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Impending Water Crises: Desertification and Climate Change

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ABSTRACT: As populations increase throughout the world, water consumptive use is increasing, resulting in dramatic implications for many countries of the world. The expansion into and creation of, desert-like conditions in areas where such conditions have not naturally occurred, is approaching critical conditions as a result of overgrazing, overcultivation, deforestation and extensive and unsustainable irrigation practices.

The result is that one-third of the present global deserts are man-made, the result of human mis-use of the land. As a demonstration of the situation, in 1990, only 5 countries were in water scarcity. In 1995 there were 26 countries in water scarcity and in 2025 it is projected there will be 50 countries with a total population of 3 billion, in the situation of water scarcity.

The paper reviews the situation, providing examples in China, Iran and Canada including reflections on the basis of available water per capita and the lack of sustainability of the current situation and indications of trends from historical data. Some of the pressures for water transfer and some indications of the potential impact of global climate change are considered, all of which point to growing crises which are imminent in many countries of the world.

BACKGROUND

Impending water crises in arid and semi-arid regions of the world are intensifying in response to population growth, periodic drought, climate change and mis-management of water resources. These features are creating increased desertification, which is now widely recognized as a serious threat to arid and semi-arid environments. Desertified lands currently encompass 40% of the global land surface, housing a population of 1 billion. As populations increase, water use increases, intensifying the situation and resulting in dramatic implications to many parts of the world. Poor water use practices are resulting in permanent challenges for governments to provide water for cities in those areas.

Water, with its qualitative and quantitative effects, plays a critical role in economic and social expansion of societies and, unlike many other inputs, is irreplaceable. However, today's world is rapidly approaching a "Water Crisis", particularly in arid and semi arid regions. Reasons for the impending crisis include: accelerating rates of population increase, periodic droughts, climate change and mismanagement of water resources, all of which are increasing desertification trends.

According to IWRMO (2002) in the 1950s, only 5 countries were in water scarcity. Now, more than 26 countries are in water scarcity, with a total population exceeding 300 million. By 2025, projections indicate more than 50 countries with a population over 3 billion will be in water scarcity (see Figure 1).

Although extensive quantities of water exist on Earth, much of the world's water is not available for "consumption" due to salinity levels. The amount of water which is readily available represents only approximately 3%, as summarized in Figure 2. Making matters much worse is the unequal distribution of water where there is a frequent mismatch between the locations of people, and of water. Six countries namely Brazil, Russia, Canada, Indonesia, China and Colombia have one-half the world's total.

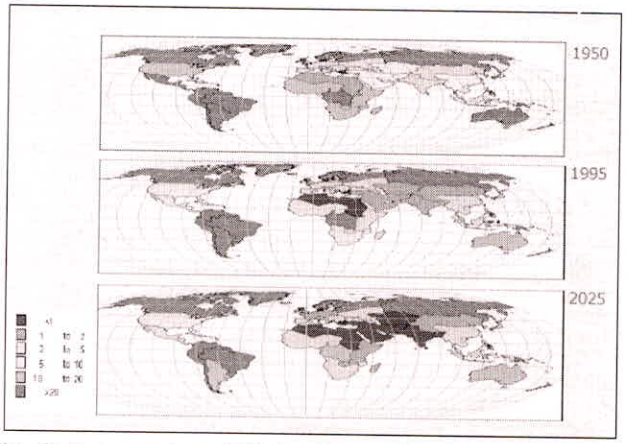

Fig. 1: Progression of Water Scarce Regions in the World from 1950 to 2025

Table 1 lists the volume of water per capita for a number of countries and demonstrates the extensive disparity from some of the most water-rich countries to some of the least water-rich countries (Water Encyclopedia, 2005).

