The extent of desertification on Saudi Arabia

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Abstract Desertification is the process that turns productive deserts into non-productive deserts as a result of poor land-management. Desertification reduces the ability of land to support life, affecting wild species, domestic animals, agricultural crops and humans. The reduction in plant cover that accompanies desertification leads to accelerated soil erosion by wind and water. South Africa is losing approximately 300–400 million tons of topsoil every year. As vegetation cover and soil layer are reduced, rain fall impact and run-off increases. This paper discusses the extent of desertification, its potential threat to sustained irrigated agriculture and possible measures adopted to control ongoing desertification processes to minimize the loss of agricultural productivity in an arid country such as the Kingdom of Saudi Arabia.

Keywords Desertification · Desert sands · Land productivity · Deforestation · Low precipitation · High evaporation · Overgrazing · Drought meteorological · Saudi Arabia

Introduction

Desertification is difficult to define in measurable terms, and many of the assertions made in its name are pessimistic. In large measure, the problems arise because environmental damage is judged differently by different cultures at different times. Desertification is land degradation in arid, semi-arid and dry sub-humid areas arising mainly from human activity. Modern desertification arises from the demands of increased populations that settle on the land to grow crops and graze animals.

Drought is a general term meaning a sustained period of significantly subnormal water or soil moisture supply. It has different meanings to agriculturists, meteorologists and hydrologists as discussed by Hoffman and Rantz (1968). Veits (1972) defined drought as any period when water deficiency, either acute or chronic, affects plant growth. Drought can be defined simply as short periods without rain in humid regions or the prevailing conditions in the desert. Saarinen (1966) discusses three types of drought: meteorologic (lack of precipitation); hydrologic (diminishing of stream and groundwater sources); and agricultural, where due to timing, volume or both, the crops do not develop properly. These factors causing drought are mainly responsible for desertification limiting the productivity of agricultural lands.

The term desertification was first used by Aubreville (1949) in connection with the loss of productivity of good land through loss of soil as a result of mindless tree cutting in humid and sub-humid tropics. The first use of the word desertification by an International Agency was in 1962 by FAO (Paylore and Mabbutt 1980). Whitford (1992) defined desertification as the diminution or destruction of the biological potential of the land leading to desert like conditions. Deserts are a climatological and geographic phenomenon, but desertification is neither climatological nor geographic. It can be defined as a destructive process in which the loss or impairment of productivity or productivity potential of a land results from the direct or indirect activity of man coupled with environmental factors. Desertification facts can be concluded as the following:

- Desertification damages 70% of the world's dry lands, which is 3.5 times the size of Canada. About 30% of the Earth's total land surface is affected.
- Land permanently degraded to desert-like conditions increases by 10 million hectares every year, an area twice the size of Nova Scotia, Canada.
- 110 countries are affected by desertification. Eighty are low income or developing countries with limited resources to restore degraded areas. Two-thirds of Africa is desert or dry lands.
- North America has the highest proportion of dry lands (about 74%) severely or moderately affected by desertification.

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- There are 25 million refugees in the world forced to relocate as a result of desertification. Another 250 million people are in danger of losing their land.
- The United Nations estimates that desertification causes affected countries to lose US $45 billion in income per year.

Global efforts to prevent or correct desertification cost less than half of the United Nations estimates of US $45 billion that is a net loss of income per year due to desertification. Figure 1 indicates the global desertification vulnerability. Different researchers have defined desertification differently, keeping in view the existing soil, water and plant growth conditions. Dregne (1976, 1977, 1978) defined it as the process of impoverishment of arid, semi-arid and subhumid ecosystems by the combined impacts of man's activities and drought. It is the process of change in these ecosystems that can be measured by reduced productivity of desirable plants, alternations in the biomass and the diversity of the micro and macro fauna and flora, accelerated soil deterioration and increased hazards for human occupancy. However, Sheridan (1981) described desertification as an affliction that hinders an arid land's ability to support life. Land degradation tends to reduce surface moisture. Because less water is available for the sun's energy to evaporate, more energy is left over for warming the ground and, as a result, the lower atmosphere. Meanwhile, wind erosion in drylands releases dust and other particulates into the atmosphere. By absorbing the sun's rays or reflecting them back out into space, they may help to cool the Earth's surface. However, the energy they absorb can heat the lower atmosphere and in this way reduce temperature differences between the atmosphere's vertical layers; this can lead to fewer rainshowers and thus drier land. Finally, the periodic burning of arid and semi-arid grasslands, often associated with unsustainable slash-and-burn agriculture, emits greenhouse gases; so does the unsustainable use of fuel-wood and charcoal, a major cause of land degradation. On the other hand, reforestation is likely to have a cooling effect and is also, of course, an important way to combat land degradation.
Its major symptoms are declining groundwater tables, salinization of top soil and water, reduction of surface waters, unnaturally high soil erosion and desolation of native vegetation. Bashour and others (1983) stated that the Kingdom of Saudi Arabia is characterized by a hot-dry climate and is classified as an arid region occupying about 5% of the world's arid region. Desertification causes economical loss of productivity of arable land to a bare sustainable level due to natural and man's activities.
A review of some historical case histories of Arabia for the past three centuries revealed that Arabia underwent periods of severe drought (Bin Bisher 1974; Abo Aliah 1974). Unfavorable weather conditions played a dominant role in causing major declines in food production in 1964–1966 and 1972–1974. Similarly, the effects of rainfall on wheat yield in India (Chaudary and Rao 1976) and that of drought on groundnut production in Nigeria were reported (Julius and Richard 1979, Grove (1973). Therefore, it is important to study factors causing desertification of arable land and to find solutions to diminish the intensities of these factors. This paper

