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Review

Changing demographics, expanding urban areas and modified agricultural extents and their impacts on water availability and water quality in Jordan

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Current water use in Jordan is unsustainable in terms of both supply and quality. The growth in population, primarily as a consequence of pulse immigration stemming from regional conflicts, has led to serious water shortages in urban centers, which is expected to worsen in the future. The agricultural sector is moving towards intensification and a high reliance on irrigation, which is unsustainable in the face of dwindling supplies and rising contamination, principally due to salinity. The decline in field crops is a consequence of climatic fluctuations such as rainfall, while the nature of the plots, often small and isolated, make economies of scale problematic. Unless there is a significant shift in the trend of population growth, and controls on the use of irrigation, Jordan faces inevitable social conflict and irrevocable loss of agricultural land.

Key words: Water contamination, population growth, agriculture, climate fluctuation, salinity.

INTRODUCTION

There has been a significant rise in the population and standard of living in Jordan and this has placed pressure on the domestic water management. The understanding for the need to conserve water resources and manage urban waste has become an issue for large cities and the agricultural lands that surround them (Daigger, 2009). Jordan is suffering significant water pressure on demand and supply with the total available water per capita at less than 142 m^3 per annum (Ministry of Water, 2011). The pressure on the water supply has risen in the urban environment driven by population and industrial growth, while poor agricultural practices and increasing salinity has affected water availability to the agricultural sector. The agricultural sector accounts for the consumption of 60% of available water in Jordan (Ministry of Water, 2011). Increased efficiencies in irrigation as part of reform to on-farm water management has been identified as key to resolving the water issues in Jordan (Table 1). Irrigation is critical to agriculture in Jordan, with less than 4% of the total area under production able to be sustained by average rainfalls, and water is the primary regulator of the size of the agricultural sector.

There are three distinct agricultural regions in Jordan: the rangelands where gazing forms the basis for primary agricultural practice; the highlands with rain-fed dependant field crops and forestry projects; and the Jordan Valley with a high dependence on irrigation (Al-Rahahleh et al., 2007). The use of inappropriate

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Table 1. Current water consumption in Jordan by source (million m^3 per year) (Hussein et al., 2010:185).

Area	Surface water	Groundwater	Waste water	Total
Municipal	46	170	-	216
Irrigation	350	313	52	715
Industrial	2.5	22	-	24.5
Others	51.5	3	-	54.5
Total	450	508	52	1010

agricultural practices for the topography of Jordan, and the increase in population, has led to continued long term degradation of land, with overgrazing demonstrated as a significant negative agricultural practice that affects agricultural water budgets primarily through the loss of rainfall to runoff (Raddad, 2005). The use of waste-water for agricultural production is problematic, primarily due to the treatment processes and potential for contamination (InWEnt, 2005).

Jordan is a net importer of food and the Jordanian government has moved to address this issue through intensification of the agricultural sector, particularly in the Jordan Valley. Poor resource management and the lack of consistency in policy have impacted on agricultural production nationally. The Jordanian agricultural sector has been in relative decline with GDP falling from 14.1 percent in 1971 to 3% of GDP in 2006. This decline is mirrored in absolute value declining from a peak of JD 223 million on 1991 to 115 million in 2006 (Royal Commission for Water, 2009).

There have been significant historical events in Jordan that have caused the population to swell, leading to increased pressure on state resources. The population of Jordan has risen from just over 500,000 at independence in 1946 to over 6 million by 2010, causing significant shifts in water use. This increase in population has strained water resources and land use in Jordan. Farm management practices have been modified with changes in land availability towards a more intensive high input set of farm practices. This shift in intensification has led to increased production, but at the cost of increased water demand and significant declines in water quality (Menzel et al., 2009). The quality of water has also been affected by change in climate with droughts leading to irreversible hyper-salinity. This paper will examine the impact of the increase in population, changes in aspects of agricultural practice and the decline in water availability and quality to all sectors through time. This paper will demonstrate that the increased population and change in agricultural practices have led to a significant degradation of Jordanian water assets.

WATER RESOURCES

Jordan is highly dependent on groundwater resources as it represents a viable supply for 80% of the country (Royal Commission for Water, 2009). The physical boundaries of groundwater differ from the administrative boundaries that have been designated by the various water-resources institutions in the region and this discrepancy makes protection of water resources problematic as regional bodies have differing policies on the draw-down of this groundwater (Royal Commission for Water, 2009). The groundwater in Jordan can be divided into two forms, renewable groundwater which accounts for 4% of total available groundwater and is fed primarily by rain infiltration, and fossil water which constitutes 96% of all groundwater (Hussein et al., 2010). Whereas groundwater is one of the primary water resources available in Jordan, current usage rates are unsustainable or unusable as the underlying bedrock contributes to the high rate of salinity of the water (Dottridge and Jaber, 1999).

