per person per day, two to three times the world average of 180–200 liters.

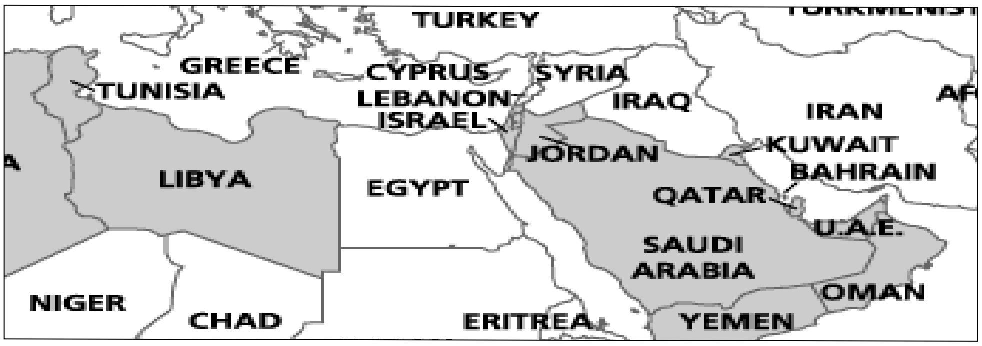
WATER SCARCITY

The issue of water scarcity is the most serious threat to Arab security, as virtually all Arab countries are well below the line of "water poverty." The World Bank has classified 22 countries as below the water poverty line (when per capita water availability cubic meters/year is below 1,000). Fifteen are Arab countries, and nine of them in the Middle East (see Table 1). Per capita water cubic meters/year in Qatar, Kuwait, and Bahrain is 91, 95, and 112, respectively. In the

1. United Nations Development Programme (UNDP), *Arab Human Development Report 2009,* "Challenges to Human Security in the Arab Countries."

cases of Saudi Arabia, Jordan, Yemen, Tunisia, and Oman the figures are 241, 318, 340, 434, and 874, respectively.[2] If this is the case today, one can imagine the water shortages that the region will have to confront in ten years. An increasing population's demand for water would reduce per capita share to 460 cubic meters by 2025, lower than the extreme water poverty level according to international classifications.

Figure 1: Water-Scarce Countries in the Middle East and North Africa



Note: Water-scarce countries (shaded above) are those with less then 1,000 cubic meters of renewable fresh water per person per year.

Due to poor agricultural technologies, agriculture remains the major user of water sources in most of the region's countries. There is a low level of efficiency in the utilization of water in all sectors that use water, typically between 37% and 53%. This has generated a range of problems such as water logging salinity, low productivity, infertility of soil, and the deterioration of the quality of ground water.

Water governance remains fragmented among various institutions, which generates problems of the rationalization of water use. The problem is further aggravated by the high rate of population increase, the geographical location of the region's countries in the Great Desert belt, and the lack of national programs to rationalize water consumption. In addition, a high percentage of the water resources upon which the countries of the MENA depend originate outside the region, giving rise to tensions in using jointly-shared water. This is acutely clear in the cases of the Nile, the Euphrates, and the Tigris rivers.

Poor distribution and heavy demand, especially of ground resources, characterize water use in the Arab countries. This leads to a lack of clean water for much of the population and the waste of significant amounts in the agriculture, industry, and tourism sectors. A report from the UN Economic and Social Commission for Western Asia (UN–ESCWA)[3] applies the question of water stress to the national level in the Arab states (UN–ESCWA member countries are Bahrain, Egypt, Iraq, Jordan, Kuwait, Lebanon, Oman, the Occupied Palestinian Territories (OPT), Qatar, Saudi Arabia, Syria, UAE, and Yemen). The report distinguishes between four levels of water stress as gauged by the ratio of population to

2. UN Development Programme (UNDP), Arab Human Development Report 2002, "Creating Opportunities for Future Generations," http://www.arab-hdr.org/publications/other/ahdr/ahdr2002e.pdf.
3. United Nations Economic and Social Commission for Western Asia (UN–ESCWA), *Water Development Report 2, State of Water Resources in the ESCWA Region* (December 4, 2007), http://www.escwa.un.org/information/publications/edit/upload/ sdpd-07-6-e.pdf.

renewable freshwater — slight, significant, serious, and critical. As shown in Table 1, the study reveals that four countries are facing "slight" water stress, two are facing "significant" water stress, five are facing "serious" water stress, and two — Kuwait and the UAE — are facing "critical" water stress.

Table 1: Levels of Water Stress in Thirteen Arab Countries, 2006

Slight water stress (less than 2,500 persons per million cubic meters)	**Significant water stress (Between 2,500 and 5,000 persons per million cubic meters)**	**Serious water stress (Between 5,000 and 10,000 persons per million cubic meters)**	**Critical water stress (More than 10,000 persons per million cubic meters)**
Egypt	Jordan	Bahrain	Kuwait
Lebanon	Saudi Arabia	Iraq	United Arab Emirates
Oman		Occupied Palestinian Territories	
Syria		Qatar	
		Yemen	

Source: UN–ESCWA, 2007.

A particularly striking example of the conflict that exists between rapid economic development and scarce water resources is the recent boom in the construction of golf courses in certain parts of the region. In fact, most of the current and planned golf courses are in Egypt and the Gulf region, particularly the UAE, where water resources are already low, even by regional standards.

Expansion of water-intensive projects like grass golf courses cannot go on unchecked, especially with meager investments to develop sustainable desalination technologies. There are plans to increase the 16 golf courses operating in the Cooperation Council for the Arab States of the Gulf (CCASG) to 40 in the near future. In most cases, golf courses in the region are irrigated with desalinated sea water, treated effluent, or a combination of the two. A 2007 report released by the international consultants Klynveld Peat Marwick Goerdeler (KPMG) estimated the use of water for each golf course in the region at an average of 1.16 million cubic meters per year, reaching 1.3 million cubic meters in Dubai, enough to cover the water consumption of 15,000 inhabitants. Currently, the quality of water resources in the region is affected by pollution, urbanization, floods, and over-use of water resources. So, fresh water is another problem in the region. (See Table 2).

In the Northern part of the Jordan Valley, Abu-Thallam has estimated the impact of water shortage on the planted area, income, and labor at the regional level. It has been found that reducing the quantity of irrigation water has lowered cropping intensity and thus the area in cultivation has contracted. This, in turn, has resulted in a reduction in total net income, and consequently a reduction in labor used in the area.

For instance, decreasing water supply by 20% will be followed by a reduction in the total cultivated area by about 14%. This will lead to a decrease in the total net income generated by 15%. The reduction in employment will also be accompanied by a direct and indirect loss in income too.[4]

Table 2: Per Capita Annual Renewable Fresh Water

	Per Capita Annual Renewable Fresh Water (m2)			% of Freshwater Use, by Sector	
	1970	**2001**	**2025**	**Domestic**	**Industrial**
MENA	3,645	1,640	1,113	8	5
Algeria	1,040	462	331	25	15
Bahrain	455	140	97	39	4
Egypt	2,460	1,243	903	6	8
Iran	4,770	2,079	1,555	6	2
Iraq	10,304	4,087	2,392	3	5
Israel	740	342	247	16	5
Jordan	555	174	103	22	3
Kuwait	27	9	5	37	2
Lebanon	1,944	1,120	896	28	4
Libya	302	114	72	11	2
Morocco	1,960	1,027	741	5	3
Oman	416	206	5	2	94
Qatar	901	170	129	23	3
Saudi Arabia	418	114	59	9	1
Syria	7,367	2,700	1,701	4	2
Tunisia	800	422	327	9	3
Turkey	5,682	3,029	2,356	16	11
United Arab Emirates	897	60	44	24	9
Yemen	648	228	103	7	1

Source: Peter Gleick, The World's Water 2000–2001, The Biennial Report on Freshwater Resources.