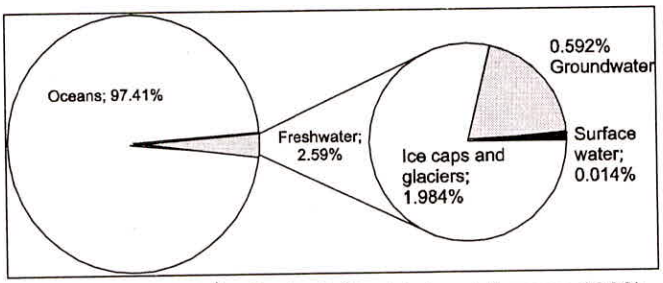

Fig. 2: World Water Budget (Speidel and Agnew, 1988)

Issues of water availability have greater impacts within the arid and semi-arid regions. Not only is there over-withdrawal from groundwater, shortages of water are intensifying due to agriculture (e.g., the growing of rice in water-short areas). This results in the deterioration of lands into desert conditions. Therefore, people from these regions are obliged to immigrate to other regions with more plentiful water resources. Due to the unsustainable situation in these regions and the lack of response from individual governments, massive migration of people will likely occur.

Table 1: Volume of Water Per Capita for a Number of Countries

Country	*Total (km^3/yr)*	*Volume of Water per Capita 10^3 (m^3/yr/capita)*
Canada	3122	134.0
China	2680	3.2
USA	2478	11.5
India	1850	3.0
Argentina	694	26.7
UK	163	2.9
Ghana	53	6.2
Libya	0.7	0.3
Oman	0.7	0.9

Arid and semi-arid environments cover more than 40% of the global land surface and provide habitat for more than 1 billion humans (Veron *et al.*, 2006). Rural people in these regions ultimately depend on the effective use of natural resources (Reynolds and Smith, 2002).

The global notion of desertification is a process of degradation that affects the arid and semi-arid portions of the earth. Aubreville (1949) used the term desertification to describe the change of productive land into desert, as a result of human activities. Later, Kassas (1995) described desertification at the United National Conference on Environment and Development as 'land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities'. The phenomenon of desertification is a dynamic process that includes both biophysical and socio-economic factors (Reynolds and Smith, 2002).

Hermann and Hutchinson (2005) cited UNEP (1991) wherein the definition was provided 'desertification as a result of human misuse of the land, is a worldwide problem directly affecting 250 million people and one-third of the earth's land surface'. Veron *et al.* (2006) indicated that 70% of all drylands are affected by desertification, indicating the widespread character of desertification.

The main causes of desertification are:

1. *Increases in population in arid and semi-arid countries:* Direct consumption (ingestion) of water amounts to approximately 1 m^3 in a year. Within and immediately adjacent to a dwelling, people use between 50 to 100 m^3/year. However, growing the crops to feed and clothe a person entails 1500 to 2000 m^3/person/year (Pearce, 2006) and hence, when populations increase, total consumption of water increases substantially. As an indication of status of supply, the World Health Organization's figures for 1980 show that among the urban population of developing countries, only about 55% had house connections and an additional 20% had access to public taps. Approximately one-half of these water supplies were intermittent. For the rural population, less than a quarter had access to safe water and many of these did not have house connections (Ahmed and Rahman, 2003).
2. *Over-withdrawal of groundwater:* To meet irrigation needs and also, to a significant extent, the needs for urban populations, widespread reliance is now on groundwater withdrawal. Ninety percent of the water abstracted from groundwater in Central Asia is for irrigation. However, the current rates of extraction of groundwater for the purposes of irrigation are not sustainable. For example, in India, current annual abstractions for irrigation are approximately 250 km^3 of water/year which is about 100 km^3 more than the rains replace (Pearce, 2006). The consequence of these huge withdrawals of groundwater is that the groundwater levels are dropping precipitously. Fifty years ago, groundwater

levels in Gujarat, India were 10 m below ground surface (bgs) and now, these same water levels are 500 m bgs. One of the consequences is that approximately one-half of India's heavily subsidized electricity is being used by farmers to pump water to the surface (Pearce, 2006). Even in New Zealand, six percent of the electricity is now being used to pump irrigation water from groundwater supplies (Sinton, 2007).