The assessment of groundwater needs to be considered on an aquifer by aquifer basis to achieve effective management and reduce the impact of salinity due to depletion (Dottridge and Jaber, 1999; Salameh and Bannayan, 2004). The national approach however, unites all aquifers under one set of policy guidelines for their use and fails to address the particular issues for each aquifer which has led to significant environmental problems such as hyper saline water being drawn to the surface, leading to salinity problems faced in many regions of Jordan (Royal Commission for Water, 2009).

Surface flows from springs occur where the water table intersects the surface topography with concealed discharge, including seepages and it offers localised sources for fresh water. Under natural conditions, the aquifers discharge water proportionally to total annual infiltration that they receive. Recharge into aquifers is derived naturally from infiltration of precipitation, streams, wadis (valleys), lakes, ponds, or other impoundments that seep through the soil profile. Recharge is induced by anthropogenic activities such as injection wells, wastewater pond seepage, or irrigation seepage, or distribution pipe leakage (Al Khandak, 2002).

Springs are valuable sources of fresh water in Jordan and vary greatly in the volume of water they discharge and their salinity (Raddad, 2005). Springs flowing from water-table aquifers are extremely variable and are influenced significantly by climatic conditions with some

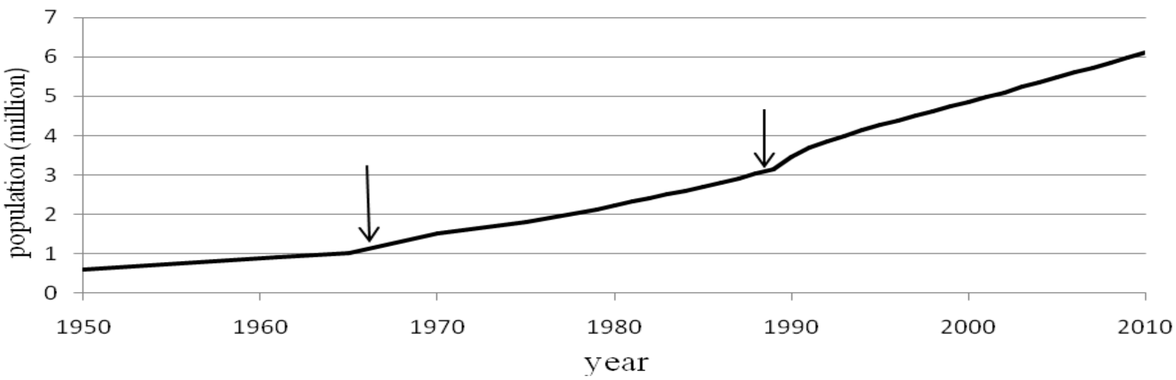

Figure 1. Population trends in Jordan since independence (Source: Department of Statistics, 2011).

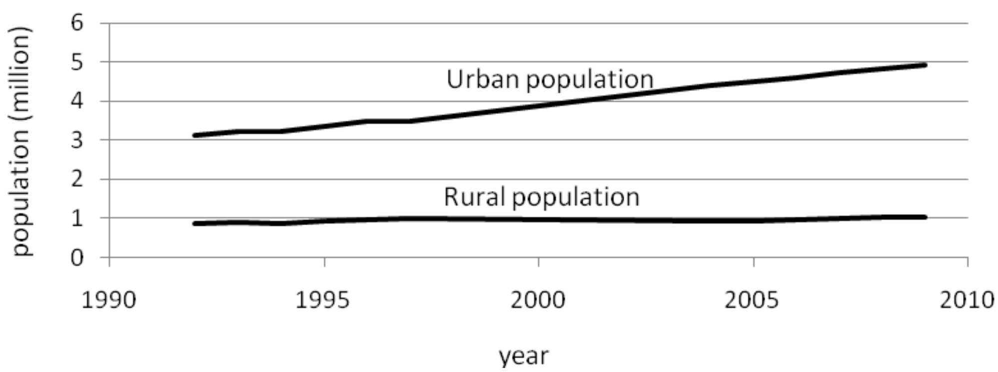

Figure 2. Growth of urban and rural population in Jordan from 1994 to 2008.

springs ceasing to flow during periods of low precipitation. Springs issuing from confined aquifers have larger and more consistent flow rates, and these springs tend to show less influence from climate than do the springs which are derived from the water table.

Surface water in most regions of Jordan drains to the Mediterranean, Red, or Dead Seas and is highly utilised (Carr et al., 2010). There has been an increasing problem of contamination of water by agriculture while greater draw-down of this water resource has led to increasing salinity as a consequence of over exploitation (Royal Commission into Water, 2009).