4. K. Abu-Thallam, "Assessment of Drought Impact on Agricultural Resources in Northern Jordan Valley," M.Sc. Thesis. The University of Jordan. Amman, Jordan (2003).

CONCLUSION

The challenge of addressing water scarcity in the Middle East is aggravated by the region's ongoing population pressures. Utilizing new sources of water to meet the increased demand for fresh water would relieve some of the region's shortages, but as new sources of water become more expensive, they become less accessible to low-income countries, given those nations' limited financial and technical opportunities. Regional cooperation and political, legal, and institutional support are critical for enabling countries to address their freshwater shortages. Sound government policies regarding water allocation, distribution, and use can help countries to adopt better strategies to manage their scarce freshwater resources.

Living with Soil Salinity: Is It Possible?

Mushtaque Ahmed and Salim A. Al-Rawahy

Soil and groundwater salinity has emerged as the most significant agricultural problem facing the Sultanate of Oman. Scant rainfall, coupled with high temperature, is always conducive to the accumulation of salts in soils. These conditions are predominant in Oman. Secondary soil salinity has increased at a very rapid rate due to the persistent use of saline groundwater, which, over time, has become more concentrated due to increased pumping by farmers in the Batinah region — the country's most important agricultural area.

The balance between total pumping and annual recharge that had existed prior to the 1990s has been greatly disturbed, resulting initially in reduction of crop yields and gradually in the abandonment of lands. Saline seawater intrusions are also present in some areas of the region that are nearer to the sea as the result of over-pumping. Salt-affected lands constitute about 44% of Oman's total geographical area and 70% of the agriculturally suitable area of the country. The annual losses due to salinity have been reported as 7.31 to 13.97 million Omani Rials (2005 data, 1 Omani Rial = 2.58 USD). When salt-affected lands go out of cultivation, their owners become unemployed — engendering a host of socioeconomic problems. Clearly, therefore, soil salinity poses a huge threat to the sustainability of agriculture in Oman, especially in Batinah.

The research project "Management of Salt Affected Soils and Water for Sustainable Agriculture," prepared and approved by Sultan Qaboos University, was undertaken to explore ways to mitigate soil and water salinity. The project focused on four approaches: soil rehabilitation, bio-saline agriculture, fodder production, and the integration of the fish culture into crop production that could have compensatory economic returns to farmers. The project aimed at developing management guidelines which are scientifically sound for farmers a) to sustain economically viable agricultural production in salt-affected areas with saline groundwater, b) improve food security of Oman, and c) combat desertification. The idea was not to try to remove all salts from soil and groundwater but to learn to live with the prevailing conditions by providing sufficient income to the farmers in the affected areas through various means. The project was conducted with the active participation of Omani government scientists, farmers, and international experts. The tasks accomplished during the project include:

- Assessing the intensity and extent of salinity in the Batinah region using remotely sensed satellite images, ground-truthing, and preparation of temporal and spatial variation maps of salinity of soil and water from GIS.
- Determining agronomic solutions (mulching, tillage, sowing methods, etc.) and nutritional aspects including microbial nitrogen mineralization in saline conditions.
- Determining engineering and water management solutions (irrigation, sub-irrigation, leaching, leveling, etc.) to reduce water loss and salinization.

- Determining biological solutions by identifying salt-tolerant crops and fruit trees for various salt-affected regions of Oman. This includes introduction of halophytes.
- Assessing the effects of feeding salt-tolerant forage crops to Omani sheep.
- Integrating fish culture in marginal lands.
- Determining socio-economic costs and benefits of salinity management practices in the Batinah region.

Tomatoes grown under saline irrigation

Findings from the project confirmed that:

- Salt-tolerant varieties of tomatoes, barley, sorghum, and pearl millet can be grown successfully in saline soils of the Batinah coast. It was possible to grow such crops with saline irrigation of 6-9 dS/m water (1 dS/m water is equivalent to 640 ppm of salts). Tomato (Ginan variety) was best grown with irrigation water of 6 dS/m and by adding mixed fertilizer (organic and mineral in 1:1 combination).
- Mulching surface soil with a thin layer of shredded date palm residues resulted in lesser salt accumulation in the soil resulting in more crop yield than other methods.
- Fodder (sorghum) grown in saline soils with saline water has no negative effects on growth or meat quality of goats.
- Incorporation of aquaculture (using red hybrid tilapia *Oreochromis sp.*) in saline areas was proven feasible and could partially compensate for salinity induced crop losses. Nutrients in water that come out of fish ponds enhanced crop growth.

Sorghum grown under saline irrigation

The project has shown that under careful management, it is possible for farmers to make a living from salt-affected lands by adopting various techniques such as appropriate use of salt-tolerant crops, fertilizers, and mulches; and by diversifying into non-traditional areas of income generation such as aquaculture. This low-cost system for treatment of greywater and low quality surface water, if adopted on a large scale, will contribute to the overall environmental sustainability by lessening demands on freshwater resources in many countries of the world.

Aquaculture using saline water

Innovating Ways to Face the Effects of Environmental Degradation

Mahi Tabet-Aoul

The environmental degradation process in the Maghreb is mainly of natural origin, but has been accelerated by human activities. The most dangerous threats caused by environmental degradation are soil degradation and desertification, pollution, droughts, floods, and water scarcity.

Action is urgently needed to return lands to their original vocation, to implement large-scale reforestation, to rehabilitate the steppe and oasis, and to ensure the stability of rural communities. But what kind of action, and action by whom?

Addressing the causes and consequences of environmental degradation requires a new model of governance — one that is democratic and decentralized. More specifically, it requires the involvement of local communities in development projects — from conception, through implementation, and after completion. Enlisting this involvement and unleashing its potential in turn requires imagination, bold experimentation, and the application of new tools and technologies. As this essay demonstrates, some of these initiatives are already underway, providing encouraging evidence that many others may lie within our reach.

INQUIRIES ON THE EXPOSURE OF VULNERABLE COMMUNITIES TO ENVIRONMENTAL RISK

Conducting surveys on the perception of the effects of environmental degradation can be an effective way to raise the awareness of local policymakers, institutions, and communities to act against the sources of degradation. As a case study, we conducted an investigation[1] regarding the environmental risk perception by the community living around the industrial zone of Arzew in Algeria, which contains ten petrochemical complexes.