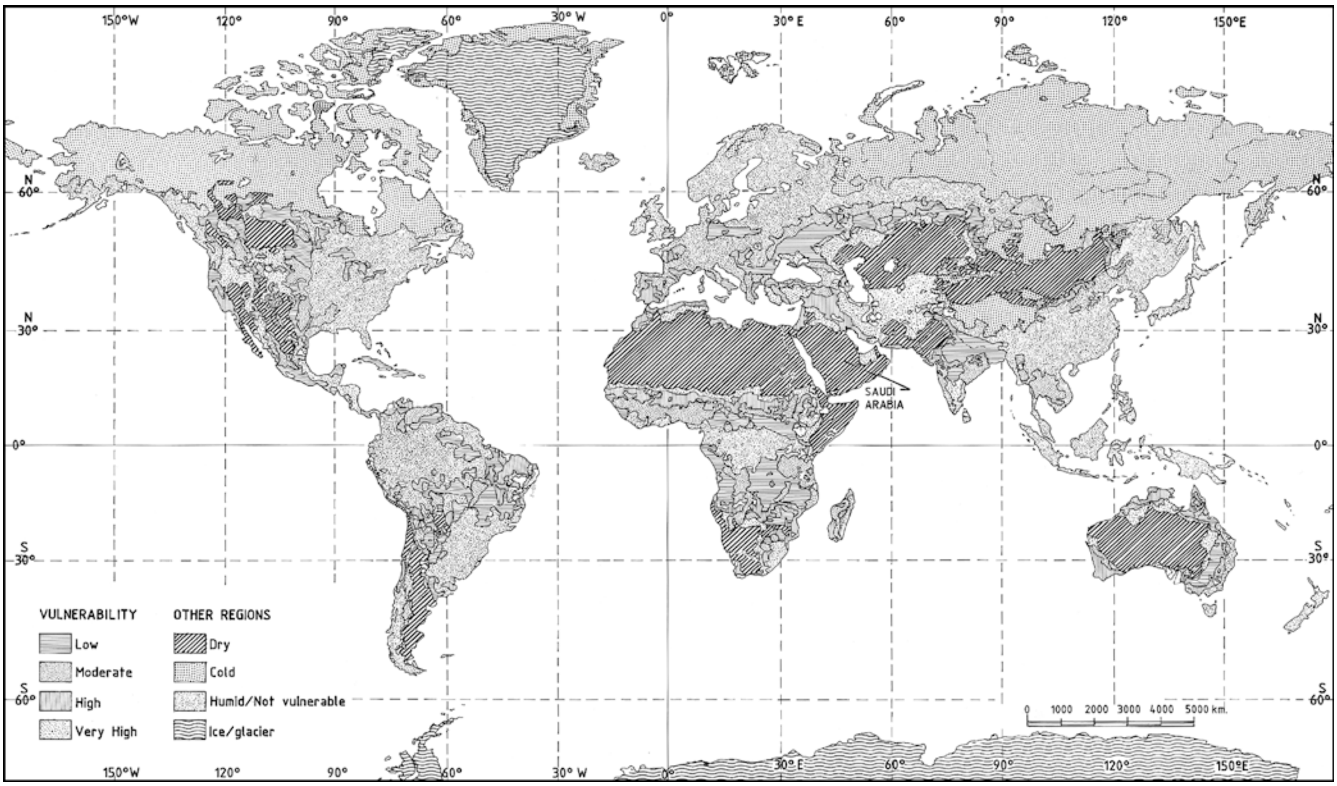

Fig. 1
Global desertification vulnerability map showing the dry regions (soil map and soil climate map, USDA-NRCS, Soil Survey Division, World Soil Resources, Washington, DC 2001)

reviews the potential causes of desertification in the Arab states of the Gulf with special reference to the Kingdom of Saudi Arabia and proposes management alternatives to minimize the process of desertification in sustainable irrigated agriculture in the Gulf region.

Understanding desertification

The United Nations at the 1992 Earth Summit expressed the condition as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities. According to Nelson (1990) land degradation reduces resilience and productive potential to an extent that can neither be readily reversed by removing the cause nor easily reclaimed without substantial investment. The term conjures up images of desert sands expanding over areas previously green and fertile, but it can take many forms and is not limited to farmland adjacent to arid zones. Eckholm (1977) stated that deserts themselves are not the sources from which desertification springs. Desertification breaks out, usually at times of drought stress, in areas of naturally vulnerable land subject to pressures of land use (United Nations 1997). Small areas of land degraded by human activity and/or drought may develop far from the desert, but these areas can expand and connect with other areas, creating desert-like conditions (Hagedorn 1977). Mainguet (1994) at the United Nations Conference on Desertification equated these patches of desertification with a skin disease that links up to carry the process over extended areas. He also mentioned that deserts act more like the oceans, ebbing and flowing on the meteorological tide. Desertification is generally identified as a manmade condition, a result of inappropriate farming and land management techniques, and so remediation of the problem remains in human hands. Eckholm (1977) warns that such a change in the dynamics of the Earth's surface will prove to have dramatic effects on the ability of all species to survive into the future. Recognition of the problem now, at the turn of the century, has made it into a greater crisis, producing more interest by government and the public to address and resolve it. An action taken by the United Nations and other organizations has led to greater awareness and more attempts to develop technology, change social attitudes, and modify land management. Desertification must be handled proactively because a wait-and-see attitude will only lead to further degradation.