POPULATION TRENDS

Jordan has the highest population growth rate in the Middle East, averaging near 5% annual growth driven by increasing immigration (Martin, 1999); however this has declined in recent years to 2.8% with localised political stability (Jordan Department of Statistics, 2011) (Figure 1). Figure 1 illustrates two significant periods of rapid population growth: The first commenced in 1966 when the Middle East was in conflict involving by the 1967 Israeli wars, and the second was from 1990 during the Palestinian uprising and increasing tensions between Israel and Jordan. The Iraq war saw another wave of war refugees entering Jordan with between 300000 and 500000 Iraqis seeking shelter between 2003-2005 (Ababsa, 2010). Therefore, the population of Jordan's urban centres has been artificially swollen by people displaced by regional conflicts. These refugees have tended to aggregate in larger urban areas (Figure 2) placing pressure on existing water infrastructure (Ababsa, 2010). This is particularly relevant given the current political instability in the region, particularly in Syria, associated with the Arab spring uprisings. The population of Jordan has reached critical levels at which existing water infrastructure is currently having difficulties in meeting the needs of the urban centres with demand for sweet water rising by 6.5% annually (Magiera et al., 2006; Martin, 1999).

There has also been a rapid growth in the urban population, primarily a reflection of immigration rather than mass movement of the rural population within Jordan (Figure 2). While the rural population has remained fundamentally constant through time at approximately one million, the urban population has increased from about 3.1 million in 1994 to around 5 million in 2008. This urban growth has not been constant

Table 2. Changes in the population of Jordan through time represented by the 12 governorates) (in '000).

Governorates	Capital	1994	2008	% change
Ajlun	Ajlun	95	134	41
Al-Aqabah	Al-Aqabah	80	127	59
As-Balqa	As-Salt	276	392	42
Al-Karak	Al-Karak	170	228	34
Al-Mafraq	Al-Mafraq	179	275	54
Amman	Amman	1576	2265	44
At Tafilah	At Tafilah	63	82	30
Az-Zarqa	Az-Zarqa	639	871	36
Irbis	Irbis	752	1041	38
Jarash	Jarash	123	176	43
Maan	Maan	77	111	44
Madaba	Madaba	107	146	36

across all urban areas, with some areas having much higher growth rates than others (Table 2). For example, Al-Karak has grown from 170 thousand in 1994 to 228 thousand in 2008 (34% growth over 14 years), while the population of Al-Aqabah has grown from 80 thousand in 1994 to 127 thousand in 2008 (59% growth over 14 years) (Table 2). Amman, the capital city and the largest urban area in Jordan, has grown from 1.58 million in 1994 to 2.3 million in 2008 (a growth rate of 44% over 14 years). This growth has occurred without significant investment in the level of water infrastructure. Maladministration has been identified as one of the main causes for water shortages in urban areas and, although this problem is not recent, it illustrates systemic regulatory failure (Cooley, 1984). The supply of water in urban areas is often of such unreliable nature that many households only have mains-water for as little as one day a week, having to buy water from the market to meet domestic needs (Potter et al., 2010). The spatial extent of Amman has also grown significantly from 1918 to 2010; with most of the change post-1956. Figure 3 represents the growth of Amman from 0.32 km^2 in 1918 to over 162.94 km2 in 2010, and this rise in urban areas is mirrored in declines in fertile land from 383.86 km^2 in 1918 to over 297.41 km^2 in 2010, and vacant land falling from 232.42 km^2 in 1918 to over 158.62 km^2 in 2010.

Amman is at the centre of unregulated urban growth that has been precipitated by mass immigration and movement of refugees. This unplanned development has led to increased pressure on green areas and water resources (Ta'any et al., 2009). Prior to the arrival of immigrants from neighboring countries, the land surrounding Amman was considered fertile and suitable for cereal production (Al-Rawashdeh and Saleh, 2006). Prior to 1950, the majority of urbanisation occurred over vacant lands in close proximity to existing dwellings; however recent migration has encroached onto agricultural lands and it is estimated that 86 km^2 of fertile land has been lost to urban development around Amman from 1918 to 2010, accounting for 23% of the total arable land in the Amman region. Figure 3 clearly illustrates the extent of urban growth around Amman, as compared to 1918.

Table 3 illustrates the change in land use in the greater Amman region from 1918 to 2002. There have been two significant waves of Palestinian migration: The first in 1948 which saw the capital expand 1,284% in size (from 1918 to 1953); the second major population growth spur came in 1967 when the city limits expanded to 101 km^2, representing a rise of 2,280% (from 1953 to 1983). The close of the twentieth century saw the Gulf wars in the Middle East and this lead to the displacement of a large number of Iraqis which swelled the urban area of Amman by 45 km^2.