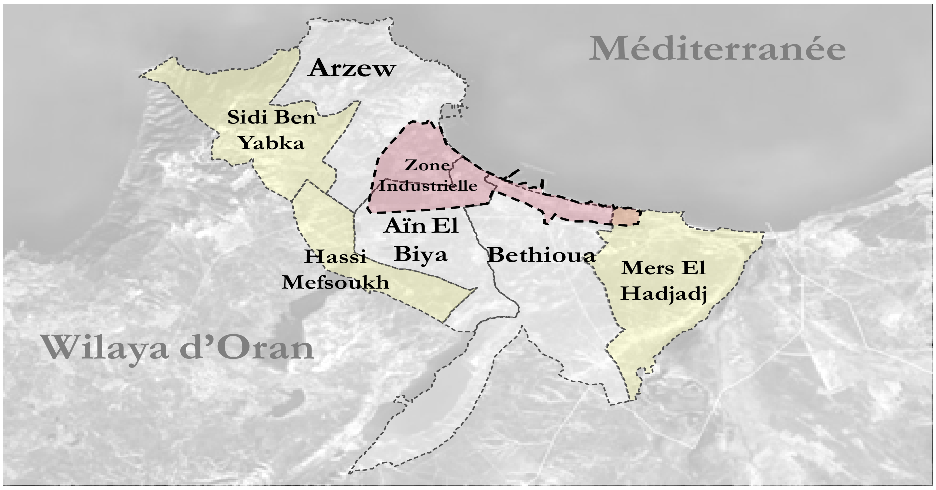
This industrial zone is located near a large urban area. It is devoid of an environmental monitoring system. The adverse effects on the health of nearby residents, and especially on the most vulnerable population, are patently obvious.

To assess the perception of environmental risk on the population, a survey was undertaken in 2006. This investigation had two objectives: to understand peoples' grievances and to raise awareness of industrial and institutional actors about the environment.

The survey covered 1,000 households randomly distributed over six municipalities, including the industrial area and its surroundings. It focused on four topics: economic data, environmental knowledge and risk perception, health status,

1. *Revue des Cahier du Centre de recherche en Anthropologie Sociale et Culture (CRASC)*, SENS – Société- Environnement et Société, December 2009.

Figure: Area Covered in the Survey



and actors' role. This investigation allowed the gathering of a lot of information. It appears that the population lives in relatively good conditions. With regard to the environment, 58% of the respondents attributed the occurrence of diseases to air pollution, 24% to solid wastes, and 14% water quality. In terms of health, 44% of households reported that at least one person is sick. 60% of diseases are respiratory deaths, including 83% related to air pollution. Regarding the issue of who is responsible for pollution, 37% of those surveyed blamed the decision-makers and 30% blamed the citizens.

These results show the high degree of awareness on environmental issues at the population level. This survey shows also that the Arzew population is cognizant of the dangers of air pollution and its impact on their health. Consequently, their involvement is crucial. The survey highlights the necessity for mutual listening and shared responsibility among all stakeholders.

SHARING AVAILABLE INFORMATION ON THE ENVIRONMENT AT THE LOCAL LEVEL

Today, everyone agrees that whereas environmental degradation is occurring on a global scale, the responses to it must take place on a local scale. The question is how to deal locally with degradation? The goal is to involve all local actors concerned with development — policy makers, businesses, non-governmental organizations (NGOs), and community representatives — to set up local charters for sustainable development. This implies the participation of all to reach a consensus on the choice of a development model based on local natural resources and human potential.

The first step to initiate this process is to raise awareness and to gather research, studies, and information already available locally. This requires the establishment of centers for collecting and disseminating information. New media and communication can serve as effective carriers for this action. Setting up platforms[2] on the internet can boost information exchange on climate, environment, and sustainable development in the Maghreb region. These sites are often initi-

2. See, for example, the author's website: http://maghreb-clim-env.jimdo.com.

ated by volunteer leaders who are fighting against environmental degradation. The sites allow researchers, students, and the general public to find reports on environment and development for the region that were carried out either by local researchers or institutions, or by researchers and experts involved in projects financed by international partners. These sites serve as a bridge between different actors, and are asked to provide information, expertise, and advice and run workshops and conferences on the environment at the request of institutions, universities, and associations. Through these sites, actors learn to exchange their views in developing a "consensus culture." The sites also help build local institutional capacity.

IMPLEMENTING VOLUNTARY ACTIONS ON ENVIRONMENTAL EDUCATION

The "Synthetic Course on the Environment and Sustainable Development" is a training program for experienced staffs of institutions, companies, universities, and associations. This initiative, begun in 2004 and based on two books[3] by the author, was taken outside any institutional, partisan, or associative tutorship.

The basic idea is to provide concise and practical instruction on environment through "study days." Each study day lasts for five hours and gathers groups of about 20 people. As of December 2010, 16 such groups, totaling more than 400 persons, have been trained. The total production is of nearly 2,400 man days, covering the full cycle at the rate of one day every three weeks.

The mission of this project is to invest in younger generations in particular — to provide them with the conceptual and practical tools that will help them to improve their environment and thereby protect their health and well being. The success of the project in fulfilling this mission is attributable to the solidarity, availability, and assistance of many willing partners who have sometimes engaged their own staff and have graciously provided all the logistics necessary to convene the study days.

However, many things remain to be done for the effective implementation of the lessons learned through use of acquired tools and environmental management. At the end of the training, participants are asked to think about a number of fields to be explored, such as: strengthening links to form an active relationship through the establishment of an exchange network via the internet; initiation of specific community projects to protect and rehabilitate the environment; types of contributions that can bring everyone to his/her own environment; a definition of a practical and common process for short-, medium-, and long-terms; and need to build consensus around the learned concepts and techniques.

Each trained participant is called upon to share and disseminate his/her own experience as a new trainer or to develop an

3. Mahi Tabet Aoul, *Environnement et développement durable au Maghreb: Contraintes et enjeux* [*Environment and Sustainable Development: Constraints and Opportunities*] (Quebec : Centre des Hautes Etudes Internationales (HEI), Laval University, 2010) ; and Santé — Environnement — Société, [Health — Environment — Society] Cahiers du Centre de Recherche en Anthropologie Sociale et Culturelle (CRASC) (December 2009).

environmental initiative to ensure sustainability and amplification of this training action by implementing local projects.

CONCLUSION

The initiatives described above have sought to raise awareness, inform, train, and develop projects to address the environmental degradation. Each of these initiatives has elicited positive feedback. Together, they have enlarged the circle of participants who are actively engaged in combating environmental degradation. They are illustrative not only of the innovative work that is needed to arrest environmental degradation, but of its potential.

At one time or another, everyone feels concerned about environmental degradation. However, we must go beyond sterile criticism and, instead, assume personal responsibility for working to combat it. The solution to addressing environmental degradation lies within each of us.

Improvement of Air Quality in Egypt: The Role of Natural Gas

Ibrahim Abdel Gelil

Egypt has had more than four decades of intensive natural gas exploration and development activities, which have become the main focus of the country's hydrocarbon industry. Current natural gas reserves estimated at around 78 trillion cubic feet have developed to be far more abundant than those of oil and are continuing to increase steadily.[1] Since the early 1980s, the Government of Egypt recognized that utilizing Egypt's abundant natural gas could, in addition to fostering economic growth, make a significant contribution toward improving air quality and protecting public health. Given its unique economic and environmental advantages, Egypt's energy policy was developed to maximize switching to natural gas in various economic sectors. Strategies to achieve this policy included developing natural gas infrastructure, whereby the national gas pipeline grid has expanded from 1,000 to more than 17,000 km. Expanding the local gas market and developing domestic gas demand have been other strategies that proved to be effective. As a result, the share of natural gas in Egypt's primary energy consumption has grown from about 24% in 1990 to nearly 45%.[2] The number of domestic gas consumers reached about 3.3 million and planned to grow to 5.5 million by 2015. Consuming about 60% of the total gas consumption, the electricity sector is the largest gas consumer, which plans to depend 100% on natural gas in the years to come.