3. *Destruction or reduction of the vegetation and organic content of the soil:* Poor agricultural practices are reducing the stability of soil aggregates, by overgrazing and the needs of humans for trees for fuel. These destructive activities include the destruction of perennial vegetative cover and simplification of the vegetative structure which leaves the system less robust against disease intrusion, reduces infiltration to groundwater and increases the erosive stresses on the land.

   Problems also arise as a result of periodic drought. Specifically, when normal periodic conditions occur in the form of drought, which involves the incidence of below average availability of natural water, desertification may expand. WMO (2005) defined drought as: "A deficit of rainfall with respect to the long term mean, affecting a large area for one or several seasons or years, that drastically reduces primary production in natural ecosystems and rain-fed agriculture." (Le Houerou, 2002). Periodic drought is expected and hence a normal recurrent event in arid and semi-arid lands. However, when irrigation is extended to lands which should not be irrigated, desertification spreads and becomes self-propagating. The progression of features which form new deserts can be described by:

   Periods of better than average rainfall →
   Overcultivation and overgrazing on marginal lands →
   Normal or periodic drought →
   Destruction of grasslands →
   Formation of new deserts.

   The result is that poverty increases desertification. Droughts are a common and naturally recurrent event in arid and semi-arid lands. While well-managed lands can recover from droughts when the rains return and desertification can occur without drought, desertification is caused primarily by human abuse of the land. However, climate conditions such as drought may accelerate the phenomenon of the desertification (Dregne, 1986). Meanwhile, the relationship between desertification and drought and human influence, are complex. Prolonged drought has also lowered water tables in rivers, lakes, aquifers and dams. In many countries, the lowering of the water table has had serious repercussions for productive capacities and basic social services (UN, 1985). Hence, normal periodic drought may cause desertification because attempts at agriculture where conditions don't warrant it causes deserts to form when drought returns and groundwater sources are not sustainable. Incorrect irrigation practices in arid areas may cause salinization (the build-up of salts in the soil) which can prevent subsequent plant growth. Determining the contribution of climate variability to desertification is a complex matter. It is virtually impossible to separate the impacts of drought and desertification, because these processes often work together (Nicholson *et al.*, 1998).

4. *Climate change impacts in arid regions:* According to the World Meteorological Organization (WMO, 2005) "While approximately one-third of the world's land surface is arid or semi arid, it is predicted that there will be a 17 percent increase in the world area of desert land due to the climate change expected, with a doubling of atmospheric CO_2 content".

   A potential increase from 1–4.5°C in arid and semi-arid regions over the next decades due to increases of atmospheric carbon dioxide (McBean and Motiee, 2006), are predicted to increase global potential evapotranspiration (PET). This will cause the decrease in ratio of mean annual precipitation to PET by 4–5% (Le Houerou, 2002). However, not only can global warming contribute to desertification, it is expected that desertification will also contribute to global warming, by altering sources and sinks of greenhouse gases and the creation of dust storms. It is noted that the contribution of dryland degradation to global warming is unlikely to be more than a few percent of the effects of global warming (Hulme and Kelly, 1993).

CASE STUDY OF WATER RESOURCES IN CHINA

China has a mean annual precipitation of 648 mm per year. The total water resources in China ranks the country sixth in the world but the distribution of the water resources is extremely uneven and does not coordinate with the distribution of population, cultivated land and mineral resources. In the northern sector of China, the availability of water is just 500 m^3

per capita, but in the south, the availability of water is 20000 m^3 per capita (Guodong *et al.*, 2005). According to recent statistics, more than 400 of China's 668 cities are facing water shortages and of the 400, more than 100 are facing serious water shortages. Using any of the typical metrics, (i) water shortage (less than 2,000 m^3 per year per capita), (ii) water stress (less than 1,700 m^3 per year per capita), (iii) water scarcity (less than 1,000 m^3 per year per capita) and (iv) extreme water stress (less than 500 m^3 per year per capita), Rogers (1997) shows that if northern China was a separate country, it would be one of the most water-stressed areas in the world. And yet, farmers are growing rice in these same areas as evidenced during the senior author's recent visit to northern China.