Amman, at the turn of the last century, housed 5,000 residents, but Amman city and surrounds today covers an area of 618 km^2 with 2.3 million residents with a long historical tradition dating to the Ammonites. This rapid increase in population came with little or no regulation and has placed significant pressures on the water resources in the areas that have been urbanised, particularly as domestic wells become contaminated from infiltration of waste products (Salameh et al., 2002). Coupled with the increase in water demand associated with population growth, Jordan, and Amman in particular, has seen declines in quality as a consequence of inadequate industrial and urban treatment of waste water (Hadadin and Tarawneh, 2007). The water table has risen in areas where water treatment occurs and stabilisation ponds provide seepage which raised the water table while reducing net quality of available water. In areas with rising water tables, there have not been problems with increasing salinity, but the nitrate levels and acidity have risen (Ta'any et al., 2009). This increase in pollutants exacerbates the water quality issues created by the removal of green areas, and a higher rate of runoff

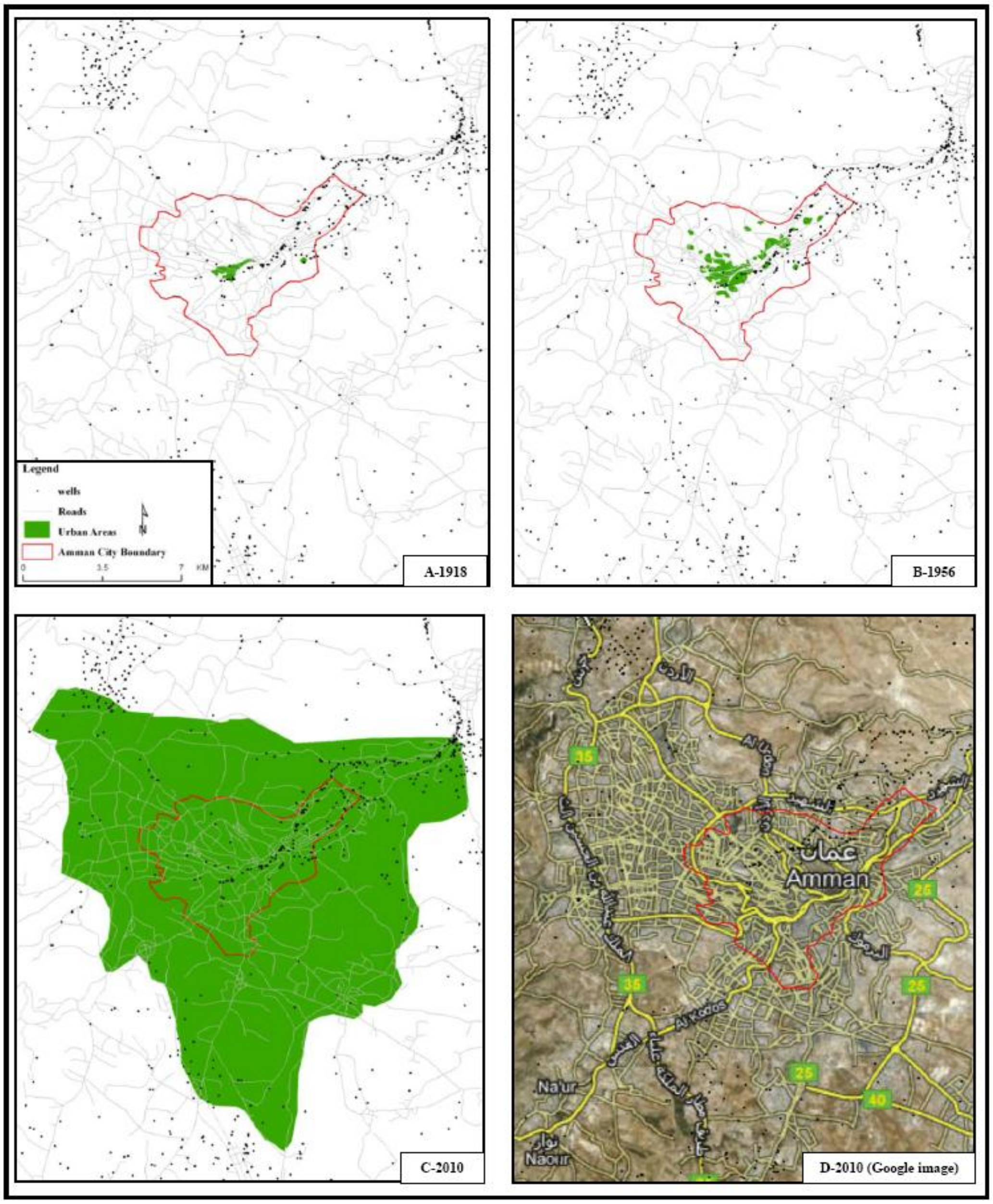

Figure 3. Changes in the spatial extent of Amman between 1918 to 2010 with the consequence of loss of agricultural land as the urban footprint rose from 0.3 km^2 in 1918, to 4.5 km^2 in 1953, and over 170 km^2 in 2010. All maps are to the same scale. Black dots show locations of bore holes and wells.

being captured. Also, one of the most significant threats to urban water supplies is the loss to the system through leakage, theft, and overflows which accounts for 50% of the total domestic supply (Mohsen, 2007; Potter et al., 2007; Rosenberg and Lund, 2009).