In addition to switching to natural gas in the electricity generation, industry, and residential sectors, the Egyptian Government encouraged the private sector to commercialize natural gas vehicles (NGVs). In December 1994, the first company to convert gasoline vehicles to natural gas was formed. Currently, there are 6 operating compressed natural gas (CNG) companies, 119 CNG fuelling stations, and about 110,000 CNG vehicles in use, 75% of which are taxis, mainly in Cairo. A primary key to the NGV industry's success in Egypt is a package of financial incentives offered by the Government including 5-year tax holidays for CNG companies, low-cost conversion charges for car owners, and attractive price differential between CNG and gasoline. At about $0.08 per cubic meter of CNG (equivalent in energy content to a litre of gasoline), it is less than a quarter of the local gasoline price of 1.75 Egyptian Pound (LE) per liter ($0.30). In addition, a typical vehicle conversion kit costs about $900. Owners of high fuel use vehicles, such as taxis, can recover their cost of vehicle conversion in as little as six months from fuel savings alone. This clearly explains why taxis have been the most converted fleet.

Another exciting development for Egypt's CNG growth was the Joint Egypt/US-sponsored $63 million Cairo Air Improvement Project (CAIP). This initiative had focused on improving Cairo's air quality through reducing harmful emissions from lead smelters and from vehicles' exhausts. Part of this program included providing 50 dedicated CNG public transit buses to the Cairo public transport fleet. The bus bodies were locally manufactured, but the CNG engines and

1. Egyptian Natural Gas Holding Company (EGAS), 2010, http://www.egas.com.eg/Egyptian_Natural_Gas/Introduction.aspx.
2. Egyptian Environmental Affairs Agency (EEAA), Egypt's second national communication under the UNFCCC, 2010.

the rolling chasse were manufactured in the United States. Key challenges for the government have been replicating that initiative by funding the conversion of the some 5,000 public buses operating in Cairo and changing the price differential between CNG and diesel fuel, which is heavily subsidized. So far, the government has managed to increase the number of CNG buses to nearly 200. In parallel, another program is being implemented to convert government-owned vehicles to CNG. To date, more than 2,300 vehicles have been converted.[3]

Furthermore, the government is currently implementing an initiative aimed to swap a fleet of nearly 40,000 old polluting taxis with modern CNG-fuelled vehicles. The initiative started in Metropolitan Cairo, hosting 25% of Egypt's population and about 60% of registered vehicles, and will be expanded to other governorates afterwards. Again, economic incentives are playing the major role behind the success of this initiative. In addition to concessional loans, new locally-assembled CNG vehicles are exempt from about 55% of customs and consumption taxes. In return, participating taxi owners have to scrap their old vehicles. The project will have significant impacts on the air quality of Cairo, a megacity suffering from a high level of air pollution. Egypt is now being recognized as having one of the top ten most successful CNG commercialization programs worldwide.

This policy of switching to natural gas has significantly impacted the improvement of air quality, especially in Cairo. Addressing the problem of air quality has been the focus of environmental policy in Egypt for many years. The national air quality management program includes a broad array of policies and measures to curb emissions of pollutants from both stationary and mobile sources.

The total number of cars in Egypt increased from 2.1 million in 1992 to 4.3 million in 2008.

Pollution sources in Cairo include industrial activities, power stations, and vehicles emissions. Industry is a major source of pollution in Cairo. There are about 36,000 industrial establishments scattered in the area; heavy-polluting industries such as cement, steel, and chemical exist north and south of the urban center. The total number of cars in Egypt increased from 2.1 million in 1992 to 4.3 million in 2008.[4] The number of current registered passenger cars in Cairo is nearly one million, 25% of which are 20-years-old or more.[5] Additionally, power stations are also a major source of air emissions as Cairo is home to seven thermal power stations having a total capacity equal to 4600 megawatts.[6]

Moreover, the climate in Cairo is always sunny and dry. Rain is rare (about 22 mm annually) and wind speed averages about five meters per second. These climate conditions enable air pollutants to accumulate and suspend in the air, leading to the smog phenomenon. When warm air stays near the ground instead of rising, a natural phenomenon known as thermal inversion, and when winds are calm, smog forms and may stay in place for days, leading to high concentrations of toxic gases that pose public health risks. The locally-named "Black Cloud," a dense layer of smoke and fog over Cairo

3. EEAA, *State of the Environment Report*, 2009.
4. EEAA, *State of the Environment Report*, 2008.
5. The Egyptian Cabinet — Information and Decision Support Center, *Cars in Egypt*, 2007.
6. Egypt Container Holding Company (ECHC), Annual Report, 2007.

that occurs annually between October and November appeared for the first time in 1999, when it sparked widespread panic and heated debate. In addition to the sources of pollution discussed above, rice straw burning in the Delta and burning solid waste in Cairo were also named as causes of that pollution episode. According to a World Bank study, the annual cost of environmental degradation in Egypt was estimated to be 14.6 billion LE per year. It accounts for 4.5% of GDP and air pollution costs represent 44% of the total costs.[7]

Air quality in Egypt has been partially monitored since the early 1970s. An air quality monitoring network has been continuously updated with support from the Danish Government to reach a total of 87 stations covering different geographic locations. Typically, particulates (PM_{10}) and lead are the most critical air quality problems, especially in Cairo. Ambient lead concentration used to be far beyond the World Health Organization (WHO) standards mainly due to informal secondary lead smelters scattered within the residential areas. Phasing out leaded gasoline, relocation of lead smelters, and switching to natural gas have largely contributed to reduction of lead pollution.

A recent state of the environment report of Egypt recorded a gradual improvement of air quality. The report indicated a steady improvement in concentrations of sulfur dioxide, lead and carbon monoxide over the period 2004–2008. On the other hand, the chronic problem of pollution by particulates is still unsolved. It should be noted that the overall average concentrations of nitrogen oxides during the last five years had exceeded the limit. This might be a side effect of excessive use of natural gas; an issue that remains to be tackled by environmental experts. It is worth noting that the natural gas switching policy in Egypt, although achieving several economic, social, and environmental objectives, is also considered a cornerstone in mitigating greenhouse emissions. Switching to low carbon fuels such as natural gas is eligible for credit under the Clean Development Mechanism (CDM) of the Kyoto Protocol. It is estimated that about one-third of the projected carbon credits earned by Egypt within the CDM would come from natural gas projects.

7. The World Bank, *Cost of Environmental Degradation*, 2002.

The Politics of Water Scarcity in Egypt

Brian Chatterton

We are entering the era of water scarcity throughout the world. Water scarcity is different from mined resources that become scarce when the lode runs out. Water is almost always renewable. The scarcity applies to expansion. For thousands of years, supply has been expanded through engineering. Nowhere is that more obvious than in Egypt, where water demand has been met by increasing supply. Expansion accelerated during the 19^{th} and 20^{th} centuries, but has now ground to a halt as there is no more water to collect, store, and distribute.

The hydraulic mission conducted by engineers is over. The resource is now closed and must be allocated among farmers, industry, and domestic users while enough remains in order to maintain the environment.

SCARCITY IN EGYPT

The age of scarcity requires political and cultural change. Policymakers have been trained and have lived their lives during an age of plenty — not just for water but for all resources. Adjusting to a closed resource is difficult for politicians, administrators, and society as a whole.