Location of the study area

The study area includes Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates, however, covers mainly the events occurring in the Kingdom of Saudi Arabia. It occupies an area of 2.56 m$\times 10^6$ km^2, which is about 84% of the total Arabian Peninsula and about 2% of the Earth's surface. The total surface area and the population of these Arab states of the Gulf are presented in Table 1.

Table 1
Total surface area and population (in thousands) of the Arab States of the gulf (after FAO 1994)

Country	Total area (ha)	Total population
Saudi Arabia	24,969	17,451
Kuwait	1,782	1,633
Bahrain	68	549
Qatar	1,100	540
Oman	2,1246	2,071
U.A.E.	8,360	1,861

Land-use pattern

The land-use pattern in the Gulf states is presented in Table 2 (FAO 1994). The data indicate the land use for different categories. The largest portion is occupied by permanent pasture, forest and woodland; however, a sizeable portion of the total land is yet undefined with respect to its use and falls under the category of others.

Climate of Gulf region and Saudi Arabia

The climate of the whole Gulf region is not uniform due to the large area and highly topographic variations. Arabia can be divided into a tropical and an extra-tropical province according to Zohary (1973). The Arabian Peninsula comprises arid and semi-arid zones, except the high lands in the southwest and a small area bordering the Gulf of Oman (Meigs 1953). The rainfall is sporadic and rarely exceeds an annual mean of 100 mm (Table 3). The data show that the rainfall is scanty, irregular and variable with respect to time and area of occurrence. One of the main features of the rainfall is the occurrence of heavy and sporadic local rains, which usually cause severe floods. Air temperature is high in the summer, reaching an annual mean of 30.5 °C at Jizan. The effect of altitude on temperature is evidenced from the low annual mean temperature at Khamis Mushait (19 °C). Daily and seasonal variations are very wide. Freezing temperatures are uncommon in northern Arabia. An absolute minimum temperature of –5.6 °C (Tabuk) and records of air temperature ranging from 45 to 50 °C are measured. An absolute maximum air temperature of 51.7 °C (Abqaiq) was reported in the eastern zone of the Arabian Gulf. The agroclimatic conditions in the central and the eastern regions of the Kingdom of Saudi Arabia fall under the arid and semi-arid zones (Thornwaite 1943, 1948; Koppen 1900). The rainfall variability is extremely high, as is the case in all desert regions. The annual precipitation at one station shows great differences from year to year.

Table 2
Land use in the Arab States of the gulf (1993) (expressed in thousand hectares)

Category	Saudi Arabia	Kuwait	Bahrain	Qatar	Oman	U.A.E.
Total area	214,969	1782	68	1,100	21,246	8,360
Arable land	3,650 F	5 F	1 F	7 F	16 F	29 F
Permanent crops	90 F	–	1 F	–	47 F	10 F
Permanent pasture	120,000	137 F	4 F	50 F	1,000 F	200 F
Forest and Woodland	1,800 F	2 F	–	–	–	3 F
Others	89,429 F	1,638 F	62 F	1,043 F	2,018 F	8,118 F

F=Data collected by FAO (1994)

Table 3
Average monthly and annual rainfall (mm) at various stations in the Arab Gulf countries (Batanouny 1990)