AGRICULTURAL LAND USE

Historically, agriculture in Jordan had a seasonal focus and was highly dependent on the annual rain. Land holdings for crops were small and self sufficient. Nomadic grazing accounted for one third of all farming (Baer, 1957; Issawi and Dadezies, 1951). The period immediately after independence in 1946 saw the development of large scale agricultural production through the provision of long term water security for those farmers on small holdings of 20 to 30 dunums (Hazleton, 1979). These reforms often did not take into consideration the significant implications for long term water security but rather focused on long term production growth. However, increasing salinity coupled with

Table 3. Land use in the greater Amman Region 1918-2002 (area in km^2).

Class	1918	1953	983	1996	2002
Urban area	0.321	4.444	105.764	150.764	162.924
Fertile lands	383.856	383.593	331.693	301.346	297.413
Unoccupied area	234.425	230.576	181.237	166.492	158.267

Source: Al Rawashdeh and Saleh, 2006:214).

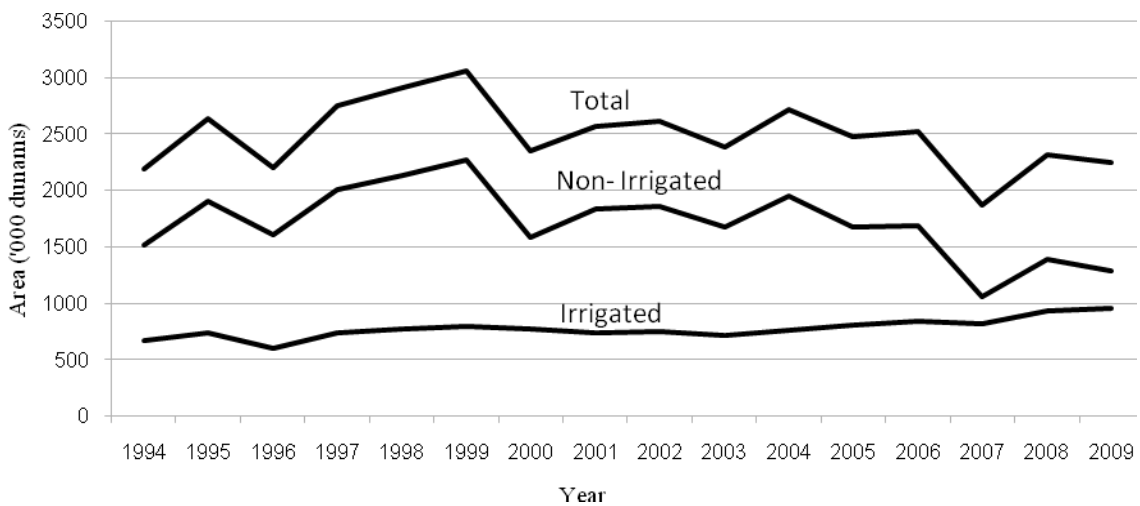

Figure 4. Agricultural land use in Jordan showing trends in irrigated and non irrigated sectors from 1994-2009 (Source Department of Statistics, 2011).

changes in the climate in Jordan, particularly frequent droughts towards the end of the last century, has seen a move away from small rural holdings to larger more intensive farming operations. This has impacted on the demographics within Jordan, with a trend for the rural youth population to migrate to urban centres as the agriculture sector is unable to sustain employment. Access to better education and a perceived higher quality of life are also causes of youth movement to urban areas.

The agricultural sector has also shifted away from non-irrigated, rain-fed agricultural practice, leading to a minor decline in the total area under production. While this decline was occurring, the period 1994 to 2004 (Figure 4) showed considerable fluctuations in the total agricultural production area, and this can be directly attributed to shifts in farm practices such as increasing salinity, irrigation and the use of fertilisers, and the onset of agricultural population pressures.

There has been a long-term trend in the decline in semi-arid and arid crop production, falling to 26.55% in 2008 of the area under field crops in 1961 (WTO). This decline represents a shift from field crops to irrigated tree crops with an accompanying movement from non-irrigated production, which reflects the government agricultural policy direction towards irrigation based food security given the level of climate variability (Al-Adamat et al., 2007; Davis, 1958). While the production of vegetables has not changed significantly, this is not mirrored by the increasing use of irrigated water for tree crops, particularly after the end of the drought in 2007. Tree crops have become more favored in Jordanian agriculture as a consequence of soil problems and the need to reduce water in irrigation systems for vegetables and other water dependant crops. There is a clear indication that agricultural production is moving away from low water rain-fed cropping systems, such as wheat and barely, to irrigated systems, such as chickpeas and bananas (Al-Adamat et al., 2007).