In Egypt there is an acceptance of closure within the senior levels of the Ministry of Irrigation and other Ministries connected to water but not within the public political discourse.

The National Water Resource Plan 2017[1] prepared for the Ministry of Irrigation spells out the details of closure. The available Nile water remains stable at 55.5 billion cubic meters and while there are small increases from fossil groundwater sources and recycling the plan goes on to predict a substantial fall in the water available per irrigated hectare. Using a rather simple formula of water = crop = income, it predicts a 20% reduction in farmers' income as a result of water scarcity by the year 2017. Farmers are already one of the poorest sectors of Egyptian society; such a fall in income will have serious political consequences.

ALLOCATION

The Egyptian water resource is closed or nearly closed to further expansion. Population and land under irrigation are increasing. Water will have to be rationed not just between agriculture and other uses but within agriculture itself.

1. "Water for the Future: National Water Resource Plan 2017," National Water Resources Plan, Ministry of Water Resources and Irrigation, Arab Republic of Egypt, Cairo (2005).

Table 1: Adapted from Table 5 in the "Water for the Future: National Water Resources Plan 2017" (NWRP 2005)

	Unit	1997 Base	2017 (a)
Population	Millions	59.3	83.1
Water resource - Nile	Billions of cubic meters	55.5	55.5
Fossil ground water (non-renewable)	Billions of cubic meters	0.71	3.96
Water /head including fossil water	Cubic meters	936	710
Self sufficiency in cereals	Percentage	73.00%	46.00%
Area irrigated	Millions hectares	3.35	4.57
Water available per hectare	Cu m./hectare/year	10700	9204
Average income of farmers	$US /year	923	742
Efficiency (consumptive use/abstraction)	percentage	67.00%	61.00%

2017 (a) Based on water development plans but excluding 105,000 of expansion in the Sinai, which is made dependent on more water reaching Egypt through the construction of the Jonglai canal.

A WATER MARKET

The World Bank and other water economists are advocating a water market as a solution to the thorny problem of allocating a closed resource.[2] In Australia, the Murray Darling basin has been converted into a water market. The Australian water market has been operating for over a decade.[3] During first decade of the 21st century, the catchment has suffered from the worst drought recorded and provides a working example of a water market as a means of allocating a scarce resource.

Property Rights

Like all markets, that for water is based solidly on property rights. In Australia, most of the water is metered already. In Egypt, that is not the case. During the Australian drought, when water scarcity was acute, the meters proved to be inadequate. Farmers could, and did, tamper with them. Australia is now investing heavily in more sophisticated meters. For Egypt, the cost of metering water to many millions of small farmers would be extremely high.

Reduction of Salinity

Reduced salinity was put forward as a benefit from the market in Australia. The reasoning was that water could be traded out of and into areas with low salinity but only out of areas with high salinity. The natural turnover of the market would gradually move water away from these saline areas. Salinity is a much greater problem in Australia than in Egypt.

2. "Making the Most of Scarcity. Accountability for Better Water Management Results in the Middle East and North Africa," The World Bank (2007).
3. Brian and Lynne Chatterton, "The Australian Water Market Experiment," *Water International*, Vol. 26, No. 1 (March 2001), pp. 62–68.

Improved Efficiency of Use

Saleable water rights encourage farmers to use water efficiently through improved irrigation techniques. This process of improvement was taking place in Australia before the water market and in Egypt farmers already have a high level of efficiency (See table above). The water market gives an added incentive to efficiency improvements as surplus water can be sold.

Without a water market, this surplus water is an on-farm reserve but when it is sold to another farmer it is used to expand the area under cultivation. When the Australian drought came, everyone suffered, as allocations had to be reduced well below the amount shown on the title certificate. The on-farm reserves had been sold.

Higher Value Crops

Another claimed advantage of the water market is that it makes the value of water obvious to the farmer and that they will then shift production from low-value crops to high-value crops. The World Bank has already suggested that Egypt produce more high-value crops for export and import cheap cereal grains.[4]

It seems obvious that shifting water to higher value crops would improve farmers' incomes [but] ... High returns to water do not necessarily represent high returns to capital, labor, or other factors of production.

Apparently, there are large gains to be made from high-value crops. In Australia, only 20% of the water produces more than 80% of the value of production. It seems obvious that shifting water to higher value crops would improve farmers' incomes.

This is a rather water-centric view of farming. High returns to water do not necessarily represent high returns to capital, labor, or other factors of production. Australia is also in the lucky position of not having to consider food security from its irrigated land, as it has a large export surplus of basic food from its dryland farming areas. Egypt has to balance the risks of low-value grain for home consumption against the risks of high-value fresh fruit for export.

While high-value crops are much loved by theoretical economists, farmers tend to be more cynical, as they have seen many high-value crops converted into low-value crops through increased production.

Whatever the theoretical arguments, the acute water scarcity during the Australian drought demonstrated the failure of concept in practice. The high-value crops were not saved. While the executives of the basin authority[5] claim a great

4. "Agriculture for Development," *World Development Report 2008*, The World Bank (2008).
5. Wendy Craik, "Irrigated Agriculture — Managing with Less," paper to ABARE Outlook 2008, March 4, 2008.

success for the water market as more water was traded during the drought and the price increased three times, large areas of high value vines and fruit trees were destroyed. Price alone could not drag enough water out from other low-value uses, and the farmers' ability to pay for the high-priced water rights was not solely based on a water price/output formula. Experience from other droughts shows that farmers' survival was mainly related to equity. Farmers with high equity survive. Those with high debts do not. Efficient farming rated very low as an indicator of survival.

The executive of the basin authority did not intervene in the water market to allocate water directly to high-value crops, but politicians in Egypt may not be so willing to give up their power to the market mechanism.

Cost to New Growers

Giving water a monetary value is seen as a great benefit by economic theorists, but again the reality as demonstrated by the Australian example is different. New farmers have to purchase water rights in order to irrigate their land. This is a real capital cost. The cost does not arise immediately, as existing farmers are given their water rights free. However, over the years they retire, and new entrants are burdened with this added cost. In Egypt, with the projected fall in income for farmers by 2017, added costs for water rights would make their position even worse.

In Egypt, with the projected fall in income for farmers by 2017, added costs for water rights would make their position even worse.

There is also the question of fairness. The water of the Nile has been used by farmers for thousands of years. The introduction of water rights would, in effect, give that water to a single generation of farmers who are lucky enough to be water users at the time. They can leave with that bonanza in cash while future generations have to find and service the additional capital needed to pay the first generation their bonanza. The second and further generations can pass the capital cost on when they leave farming, but their profits will be insignificant compared to the lucky first.

Environment Needs at Cost to Taxpayer

The Australian drought demonstrated clearly that the water had been over-allocated to farmers. The amount of water delivered was at times as little as 5% of the amount shown on the title. The environment suffered even more severely, as there was no surplus from irrigation for environmental needs. The Murray River stopped flowing into the sea. The lakes at the river mouth shrunk due to a lack of recharge, as did many lakes along the course of the river. The basin authority has now advised the Australian government to reduce the amount diverted to farming by about 25%. This would provide more water for the environment and greater stability for farmers.

Buying back such a large amount of water from the market will cost the Australian taxpayer billions of dollars. Australia can afford to do so as it has a large and prosperous economy outside irrigated agriculture. The national debt is only 9% of GDP. In Egypt, agriculture is relatively more important, and there is virtually none outside the irrigated sector.