Stations	Months												Mean annual
	J	F	M	A	M	J	J	A	S	O	N	D	
I. Arabian Gulf zone													
(a) Coastal stations													
1. Kuwait	27.8	15.9	12.1	17.6	4.7	Tr.	–	–	Tr.	3.5	12.7	20.8	115.1
2. Dharan	9.7	15.3	8.4	17.2	0.4	–	–	–	–	2.0	3.0	12.1	68.1
3. Doha	17.0	15.7	16.6	9.6	5.0	–	Tr.	Tr.	–	1.0	2.3	10.2	77.4
(b) Inland stations													
4. Hofuf	9.4	16.2	4.0	7.2	1.6	–	–	–	–	–	3.2	17.6	59.2
5. Al-Ain	10.2	27.8	16.6	7.0	0.3	1.9	2.5	4.5	3.3	–	1.9	1.8	77.8
II. Gulf of Oman zone													
6. Sohar	27.9	16.8	8.8	11.0	5.7	0.6	5.0	3.7	–	–	8.5	18.3	106.3
III. Arabian Sea zone													
7. Salalah	1.0	1.0	5.0	9.0	13.0	7.0	25.0	24.0	3.0	7.0	7.0	3.0	105.0
IV. Mountains in Oman													
8. Nizwa	19.0	40.0	12.0	49.0	15.0	8.0	31.0	9.0	4.0	4.0	3.0	4.0	198.0
9. Sayq	10.0	54.0	33.0	29.0	23.0	19.0	46.0	60.0	16.0	7.0	1.0	5.0	303.0
V. Northern Arabia													
10. Tabuk	17.3	4.7	13.6	2.7	4.8	–	–	–	–	–	20.4	1.5	65.0
11. Turaif	8.4	1.3	4.2	5.8	0.9	–	–	–	–	1.0	1.2	6.2	29.0
12. Sakaka	7.4	3.2	4.4	12.9	0.1	–	0.5	–	–	5.4	27.6	4.2	69.7
VI. Central Arabia													
13. Qassim	17.4	10.2	27.0	16.0	10.2	–	–	–	–	–	1.6	7.5	89.9
14. Riyadh	17.9	4.5	29.4	36.3	16.4	–	0.4	Tr.	–	–	3.8	7.7	116.4
VII. Hejaz Plateau													
15. Madinah	13.6	1.0	9.2	10.0	5.0	0.4	–	–	–	0.7	5.3	2.0	47.2
16. Turabah	16.2	4.6	15.1	27.1	10.2	0.9	–	–	3.5	0.2	19.5	1.1	98.4
17. Najran	19.4	3.9	3.0	8.6	2.8	0.1	1.4	1.0	0.9	–	2.0	–	43.1
VIII. S. West mountains													
18. Taif	10.4	6.4	19.8	24.8	34.8	4.5	1.4	6.3	5.2	6.0	26.8	6.6	153.0
19. Khamis Mushayt	9.1	16.8	52.9	34.2	27.6	6.4	21.6	18.1	7.4	0.4	18.1	12.0	224.6
20. Biljurshi	52.7	36.7	13.6	45.7	22.9	6.7	15.4	17.6	6.6	19.6	76.9	31.9	346.3
21. Abha	43.1	20.4	43.3	77.4	32.3	13.5	50.9	46.6	2.0	2.5	39.4	15.4	386.9
IX. Red Sea Coastal zone													
22. Al-Wajh	1.2	2.4	4.1	1.6	0.8	–	–	–	–	–	6.2	6.3	22.6
23. Jeddah	26.3	11.0	0.4	10.4	0.2	–	–	–	–	–	21.6	9.9	79.8
24. Jizan	4.9	4.2	4.7	0.9	2.7	–	0.7	3.6	0.1	5.7	0.3	0.2	28.0

Dhahran, for example, registered 186.9 mm in 1974 and only 5.3 mm in 1946 (ARAMCO 1935–1974). The temperature ranges from 27.5 to 36.8 °C in summer, from 4.5 to 20 °C in winter, from 13.2 to 32.2 °C in spring and from 13.1 to 34.7 °C in fall. However, a yearly average relative humidity of 51.1% was obtained in 1970, with a minimum and maximum monthly average of 28.4 and 73.5%, respectively. The Arabian Peninsula is characterized by a hot climate for most of the year with northerly winds moving from the eastern Mediterranean towards the Arabian Gulf. Relative humidity is low, except along the coastal zones where it reaches over 90%. The average annual temperature is 33.4 °C in summer and 14 °C in winter, but there are wide variations. For example, inland temperatures range from below zero to a maximum of 50 °C during summer. In the northern part of Saudi Arabia, the temperatures are very high in summer, the hottest month being July, whereas in the southeast regions, the hottest month is June and the coldest is January. The rainfall in Saudi Arabia is scanty, unpredictable and irregular. The mean annual rainfall in the northwestern part of Saudi Arabia varies from 30 mm in the northern part to 90 mm in the northeast. Rainfall records in the central part of Saudi Arabia indicate that rainfall decreases from north to south and from west to east, averaging between 85 to 110 mm, most of it occurring in December-March aiding the development of vegetation. Rainfall conditions in the Hijaz mountains and Asir regions are completely different and are of two types: continental in winter and monsoon in summer. The rain is well distributed throughout the year with peaks in spring and autumn. The mean annual rainfall exceeds 300 mm in the mountains and 250 mm along the Red Sea coast of Jeddah. Rainfall diminishes from Taif and Jeddah to the North towards Aqaba. Snow seldom falls in the mountains but hailstorms and winter frosts are common and the climate is cool and dry (El-Khatib 1980).

Results and discussion

Extent of desertification around the world

According to United Nations Environmental Program (UNEP 1991), about 95,000 km^2 of good land is being converted into desert. Also, 50 million ha of land affected by desertification is expected to be reclaimed and this needs huge resources and a long period of about 40 years. The extent of desertification around the world could be stated as follows: around 102 million ha is slightly affected by desertification all over the world, which is 70% of the agricultural land in the arid zones. About 34 million ha of rainfed cropped area is moderately affected by desertification, which is 23% of the total arid land in the world. Similarly, around 9 million ha of irrigated land is heavily affected by desertification.