Given the above, it is not surprising that China is faced with serious problems of desertification. The central portion and the major portion of the northwest of China has 791 counties which are threatened with desertification (Guodong *et al.*, 2005). The total area affected by this phenomenon is about 2.6 million km^2 which represents 27.3% of China. Since 400 million people live in these regions, enormous numbers of people are influenced by the consequences of desertification (FAO, 1997). Estimates show that the extension of the desertification in China is about 2460 km^2 where, according to the FAO (1997), desertification has occurred as a result of the combination of the specifics of the area, plus the influence of human activities. Rapid population increases have lead to over-utilization of land and water resources. These include intensification of agriculture and animal husbandry, agricultural reclamation on pasture land, deforestation, overgrazing, destruction of vegetation, misuse of water resources and the lack of environmental protection.

CASE STUDY IN IRAN

Iran, with a dry to semi-dry geographic environment and with an average rainfall of 250 mm/year, is facing extreme shortages of water in its southern and central parts (Figure 3). Sixty-five percent of Iran's area is 'dry', 20% is semi-dry and only 15% wet and semi-wet areas (Abedi, 2000). The result is that approximately 50% of Iran's population is living in the northern and western parts of country which have over 70% of water resources of the country (Motiee *et al.*, 2001).

The rapid growth of Iran's population, the slow process of building water reservoirs and recent dry years, has caused serious water shortages in the central and eastern parts of Iran. However, the northern and western mountainous areas of Iran have not incurred water shortages because of high rainfall (although the quality of water due to pollution remains a problem).

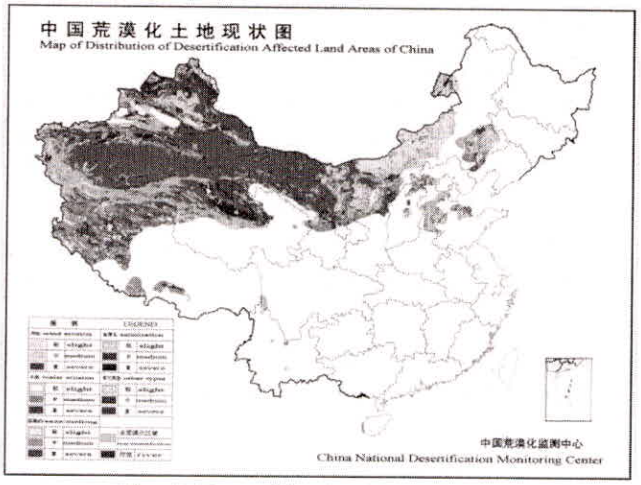

Fig. 3: Desertification Map of China
(*Source:* http://www.nrscc.gov.cn/english/about-mj21.asp)

There are four primary reasons for the serious water crisis in Iran:

1. *Rapid increases in population:* Since 1955, due to the cultural, social and economic changes in Iran, there has been a rapid increase in population such that during the last 50 years, the population has increased from 20 to 70 million people, as shown in Figure 4 (SCI, 2005), much of which has been in the major urban centers. The urban population of Iran was estimated 17 million in 1980 and the number of people who used urban water services was estimated to be 13 million. This statistic has now risen to 40 million urban people of which 38 million people take advantage of water services (Manouchehri, 2000).