THE POLITICAL SOLUTION - DEMOCRATIC DEVOLUTION TO LOCAL GROUPS

The water market provides a neat theoretical model for the allocation of scarce water resources, but the Australian example shows clearly that many of the theoretical benefits are not realized in practice while the costs to the government and future generations are extremely high. Already the Egyptian government has indicated that it is opposed to a market solution to water allocation. An alternative that is under discussion is to allocate water through democratic devolution. This is not a neat theoretical model but a messy political solution. It is a process rather than a model. By definition, the outcome is unclear, as the power is being delegated to the local farmers.

Water could be allocated in bulk to the branch canals that serve some 1,000–2,000 Egyptian farmers, who could then take responsibility for the further allocation within the group. The farmers would develop their own allocation formulas based on cultivated area, type of crop, and soil in order to produce water quotas for individual farmers.

CONCLUSION

Egypt is in a transitional phase. It is beginning to realize that the water resource is closed. However, the momentum from the old hydraulic mission is carrying expansion forward. The result is less water per hectare and lower incomes for farmers. These could have serious political repercussions.

A water market and a democratic devolution are at extreme policy poles for coping with scarcity. Markets are institutions that concentrate power in the hands of a few wealthy people while democratic devolution spreads power among a wide group of water users. While the Egyptian government is being advised to take the market route for the sake of efficiency, the Australian case study has shown that many of the claimed advantages of the market are in the eye of the economist, not on the ground. The Australian water market has also proved to be extremely costly for taxpayers. Egypt has undertaken an extensive program of land reform that has provided the government with strong support among farmers. A water market would reverse the gains made under land reform and place power over water in the hands of a few financially strong groups.

Environmental Science at Qatar University: Realizing Qatar's 2030 Vision

Malcolm Potts

ENVIRONMENTAL CHALLENGES FOR THE COUNTRIES OF THE GCC

A primary indicator of the robustness of a country's economy is the gross domestic product (GDP), which is essentially the total dollar value of all goods and services. In this respect, Qatar is recognized as the richest nation in the world,[1] with an unprecedented projected expansion in its GDP, notable during these troubled economic times, of 18.5% for 2010.[2] Oil and gas have made Qatar the second highest per capita income country, following Liechtenstein.[3] Such wealth does not come without problems, however, and like other countries in the Gulf region, Qatar is faced with a plethora of environmental challenges.

There is an expansive literature on environmental issues, urban growth, and pollution in the countries of the Gulf Co-operation Council (GCC) and an awareness that environmental pollution, degradation, and lack of resource management at the national and regional levels are priority issues of concern. Since the majority of the population lives in the coastal zone, the important issues are air quality, sewage and waste water management, garbage disposal, degradation of the near shore marine environment, land reclamation, provision of adequate electricity and potable water, conservation of natural resources, and all of the inherent social consequences.[4] These issues were the focus of a most informative international congress hosted by the Environmental Center for Arab Towns ("Challenges and Threats to the Environment — Lessons from the Past to Shape the Future") that the author attended in Dubai in 2006.[4]

In the past several years, international agencies have commented in depth on the underlying problems, which aggravate environmental issues in the Gulf region. The comments include:

> There is a persistent shortage of environmental specialists in the ESCWA (Economic and Social Commission for Western Asia) region. The existing environmental agencies need to further develop their capacities to tackle environmental challenges on a trans-boundary scale. At present, any attempts to improve environmental standards are held back by the lack of skilled manpower and technological expertise.[5]
>
> The region lacks the capacity to manage hazardous waste safely: it lacks appropriate storage and disposal facilities; it lacks the requisite skills to evaluate risks and monitor controlled dumping or recycling; and it lacks, as yet, the

1. "The World's Richest and Poorest Countries," http://www.gfmag.com/tools/global-database/economic-data/10299-the-worlds-richest-and-poorest-countries.html.
2. "Qatar's GDP Growth Seen at 16% 2010–11," http://www.ameinfo.com/227843.html.
3. "Qatar Economy 2011," http://www.theodora.com/wfbcurrent/qatar/qatar_economy.html.
4. "Sama Dubai Supports Launch of Environmental Center for Arab Towns," http://www.ameinfo.com/102992.html.
5. PriceWaterhouseCoopers issued the following document under Framework Contract EC TRADE 02-F3-03: "Sustainability Impact Assessment (SIA) of the Negotiations of the Trade Agreement Between the European Community and the Countries of the Cooperation Council for the Arab States of the Gulf (GCC)" (2004).

> capacity to undertake detection, remediation or possible treatment.[6]
>
> A joint regional body of experts and representatives of Governments, non-governmental organizations, and regional and international organizations is needed.[7]

ADVANCING SUSTAINABLE DEVELOPMENT — QATAR NATIONAL VISION 2030

The Qatar General Secretariat for Developmental Planning recently published the report "Advancing Sustainable Development — Qatar National Vision 2030" (QNV 2030), a decisive study.[8] The key conclusions and recommendations of QNV 2030 emphasize the overwhelming importance of the environment as one of four pillars for sustainable development in Qatar. Key recommendations/observations include:

- "A critical challenge is to combine economic progress with sustainable *environmental* policies."
- "The QNV 2030 commits to maintaining harmony between economic growth, social development and *environmental* management in building a bright future for the people of Qatar."
- "Innovative desalination technologies that minimize both cost of water production and the *environmental* impact should be further investigated."
- "Threats to the health, productivity and biodiversity of the marine *environment* result largely from human activities."
- "Qatar needs to continue to build its scientific and technical capacity through investments in people, research institutions and its overall science and technology context."
- "Build national capacity for developing, implementing, monitoring and evaluating environment-related policies and programs."

The report emphasizes the clear need for a spectrum of qualified workers in the environmental field, from research scientists (research experience) to workers in regulatory positions (professional experience). Furthermore, the QNV 2030 report identifies three of Qatar's environmental stress points, namely water security, threats to the marine environment, and climate change, which are driven largely by human activities. There is a compelling need to manage environmental problems in an ecologically- and environmentally-compatible manner, and this is of especial relevance with regard to the marine environment and its resources (fisheries, recreational, etc).

6. The Supreme Council for the Environment and Natural Reserves of Qatar, "National Biodiversity Strategy and Action Plan" (2004). This document, in adherence to the Convention on Biological Diversity, encompassed recommendations from the Scientific and Applied Research Center (SARC), Government Ministries, and other institutions and consultants.
7. The Economic and Social Commission for Western Asia (ESCWA) issued a document in 2005 through the United Nations (E/ESCWA/SDPD/2005/5 July) that summarized the State of the Environment in the Gulf Region conference and its recommendations.
8. The Qatar General Secretariat for Developmental Planning, "Advancing Sustainable Development-Qatar National Vision 2030," Second National Human Development Report (2009).