The total area that is actually cultivated has declined as a consequence of two independent pressures. The first is the increase in population which has usurped available land for urbanization, including dwellings, roads and other infrastructure. The second is the withdrawal from agricultural production marginal lands due to reduced viability as water allocations is diminished and economies of scale leads to reduced profitability driven by fragmented cropping systems and increasing open markets to cheaper products (Jabarin and Epplin, 1994). Intensification of irrigated agricultural land-use near urbanised areas experiencing population growth is being fueled by treated waste water. Intensification of Jordanian agriculture will continue to place pressures on water

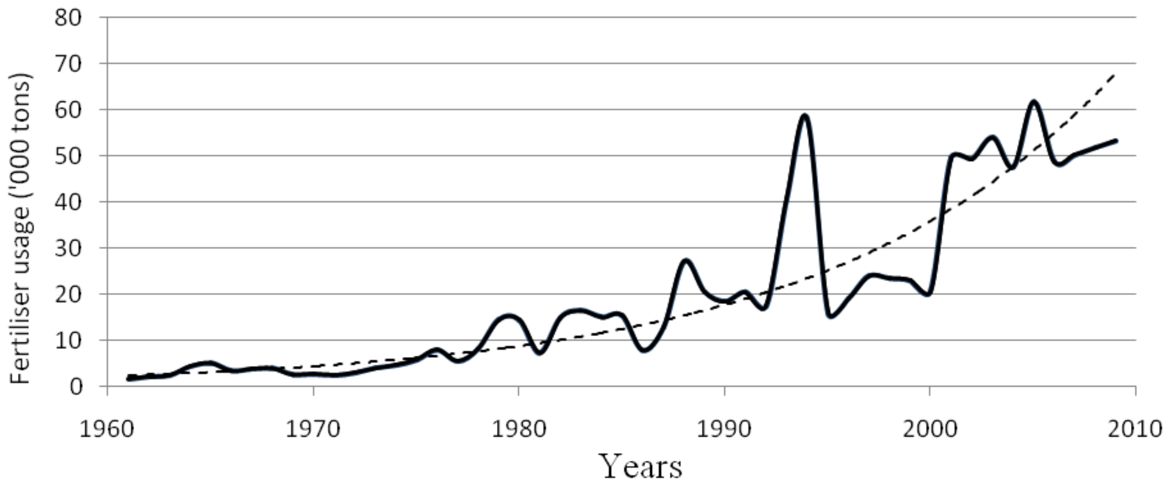

Figure 5. Agricultural fertiliser use in Jordan 1961-2009 (Adapted from Assi and Ajjour, 2009).

allocation, availability and quality, particularly as suitability, climate variability and increased domestic demand all affect water insecurity and the uptake of farming on marginal lands (Millington et al., 1999). Improvements in varietal use has also allowed for the continuation of agricultural production under rain fed conditions in limited parts of the country such as Mashagar (Badarneh and Ghawi, 1994).

One of the most significant changes in farm practices has been in the use of fertilisers. The use of fertiliser is dependent on water availability, with a peak in fertiliser imports prior to the drought of 2003 to 2004, and the long term growth of fertiliser use with intensive and irrigated farming (Figure 5). Fertiliser use has risen steadily from an annual average of less than 5 thousand tons per annum in the 1960s to an average of over 50 thousand tons by 2000. Jordanian fertiliser use is highly variable over time, and the periodic pulse rise in application of fertiliser is indicative of the uptake of improved agricultural farming practices and a rise in intensification. There are four distinct periods in the development of fertiliser use in Jordan during the last half century (Assi and Ajjour, 2009). The pre Green Revolution (per 1970s), saw limited fertiliser application and highlights the simple, low input farming practices of that period. The period of the green revolution during the seventies led to the doubling of fertiliser inputs during that period, much of which was in association with the introduction of drip irrigation systems. The third modernisation period, 1988 to 2003, saw a rise in the total inputs through time almost doubling for the previous period and representing an increasing internal production of fertiliser in Jordan. This new production enabled the overcoming of the supply problems associated with importation. The fourth period, from 2004 to 2010, represents a saturation and plateauing of fertiliser use in agriculture as farmers faced increasing production issues such as water supply and land availability pressures, and increased competition as a consequence of increasing international trade. There is significant deviation within each period and these can be attributed to rainfall and modernisation, such as the 1992 use of fertilisers through the suction pipes attached to the irrigation system. More recent applications are informed and targeted on achieving effective soil nutrition and avoiding significant pollution from excessive application of fertilisers.

It is estimated that the restrictions on agricultural expansion will occur based on declines in land availability and the ongoing decline in available sweet water and this will continue without significant mitigation works to adjust for increasing salinity. Notwithstanding peace and regional stability, cooperation is the key to effective management of the agricultural sector in Jordan (Menzel et al., 2009).