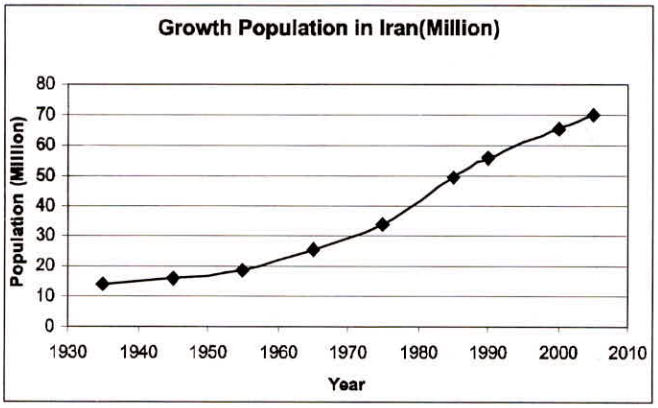

Fig. 4: Increasing Total Population of Iran during 1935–2005 (SCI, 2005)

2. Lack of proper water management, consumption and over-withdrawal of groundwater resources.
3. Occurrence of periodic drought. Land degradation and desertification is one of the pressing challenges for Iran. About 85% of the area (approximately 39.4 million ha out of 164.8 million ha) has been classified as arid and semi-arid and receives between 30 mm to 250 mm of rainfall annually. Many of the semi-arid areas are degraded with a vegetative cover ranging from 5% to 50% (Pakparvar, 2000). If no changes are instituted in these low rainfall areas, the incidence of desert creep and rangeland degradation will increase with further adverse social and environmental consequences.

   An example of the impact of the drought and potential climate change is apparent on the lakes in the central and southeast of Iran. Hamoun Lake in the southeast of Iran is a dramatic case of a drying of a water body to a desert. Iran's largest body of freshwater, is rapidly turning to desert and 100 nearby villages are disappearing beneath sand. Satellite images of the lake situated in Hamoun between 1997 and 2003 (Partov, 2003) show the lake rapidly disappearing.

   According to the New York Times, two years ago, fisherman "pulled around 12,000 tons of fish from the lake, but last year just 400 tons." Hundreds of thousands of migratory birds (flamingos, ducks, egrets and pelicans), "staggered around, disoriented by the lack of fish or water and then flew off elsewhere".
4. *Progress of desertification towards cities in the southeast:* Construction and operation of hydraulic structures such as dams, Qanats and conveyance channels for reservoirs and transmission and distribution systems have been functioning for more than 3000 years (Motiee *et al.*, 2006). With this infrastructure available, because of the types of agricultural activities and the low urban population, the water supply was not considered a critical problem in Iran. However, during the last three decades, large dams have been built around the big cities such as Tehran, Isfahan and Ahvaz to supply water for urban, industrial and agricultural consumption. Where surface water has not been made available, underground water has been used for water supply.

   It is now accepted that Iran is facing a water crisis and that it is facing serious difficulties in meeting the necessary water demands. Based on analyses and studies (Manouchehri, 2000), recent transfer water projects which compared the last decades' projects were more expensive and required more advanced technology for design, construction and operation. Based on the existing reports, it has been estimated that at the current rate of water usage, Iran will have a water crisis by the year 2022 and the rate of the availability of water will drop from 1800 m^3/year/capita to 1000 m^3/year/capita (Motiee *et al.*, 2001).

CASE STUDY IN CANADA

The Great Lakes of North America represent one of the most important water resources in the world and provide water for multipurposes for more than 50 million people in eastern North America. However, fluctuations of water levels in the Great Lakes is a challenge for people living and working near their shores. Rising and falling lake levels affect shipping, recreational boating and water supply and damage the coastline through flooding and erosion.

Of enormous concern is that Lake Superior, the largest of the Great Lakes, has recently dropped to its lowest water level in 81 years. The water is 50 cm below its average level (Cauchon, 2007). Figure 5(a through d) show the trends obtained by a quadratic regression model, demonstrating significant concerns regarding water availability to this crucial resource. Hence, although Canada is generally recognized as having plentiful water resources, the potential for decreasing availability of water resources is very real (see Motiee and McBean (2008) for further details).