RESEARCH AND TEACHING IN ENVIRONMENTAL SCIENCE AT QATAR UNIVERSITY – BSC AND MSC

The education of youth is of critical importance in this region. The BSc in Environmental Science at Qatar University was designed as a degree program of four years, with 125 credit hours of study and options for specialization in either Marine Science or Biotechnology. The program, with its home in the Department of Biological and Environmental Sciences (DBES) was opened in 2008 and, currently, there are more than 30 students enrolled in the program. Of this student body, it is clear that many have elected to continue their graduate studies and to complete the degree of MSc (see below) in the DBES. The BSc curriculum is an eclectic one since it draws on courses and faculty from contributing departments in the colleges of Arts and Sciences, Engineering, and Law. An important aspect of the program is a summer internship with a stakeholder, as well as a research experience (Figure 1). The specific objective of the BSc in Environmental Science is to provide undergraduate education and research in the broad field of environmental sciences to address the needs of Qatari society, particularly the workforce needs of stakeholders. The program seeks to educate students in current concepts, research, technological advances, and underlying scientific principles in the study of: marine and desert ecosystems; management and conservation of natural resources; urban and regional planning; needs of society and social consequences of urban and industrial growth; resource management (especially water); waste management; and environmental laws, regulations and environmental science policy as they pertain to the GCC in general, and specifically to the State of Qatar.

The DBES is currently pursuing accreditation for the BSc program with the Committee for the Heads of Environmental Sciences (CHES) through the Institution for Environmental Science (IES), in the United Kingdom. Accreditation of the MSc program (see below) will also be pursued through this agency.

The recently designed MSc in Environmental Science in the DBES involves two years of study (34 credits of coursework) and the option to complete either two semesters of focused research for submission of a MSc thesis or an internship with a stakeholder and submission of a technical report. The program will be opened to full-time and part-time students in Fall 2011. For the MSc program we focused on the development of foundation (core) courses and electives of particular relevance to the needs in Qatar, and designed the curriculum in the context of the Benchmark Statement for Environmental Sciences of the Quality Assurance Agency (QAA) of the United Kingdom. The MSc curriculum incorporates a graduate seminar (based on the format of the freshman seminar in the BSc program), lectures, group projects, tutorials, laboratory critical thinking, intensive writing, problem solving through research, field internships, and independent research.

The specific objective of the BSc in Environmental Science is to provide undergraduate education and research in the broad field of environmental sciences to address the needs of Qatari society, particularly the workforce needs of stakeholders.

In addition to these recent developments, from Fall 2000 to Fall 2010, some 100 undergraduate research projects were completed in the DBES (enrollment in the BSc in Biology and BSc in Environmental Science programs). In fact, the majority of these projects were (are) focused on topics in environmental science including: biodiversity, remediation, environmental health, toxicology, etc. These projects contributed to the development of the research and teaching infrastructure for the study of environmental science at Qatar University.

The DBES established "Biology Field" in the grounds of Qatar University to both conserve and protect the natural biodiversity of animals and plants there, and to serve as a resource for students enrolled in the degree programs of the DBES. Another venue for teaching and research is the University Farm, administered by the DBES, in the north of Qatar.

THE ENVIRONMENTAL STUDIES CENTER AT QATAR UNIVERSITY

A number of the faculty in the DBES are affiliated with The Environmental Studies Center at Qatar University (http://www.qu.edu.qa/offices/research/esc/). The ESC is one of the oldest research centers in the Gulf region. Since its establishment in 1980, under the name of SARC, the Center has established its credibility as a lead institution for marine science in the region. The mandate of the ESC is protection of the natural heritage of Qatar. The ESC provides comprehensive facilities and opportunities for continued training and research in all aspects of environmental science, including environmental impact assessments within the country.

Further opportunities for research and education include the ESC's current ocean-going vessel, the Mukhtabar Al-Bihar, which is an effective mobile laboratory serving different branches of marine science. It is used to perform various types of projects in different marine research areas such as fisheries, marine biology, and physical, chemical, and geological oceanography (Figure 1). Very recently, a delegation from QU attended the ground-breaking ceremony for the keel laying of the national research vessel *Janan*, named after the island located in the western part of the Qatari peninsula.[9] The *Janan* will provide state-of-the-art facilities for faculty, technical staff, and students, including a sewage treatment unit, water desalination plant, an ER for medical emergencies, and a diving room.

RESEARCH AND EDUCATION IN ENVIRONMENTAL SCIENCE AND SUSTAINABILITY IN QATAR

Qatar National Research Fund has the mandate to support undergraduate and graduate education in Qatar. New infrastructure includes the development of Education City and the Qatar Science and Technology Park. Flagship programs include the National Priorities Research Program (NPRP) as well as the Undergraduate Research Experience Program (UREP); both of these programs are of relevance to the study of environmental sciences in Qatar. In the DBES, one NPRP-funded program entitled "A Middle East Research Consortium" supports collaboration between our department and the Centre for Biotechnology (CBS) in Sfax, Tunisia. CBS has extensive and well-established MSc and PhD programs that allowed in the past three years, and continue to allow, reciprocal exchanges of students, technicians, and faculty between CBS and the DBES. In addition, one UREP grant, as well as internal support from QU, made it possible to establish the

9. "QU Delegation Attend Groundbreaking Ceremony in Spain," http://www.qu.edu.qa/newsletters/campuslife/article.php?id=2047

Students from the program in Environmental Sciences of the DBES aboard the vessel Mukhtabar Al-Bihar in the Arabian Gulf (Spring 2010), sampling a bloom of cyanobacteria and utilizing techniques for plankton concentration and analyses.

Qatar University Culture Collection of Cyanobacteria and Microalgae (QUCCCM) representing biodiversity from the broad range of environments in Qatar. QUCCCM serves as a research and teaching resource for students and faculty.

SUSTAINABILITY OF QATAR

In the past decade, Qatar underwent unprecedented expansion in the development of industries from its gas and oil reserves. In fact, this expansion continues unabated despite a world recession. The QNV 2030 vision, recognition of the need to protect Qatar's natural reserves for future generations, collaboration on environmental issues with partners in the GCC, and the remarkable ongoing investment in higher education, constitute a paradigm — one that instills considerable optimism for the future of this small yet dynamic country and its efforts to bring positive change to the region.

Low-Cost Methods to Treat Greywater: A Case Study from Oman

Mushtaque Ahmed, S.A. Prathapar, and Seif Al-Adawi

Oman is an arid country where the pressure on freshwater reserves is as severe as that of any other arid or semi-arid country in the world. Increasing water availability by treating and reusing wastewater, particularly for irrigation, is a government policy in Oman. Identification of alternative sources of water and development of appropriate technology to harness them in order to reduce pressure on freshwater reserves and production capacity in Oman is a priority.