CLIMATE

Intensive and irrigation agriculture, along with the sweet water resources in Jordan, are highly concentrated in the 4% of the country that is considered semi-arid to semi-humid (Table 4). There are three major regions associated with a semi-arid to semi-humid climate zones in Jordan, and these are located in the Jordan Valley, the Dead Sea, and in the south part of the country near the Red Sea. In contrast, the major urban centres are located in the climate zone predominantly responsible for the desert and arid regions which dominates over 96% of the country, primarily allowing grazing and sporadic cropping (Table 4). The immediate agricultural surrounds of urban centres have benefited in recent years through improved water recycling and treatment centres.

Rainfall in Jordan is seasonal and variable, with the desert regions receiving less than 200 mm of rain annually. In contrast, the semi-humid regions receive more than 500 mm annually. The fundamental climatic

Table 4. Climate and regional classification in Jordan.

Region	Rainfall (mm) (annual average)	Temperature (°C) (annual average range)	Area		Primary agricultural use
			'000 ha	% of Total	
Desert	<200	1-44	8080	90.5	Sporadic grazing
Arid	200-350	3-40	490	5.5	Grazing and limited grains
Semi-arid	350-500	3-33	170	1.9	Grazing, barley and wheat
Semi-humid	>500	3-33	2.1	2.1	Tree crops, wheat, tobacco, sorghum, and summer crops

problem faced in the water crises is that the semi- humid regions account for less than 2.1% of the total country (Table 4). Drought is a significant agricultural and environmental problem, and is an inevitable result of the irregular climate. During a drought, there is reduced infiltration into ground water and a lack of flow in natural water ecosystems; both reductions exacerbate the issue of salinity due to the national soil mineralogy.

WATER CONTAMINATION

There are four primary vectors for water contamination from agricultural production: First, fertilisers, pesticides and herbicides that are leached from farm lands; second, the use of saline and untreated water which accumulates in the soil or is washed into waterways; third, return flow from irrigation which is one of the leading causes of hyper-salinity with the salinity of irrigation water ranging from 250 to 8000 mg/L depending of the aquifer where the water is sourced with the salinity of ground water highly variable between regions; and fourth, the transportation of contaminants with run-off water both into the river systems and through infiltration (Royal Commission for Water, 2009).

The river systems in Jordan have a natural saline character resulting from the underlying soil chemistry. The Jordan River is saline and is not suitable for irrigation or domestic use without treatment. The Zarqa River is only usable for irrigation and drinking outside of dry periods as the contamination from agriculture and waste water renders it unusable during the dry periods. The Yarmouk River is still a sound source for water but is increasingly becoming more stressed as municipal waste water is added. The diversion of inflows by Syria and Israel has exacerbated the problem of reduced flows in Jordanian water courses (Royal Commission for Water, 2009).

In Jordan, landfill leachate is a significant threat to groundwater and aquifers. Such leachate has led to a reduction in irrigation in areas surrounding landfill sites, primarily because of high concentrations of chloride, bicarbonate and nitrate, with nitrate levels rising from 4 mgL^{-1} in 1978 to 423 mgL^{-1} in 1996 (Abu-Rukah and Al-Kofahi, 2001).

CONCLUSION

Jordan is facing significant continued water shortages in the near future without significant reform. The fundamental problems are the rising levels of contamination; draw down of non-renewable aquifers, the intensification of agriculture, as well as a high population growth rate. The decline in the agricultural sector is primarily restricted to the arid and semi arid regions and in field crops. This trend is reversible if climatic conditions improve, such as good rainfall. The long term trend, however, is a move towards irrigated trees and vegetables crops. The use of irrigation water, with high salinity as a consequence of the underlying soil chemistry, will continue to exacerbate the salinity problem which significantly impacts on the agricultural sector (Möller et al., 2007). The increase in urbanisation, driven by pulse immigration and the rural urban shift, has led to water shortages in Jordan's major cities, particularly the capital Amman. Amman has undergone signification growth in both population and spatial extent, and this has led to increased pressure on fresh water supplies and created declines in water quality. As the population increases, the urban footprint increases, and the land available for agriculture declines. The level of water pollution from urban areas is also increasing as treatment infrastructure is unable to process wastewater. The water quantity is also declining as more intensive farming systems and inputs such as fertilisers exacerbate problems with water quality through contaminated runoff and increasing salinity. Without a significant shift in policy, the current population growth and agricultural policies are unsustainable in the context of the currentwater situation and land use.

REFERENCES

Ababsa M (2010). The evolution of upgrading policies in Amman. *Second* International Conference on Sustainable Architecture and Urban Development; Amman.