CONCLUSIONS

Water resources in the arid and semi-arid regions of the world are at critical levels and increased desertification is occurring. The combined effects of rising populations, increased irrigation from groundwater sources and climate change, are not sustainable. The lack of sustainability is increasing in severity, as demonstrated by three examples discussed and the situation is widespread and intensifying.

The expansion of desert land causes the immigration of people from areas of low water availability to areas of high water availability. As a result, water transfer from watersheds with excess water resources to those of the arid and semi-arid areas is increasing, in an attempt to reduce the migration from these regions to other cities.

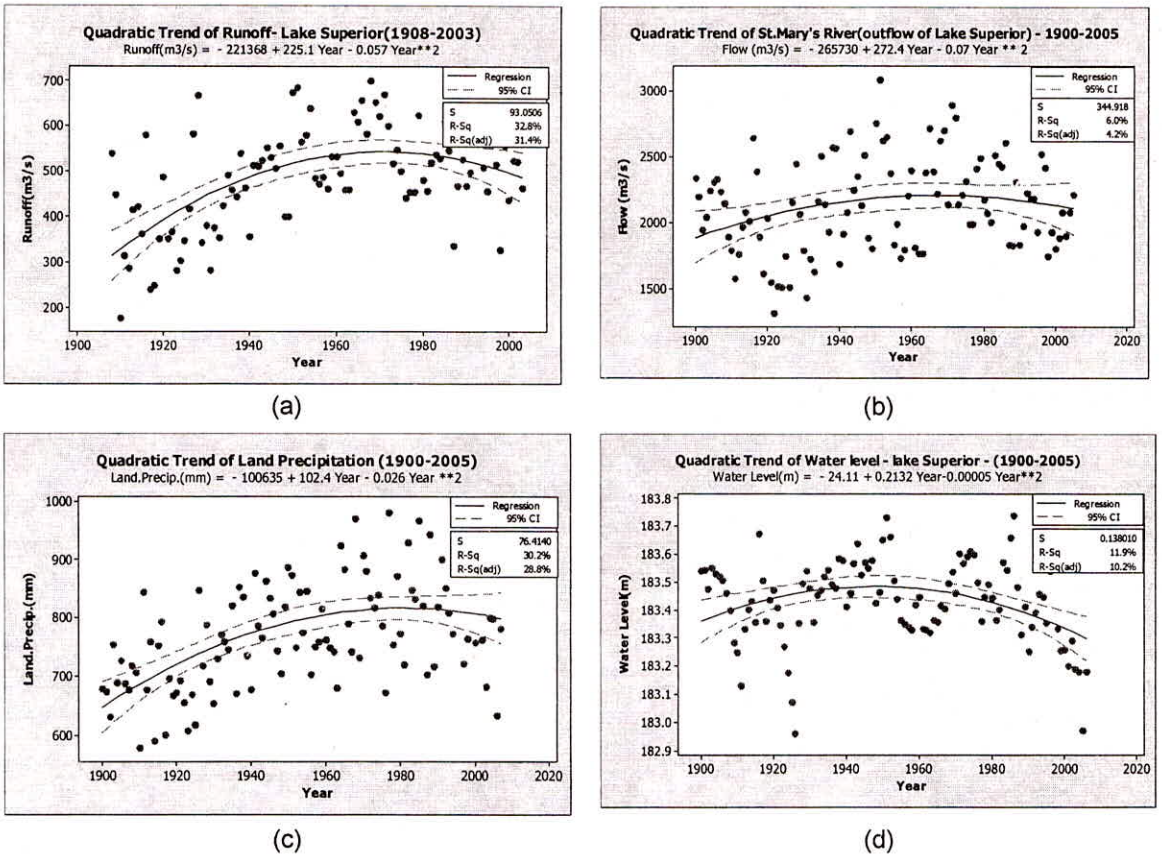

Fig. 5: (a through d): Runoff, Release Levels, Precipitation and Water Levels for Lake Superior (from Motiee and McBean, 2008)

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