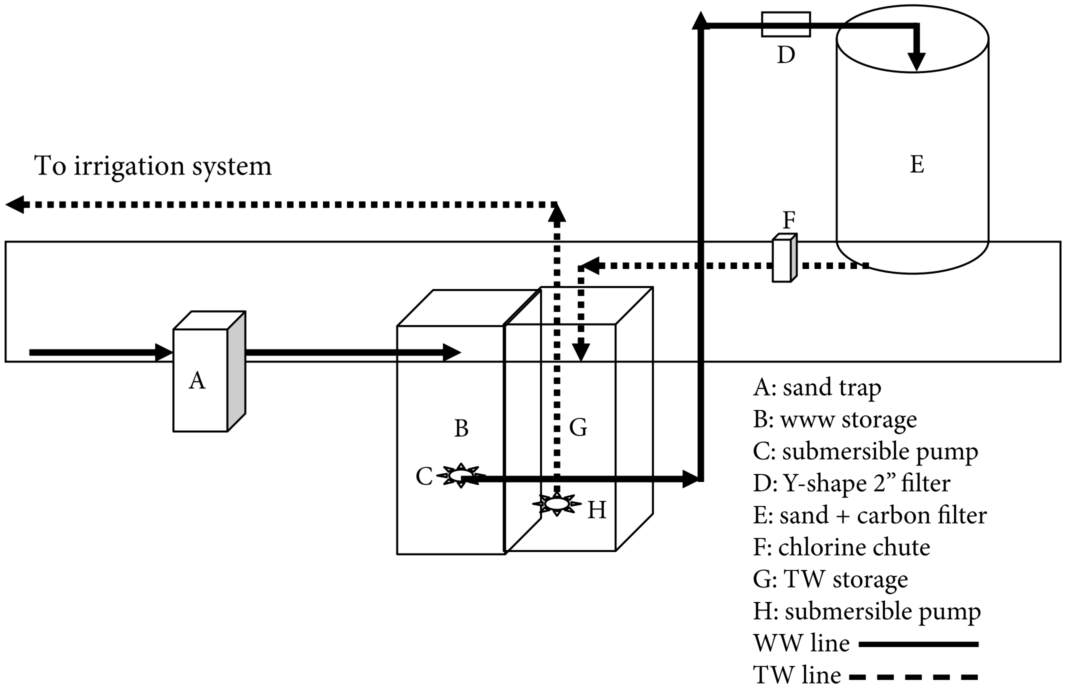
Experience from overseas, and in particular from arid and semi-arid countries, indicates that greywater can be a cost-effective alternative source of water. Greywater is washing water; water coming from baths, showers, washing machines, and bathroom sinks. Some sanitary experts define greywater as water that is lower quality than potable water (drinking water), but of higher quality than blackwater. Studies have shown that 80% of water used in Omani households is greywater.

Greywater can be used to further sustainable development and resource conservation without compromising public health and environmental quality. Under most conditions, it would be possible to reuse greywater with minimum treatment. Water for domestic use is produced at a very high cost. Domestic wastewater (combined greywater and blackwater) is also treated at high cost and then used for limited irrigation. If greywater is separated from blackwater, likely benefits will include water savings, reduction in wastewater treatment costs, and reduction in groundwater pollution, and will have positive environmental and economic benefits.

A research project was completed at Sultan Qaboos University in Oman with the objectives to quantify greywater production in urban Omani households and mosques, characterize important water quality parameters, and design simple

A mosque lawn irrigated with treated greywater

Figure 1: Simple Greywater Treatment System

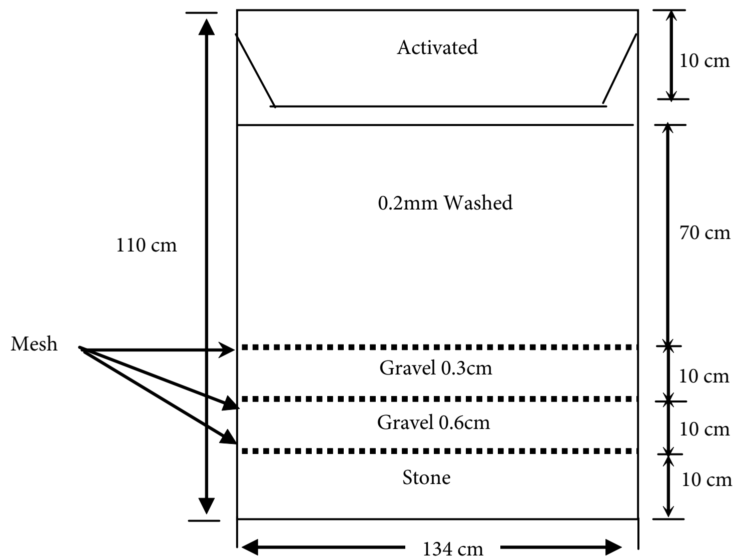


treatment systems. Results show a high degree of variability of greywater production and its quality from individual households and mosques. Experimental data show that a simple treatment system combining aeration, sand filtration, and chlorination will be able to meet the existing Omani reuse standards.

Commercially available greywater systems are too expensive for individual households and small mosques. Therefore, a low-cost low-maintenance treatment system was designed (Figure 1), constructed, and operated at a mosque (Al Hail, See photo above).

The ablution water was sent through a sand trap (A), to allow settlement of soil particles. Since the sand trap was shallow, periodic cleaning of this trap was easy. Subsequently, the ablution water was conveyed by gravity to the ablution water storage tank (B), and the water dropped from near soil surface to the water level, aerating on its way. The ablution water storage tank has a storage capacity of 3.82 m^3 per day if necessary, but it was noted that maximum ablution water produced in a day was only 1.94 m^3. Therefore, the storage tank will be adequate to store more water, in the event that the number of worshippers increased in the future. A submersible pump (C) of 0.4 horsepower was installed in the ablution water storage tank, which was controlled by a float. The pump operated whenever approximately 0.68 m^3 was added to the storage tank. Thus, untreated water was not held in the storage tank for prolonged periods. Water lifted by the pump was sent through an irrigation filter (D). This prevented floating matter proceeding further. Subsequently, water entered a filter unit (E), which consisted of an activated carbon tray (10 cm deep), 0.2 mm washed beach sand (70 cm deep), gravel 1/8 mm (10 cm deep), gravel ¼ mm (10 cm deep), and stones (10 cm deep) (Figure 2).

Figure 2: Design of sand and activated carbon filter (drawing not to scale)



Following filtration, the water passed through a chlorination chute (F), packed with chlorine tablets. These tablets contain 90% chlorine as Trichloroisocyanyric acid with solubility of 1.2g/100g of water at 30° C (its commercial name is NEO-CHLORO). Filtered water mixed with chlorine was then dropped into the treated water storage tank, being aerated on its passage. The treated water storage tank could store up to 3.825 m^3 per day if necessary.

A commercial system was installed at Sultan Qaboos University mosque which is much larger and produces a lot more greywater. This system also performed well and produced water satisfying the existing Omani standards for reuse. A commercial system was also installed in a household in Al Hail and its performance was also excellent.

The financial analysis showed that the internal rate of return (IRR) for the locally manufactured (Al Hail mosque system) and the commercial systems (SQU mosque) for the mosques were 14.9% and 19.06%, respectively. This shows that such systems will be cost effective. IRR for the commercial system at a private house indicated that such systems will not be cost effective. Costs of the systems and the amount of greywater treated were the main factors affecting the outcome of the financial analysis.

It is worth mentioning here that such systems are not restricted for treatment of greywater only. It is possible to use this system for improving the quality of low-quality surface water. A similar system was installed in the Al Jabal Al Akhdar area of Oman (see photo below). The government completed the building of 24 retention dams for storing surface water in this mountainous area. Most of these reservoirs are eutrophic because of the fecal matter of goats and donkeys that gets washed into the reservoir via surface run-off. These waters are also contaminated with unacceptable levels of coliform bacteria and some also had pathogenic *Escherichia coli*.

The constructed treatment system in Al Jabal Al Akhdar, Oman

The treatment unit significantly improved the quality of water with regards to COD, TSS, and a few other water quality parameters. Coliform and *E. coli* were completely eliminated. Treated water met the Omani standards for reuse for irrigation. A survey among the adult male population of the village overwhelmingly showed their eagerness to adopt this system and use the treated reservoir water for uses other than agriculture. Such change in water use patterns will definitely have an impact on groundwater extraction, as household requirements for groundwater are likely to decrease.

Middle East Institute