Causes of desertification

Desertification is a very complex process and its magnitude depends on factors like environmental conditions and man's activities. Some of the main factors involved directly or indirectly in desertification are as follows:

Arid climate

In an arid environment, high evaporative conditions are responsible for a significant loss of vegetation, especially in sandy desert areas. For example, the yearly potential surface water evaporation losses (Hofuf — 3359 mm) are much higher than the yearly mean rainfall (Hofuf — 69.6 mm). In addition, high evaporative conditions within adequate irrigation supplies determine the hydrology, land development and vegetation of the area. This small amount of rainfall is considered practically negligible from an agricultural point of view (Leitchtweiss Institute 1979). For example, in Nigeria, droughts accompanied by famine occurred in 1890 and in 1913–1914, 1927, 1934–1935 and 1942–1948. Rainfall records show that the 1972–1973 drought exceeded all the previous droughts in area and in severity. In 1973, the rainfall deficit ranged from 10% of the average to over 50%. Many crops were destroyed and there was considerable loss of livestock as herds moved northwards to seek shelter. Groundnut production was badly affected and exports were discontinued. Food prices rose by more than 200%. The drought caused major damage to the Nigerian economy. Other evidence of the severity of drought and its impact on land use has been reported by Khalil (1977). He found losses in livestock amounted to about 400,000 and losses in food crops exceeded 1.1 million t, about 50% of the average annual production. It can be concluded that under extremely dry conditions, the maintenance of vegetation is more difficult than under natural growing conditions.

Sand erosion and deposition

Drifting sand and migrating sand dunes in severe wind erosion areas are a continuous threat to potential agricultural land, range plant life, settlements, highways and other areas. The main effect is due to sand deposition rather than erosion, although erosion and transport of sand are the primary factors. Hagedorn (1977) stated that sand accumulation will bury crops and destroy arable land. Sharif (1960) described the nature and scope of problem in Pakistan as follows:

> "It was in this fertile area that sand dunes developed at more than one place. These sand dunes moved with every storm, and in course of time, 10 km^2 of productive land was under sand dunes. The storms blew enormous quantities of sand from these plagued spots and dumped it on highways, in the habitats, water channels or on crop land, burying crops and raising the level of orchards and fields above the command of irrigation water. Fields, Karezes or orchards damaged in this way had to be abandoned", (Sharif 1960).

Similarly in China, 1.09 million km^2 were effected by shifting sand dunes and drifting sand in many desert districts of which 59% is covered by sand dunes. This problem of wind erosion was partially controlled by afforestation and proper land use (Chinese Academy of Sciences 1980).

Resalinization of agricultural lands

Resalinization of irrigated agricultural lands is a regular phenomenon because all irrigation waters contain salts in different amounts and proportions. This results from many factors, such as arid climate, geology and configuration of the terrain, which determine soil properties, land drainage as well as soil, water and crop management practices (Khatib 1977). In an arid climate, where evapotranspiration exceeds that of rainfall, this problem of salinization is of high magnitude. This problem of salinization is of world occurrence (United Nations 1997). The countries of the Middle and Near East suffer from this problem to a greater extent. The main factors are irrigation water quality, poor drainage, inadequate irrigation water supplies, low rainfall, initial high soil salinity, adoption of poor soil, water and crop management practices and inadequate agricultural extension services to the farming community. The extent of this problem can be studied from Table 4 (El-Gabaly 1977) for some arid countries. The Middle East countries also have the problem of

Table 4
Extent of the soil salinity problems in the Near East (El-Gabaly 1977)

Country	Total irrigated area (in thousands ha)	Total salt affected area (in thousands ha)	%
Cyprus	65	18	28
Egypt	2,600	810	31
Iran	2,800	1,176	42
Iraq	6,800	3,400	50
Jordan	50	8	16
Lebanon	65	Potential	–
Pakistan	15,000	10,000	67
Syria	400	200	50

resalinzation of agricultural land, but no statistics are available. According to Vidal (1951), arable land in the Al-Ahsa Oasis was estimated to about 16,000 ha; however, during the last 15 years, this area decreased to about 8,000 ha due to resalinization of the soil because of over-irrigation and/or inadequate drainage.

Deforestation

In general, the plant community in an arid environment is patchy and scarce. It is not only fires that destroy the plant community in the desert, but cutting wood for fuel purposes is common. People living in an arid environment cut trees to feed animals and use them as a source of dry wood for sale to the rural people as a source of income to buy the necessities of life (Grove 1973). For example, the destruction of acacia vegetation in Sudan and Sahel is quite apparent. Consequently, desertification has increased not only by the selling of trees, but also as a result of overgrazing and unwise agricultural practices, in addition to salinization and water logging resulting from faulty irrigation (Cloudsley-Thompson 1977; Mortimore and Wilson 1965; Forbes 1958). Thus, removal of vegetation from an arid environment aggravates the magnitude of wind erosion and sand movement, thus endangering the life of the surrounding people, because vegetation removal increases not only the rate of water evaporation from the soil surface, but also minimizes rainwater conservation. It has been observed in India that the growing population destroys forests for timber and fuel. When they do not have trees, they start burning cow dung as fuel instead of using it as manure. Thus, the loss of trees and soil fertility contribute to desertification (Office of Science and Technology 1972).

Overgrazing of rangeland plants

Grazing land is estimated to cover around one-third of the world's land surface. Grazing is considered one of the prime menaces of environmental degradation in an arid region. Overgrazing is a kind of over-exploitation, which leads to soil erosion and pasture deterioration (Sherbrooke and Paylore 1973; United Nations 1997). Moreover, the magnitude of overgrazing depends upon the types of animals involved as well as on the movement of nomads in the pasture areas.

Increase in atmospheric dust

Human activities can also induce desertification through production of airborne dust. This may cause an inversion of temperature so the atmosphere is hotter at higher altitudes, preventing the formation of rain-bearing cumulus clouds. Observations and theoretical studies in Northwestern India and Western Pakistan have demonstrated that dust engenders atmospheric subsidence over a desert (Bryson and Barries 1967). The same could be applied to any arid country.

Reduction in soil moisture

Walker and Rowntree (1977) demonstrated that desert soils normally retain moisture for several weeks after precipitation, whereas ground dryness may cause a desert to persist. This is because rain-producing depression cannot be simulated to engender precipitation by the evaporation of soil moisture, and rainfall anomalies may therefore continue for a year or more. Changes in surface albedo could well have a positive feedback effect, which is enhanced by this process (Goudie 1990).

Human causes

A man is a social animal. His priorities differ with the situation. The main factors involved in desertification consists of man's social setup, land-use patterns and others. Figure 2 indicates the risk of human induced desertification.

Unscientific use of available irrigation supplies

It is the general desire of the farming community to increase output from land. This results in overuse of irrigation water and other farm inputs. The efficient use of water depends upon soil type, quantity and quality of irrigation water, irrigation method adopted and many other crop growth factors. Hence, the overuse of irrigation water, in some cases, has resulted in soil salinization, especially when the hard layer is very close to the soil surface. Such a situation is clearly evidenced in the Al-Ahsa Oasis, where much irrigated agricultural land has been salinized due to poor drainage conditions.

Management alternatives to minimize desertification

Much work has been done under local conditions to minimize the menace of wind erosion, control of sand dune movement and enhancement of soil moisture conservation to minimize desertification in Saudi Arabia.

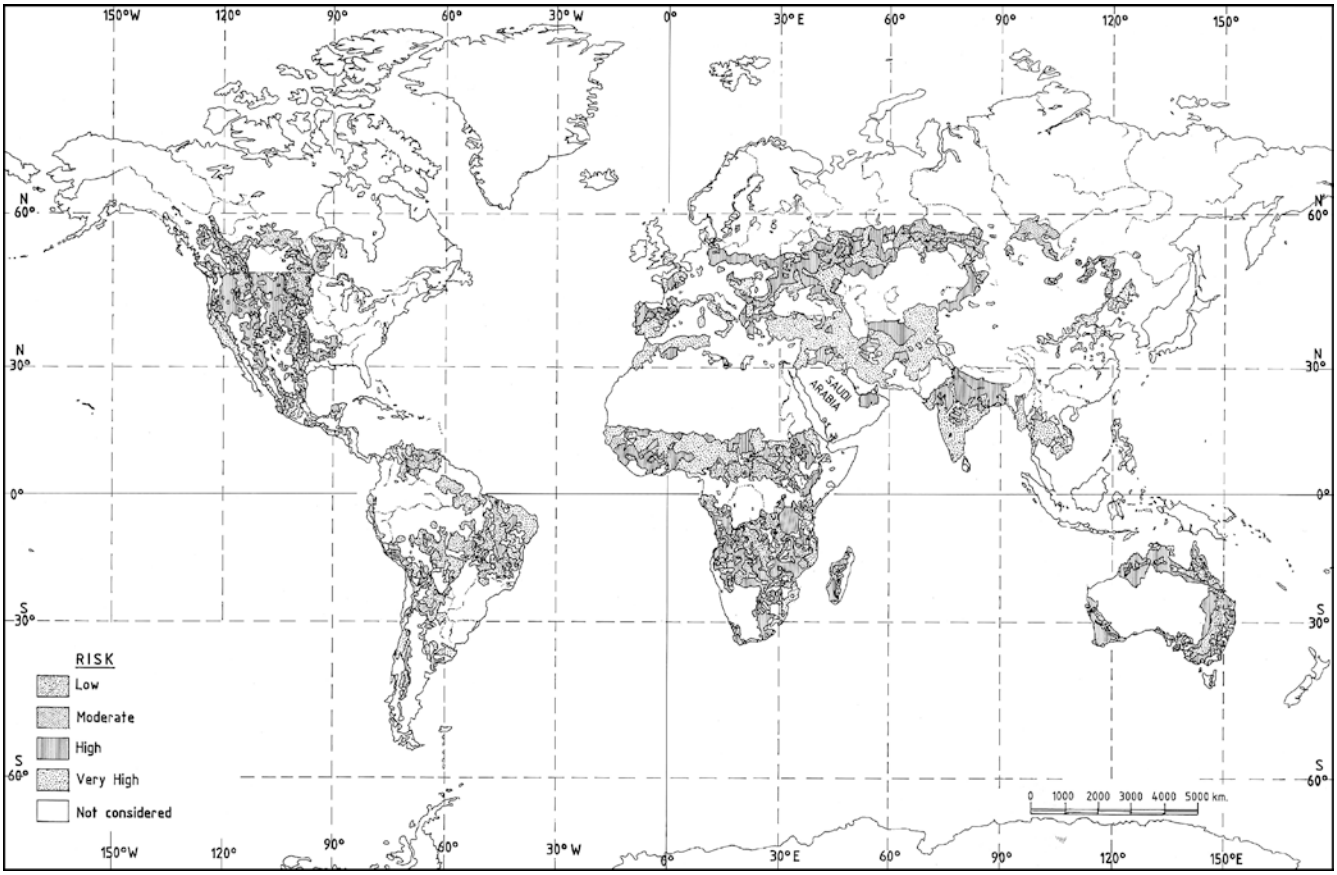

Fig. 2
Showing the risk of human induced desertification (USDA-NRCS, Soil Survey Division, World Soil Resources, Washington, DC 2001)

Wastewater availability and its use

It is important to quantify wastewater availability from different sources in different major cities of the Kingdom because this will help in planning future irrigation projects for the control of desertification on small and large scales. The total amounts of wastewater available in some major cities in the Kingdom are in Table 5. The data indicate that about 0.88 million m^3 of wastewater is available daily for use in landscape development projects as an alternative source of irrigation water. The quality of this wastewater should be monitored regularly to establish guidelines for safe use without creating hazardous problems for the environment. Recently, Al-Jaloud and others (1993) found that aquaculture effluent containing 40 mg NL^{-1} was a promising substitute for inorganic nitrogen fertilizer for wheat production in Saudi Arabia, thus saving 50% in fertilizer application.

Use of saline waters for irrigation

Increased use of highly saline drainage and wastewater as a supplemental source of irrigation can play a greater role in the control of desertification. Hussain and others (1994) conducted a greenhouse experiment to determine the effect of saline water on the establishment of windbreak trees and soil properties. They stated that the survival period of trees decreased significantly with the increase in soil salinity resulting from irrigation water salinity. The survival period of *Prosopis juliflora* was significantly more than *Casuarina equisetifolia* and *Eucalyptus camaldulensis.* The decrease in total biomass was significant with increase in soil salinity. *Prosopis juliflora* tolerated soil salinity (EC_e) up to 38.3 dS m^{-1} with irrigation water

Table 5
Wastewater available in some major cities in the Kingdom of Saudi Arabia

Station No.	City	Quantity (m^3/d)	Source
1	Ar-Riyadh	420,000	SADA (1993)
2	Jeddah	118,000*	SADA (1993)
3	Buraidah	10,000*	SADA (1993)
4	Unaizah	7,000*	SADA (1993)
5	Al-Ahsa	293,782	Leichtweiss Institute (1979)
6	Dammam	187,143*	Al-Khuzayim and others (1994)
7	Al-Khobar	96,000*	Al-Khuzayim and others (1994)
8	Al-Qatif	29,571*	Al-Khuzayim and others (1994)
	Grand total	1,161,496	

*=The flow given is for the designed capacity of a treatment plant

Table 6
Effects of saline irrigation on tree biomass (g/pot)

EC_I (dS m^{-1})	Light EC_e	Yield	Medium EC_e	Yield	Heavy EC_e	Yield
(A) Casurina						
2.1	14.3	16.2a	12.8	13.7a	19.7	19.7a
6.6	36.1	4.76b	16.7	4.64b	30.1	8.09b
13.5	51.6	4.19bc	23.3	3.87bc	38.9	2.84c
18.2	67.7	2.97cd	35.3	3.13cd	47.2	1.69c
28.9	91.4	2.13d	56.2	2.34d	58.2	1.39c
(B) Prosopis						
2.1	16.7	24.3a	12.8	22.9a	15.0	26.7a
6.6	33.5	14.3b	21.5	17.0b	27.3	17.1b
13.5	41.6	5.94c	33.5	6.25c	39.7	13.7c
18.2	58.7	3.71d	44.9	4.23d	50.7	7.33d
28.9	75.3	3.12d	56.9	3.47d	74.4	3.96e
(C) Eucalyptus						
2.1	17.7	21.3a	13.3	16.0a	14.6	22.1a
6.6	33.5	4.32b	18.4	5.59b	20.3	3.82b
13.5	47.3	3.65bc	32.8	4.80bc	27.8	3.04b
18.2	55.8	2.47cd	44.4	3.56c	45.6	2.36b
28.9	75.5	2.00d	59.6	2.10d	60	1.83

Data in a column followed by the same letter do not differ significantly by LSD (p=0.05)

Table 7
Mean values of soil and sodicity after reclamation

Depth of total water applied (cm)	EC_e (^{a}dS m^{-1}) 1^c	2^d	3^e	SAR^b 1^c	2^d	3^e
0	58.00	52.00	55.00	34.15	34.61	34.38
15	6.90	38.50	22.70	7.92	26.04	16.98
30	3.65	11.30	7.48	2.54	13.21	7.88
45	3.35	9.10	6.23	1.83	11.72	6.78
60	3.10	5.10	4.10	1.52	5.87	3.70
75	3.10	4.70	3.90	1.63	4.92	3.28
90	3.05	3.85	3.45	1.37	3.64	2.51
LSD^f (0.05)	0.631	1.683	1.680	0.357	0.378	0.550

Ec_e=Electrical Conductivity of soil saturation extract,
SAR ^{b}=Sodium Adsorption Ratio,
1^c=Surface soil (0–30 cm depth),
2^d=Subsurface soil (30–60 cm depth),
3^e=Whole profile average (0–90 cm depth),
LSD^f=Least significant difference

salinity of 13.5 dS m^{-1}, *Casuarina equisetifolia* up to 27.6 dS m^{-1} with irrigation water salinity of 6.6 dS m^{-1} and *Eucalyptus camaldulensis* up to 15.2 dS m^{-1} with irrigation water salinity of 2.12 dS m^{-1} for proper establishment, provided that 15% excess water is applied as leaching requirements to control soil salinity. The experiment proved the sequence in salt tolerance for different trees such as *prosopis casuarina* and *eucalyptus* (Table 6). The results suggested the *Prosopis juliflora* should be cultivated as windbreak trees in landscape and sand stabilization projects not only to overcome desertification but to increase land productivity.

Water requirements for land reclamation

The soil infiltration rate of sandy desert soils is very high, thus leading to enormous deep percolation losses of valuable irrigation supplies. Hussain (1984) found that the infiltration of sandy soil varied from 0.1 cm to 10 cm per hour depending of the texture of the soil involved. Estimation of water requirements of saline sandy desert soils is important for speedy reclamation (Table 7). Research conducted in this area indicated that a 20–30 cm depth of water is required to reclaim the surface 0–30 cm depth of soil; a 60 cm depth of water is required to reclaim the subsurface 30–60 cm depth of soil; and a 50–60 cm depth of water is required to reclaim the whole profile 0–60 cm depth of soil for giving salt-affected soils and methods of water application in Al-Ahsa, Saudi Arabia (Hussain and authors 1988). Similarly, a 15 to 30 cm depth of water is required to reclaim the surface 0–30 cm soil depth and a 30–60 cm depth of water is required to reclaim the whole profile to 50 cm depth for a given salt affected soil in Al-Qasseem, Saudi Arabia (Al-Jaloud 1994). This work suggests that determination of water requirement of salt-affected soils for reclamation is important not only to save irrigation water but for speedy rehabilitation of sandy deserts.

Use of high water absorbing materials

Inadequate and uncertain irrigation supplies are some of the major problems faced by irrigated agriculture in many arid and semi-arid regions of the world. Low water-holding capacity coupled with low water content of sandy soils are major threats to desertification. Technology used to increase water-holding capacity and soil moisture contents will help conserve soil resources and control desertification. A study conducted by Al-Jaloud (1988) concluded that application of different types of soil conditioners such as *poly acrylamide* (PAM), *urea formaldehyde* (UF) and *bitumen-emulsion* leads to a complex change in various physico-chemical properties of soils. It was further stated that application of these materials either as surface treatment or incorporated into the soil has great potential for decreasing evaporation losses and, subsequently, for increasing water storage of the soil profile, which is beneficial for the management of sandy soils. Also, grain yields were highly affected by the addition of soil conditioners. Surface treatment gave the highest yields of bitumen and PAM. Incorporated U.F. gave the highest yield among all the treatments.

Sand stabilization

The research on sand stabilization is important for the improvement of soil productivity. Bader (1989) investigated the scientific means to stabilize sand dunes in the eastern region of Saudi Arabia. He concluded that sand drift and dune movement are the most serious natural problems facing Arabian Peninsula due to vast expansion of cities, roads, industries and agricultural development. His suggestions include preparation of basic maps, identification of types of sand dunes, placement of sand traps, measures to estimate dune movement, evaluation of water resources available, study of natural conditions of fields and, finally, preparation of integrated soil maps showing all types of sand-related problems in the study area.

Use of date palm leaf mulch

Hussain and others (1986) used date palm leaf mulch of different sizes and found that there was a good correlation between mulch sizes and soil moisture conservation. They concluded that 15–28% savings in irrigation were possible by simply using date palm leaf as a potential source of soil mulch without involving much cost.

Community service

An education-oriented extension program should be developed for the training of farming communities regarding the efficient use of irrigation water, deleterious effects of deforestation (wood-cutting), overgrazing of range plants and its aftereffects, and establishment of windbreak trees by using wastewater instead of fresh irrigation water.

Conclusions

Saudi Arabia is a vast desert area representing about four-fifths of the Arabian Peninsula. It comprises 98.5% of hyper-arid to arid lands. The high aridity in the Kingdom makes the sand areas that constitute one-third of the total area more serious for agricultural land and urban areas. The key to containing desertification while achieving sustained development and growth in the region lies in the ability to turn the ecological disadvantages of the dry lands to economic advantage. Some primary examples include cultivation of desert crops, a forestation program, and management of grazing lands. There exists a great potential to minimize the extent of desertification in Saudi Arabia if all the available water resources (irrespective of source and quality) are utilized properly. Desertification in Saudi Arabia could occur due to natural causes or man-made. An education-oriented extension program for the training of the farming community in the field of agriculture is a basic need and can play a significant role in minimizing the extent of desertification.

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