Abu-Rukah, Y, Al-Kofahi O (2001). The assessment of the effect of landfill leachate on ground-water quality- a case study El-Akader landfill site-north Jordan. J. Arid Environ. 49:615-630.

Al Khandak H (2002). Water Demand Management, Conservation and Pollution Control in Jordan. *Regional Conference* on Water Demand Management, Conservation and Control; Amman.

Al-Adamat, R, Rawajfih, Z, Easter M, Paustian K, Coleman K, Milne E,
Falloon P, Powlson D S, Batjes N H (2007). Predicted soil organic carbon stocks and changes in Jordan between 2000 and 2030 made using GEFSOC Modelling System. Agric. Ecosyst. Environ, 122:35-45.

Al- Rahahleh M, Rakabat S, Saraheen W, Awaedeh M, Khalifeh M, Sharma RK (2007). Jordan Accession to WTO: Impact on Agricultural Sector; Afro-Asian Rural Development Organization: Chanakyapuri.

Al-Rawashdeh S, Saleh B (2006). Satellite monitoring of Urban spacial growth in the Amman area. Jordan. J. Urban Plan. Develop, 132(4):211-216.

Assi R, Ajjour R, (2009). *Jordan's second* National Communication to the United Nations Framework Convention on Climte Change (UNFCCC): The Hashemite Kingdom of Jordan, Amman.

Badarneh DMD, Ghawi IO (1994). Effectiveness of inoculation on biological nitrogen fixation and water consumption by lentil under rainfed conditions. Soil Biol. Biochem. 26(1):1-5.

Baer G (1957). Land tenure in the Hashemite Kingdom of Jordan. *Land Econ. 33*(3):187-197.

Carr G, Potter RB, Nortcliff S (2010). Water reuse for irrigation in Jordan:perceptions of water quality among farmers. *Agricultural Water Management,* DOI; 10.1016/j.agwat.2010.12.011, in press.

Cooley JK (1984). The War over Water. Foreign Policy 54:3-26.

Daigger G (2009). Evolving urban water and residuals management paradigms: water reclamation and reuse, decentralisation and resource recovery. Water Environ. Res. 81(9):809-823.

Davis HRJ (1958). Irrigation in Jordan. Economic Geography 34(3):264-271.

Department of Statistics (2011). Population of the Kingdom by Sex: The Hashemite Kingdom of Jordan, Amman.

Dottridge J, Jaber NA (1999). Groundwater resources and quality in northeastern Jordan: safe yield and sustainability. Appl. Geography 19:313-323.

Hadadin NA, Tarawneh ZS (2007). Environmental Issues in Jordan, Solutions and Recommendations. Am. J. Environ. Sci. 3(1):30-36.

Hazleton JE (1979). Land reform in Jordan: The East Ghor Canal Project. Middle Eastern Stud. 15(2):258-269.

Hussein K, Nawaz K, Majeed A, Khan F, Lin F, Ghani A, Raza G, Afghan S, Zia-ul-Hussnain S, Ali K, Shahazad A (2010). Alleviation of salinity effects by exogenous applications of salicylic acid in pearl millet (*Pennistum glaucum* (L.) R.Br.) seedlings. Afr. J. Biotechnol. 9(50):8602-8607.

InWEnt (2005). *Prospects of Efficient Wastewater Management and Water Reuse* in Jordan. InWEnt, Amman Office, Jordan.

Issawi C, Dabezies C (1951). Population movement and population pressure in Jordan, Lebanon, and Syria. *Milbank* Memorial Fund Q. 29(4):385-403.

Jabarin AS, Epplin FM (1994). Impacts if land fragmentation on the cost of producing wheat in the rain-fed region of northern Jordan. Agric. Econ. 11:191-196.

Magiera P, Taha S, Nolte L (2006). Water demand management in the Middle East and North Africa. Management of Environmental: An Int. J. 17(3):289-298.

Martin N (1999). *Population, Households and Domestic Water use in Countries of the Mediterranean* Middle East (Jordan, Lebanon, Syria, the West Bank, Gaza and Israel). International Studies for Applied Systems Analysis, Interim Report, IR-99-032.

Menzel L, Koch J, Onigkeit J, Schaldach R (2009). Modelling the effects of land-use and land-cover change on water availability in the Jordan River region. Adv. Geosci. 21:73-80.

Millington A, Al-Hussein S, Dutton R (1999). Population dynamics, socioeconomic change and land colonisation in northern Jordan. Appl. Geography 19:363-384.

Ministry of Water and Irrigation (2011). Annual Report: The Hashemite Kingdom of Jordan, Amman.

Mohsen MS (2007). Water strategies and potential of desalination in Jordan. *Desalination* 203:27-46.

Möller P, Rosenthal E, Geyer S, Flexer A (2007). Chemical evolution of saline waters in the Jordan-Dead Sea transform and in adjoining area. Int. J. Earth Sci. 96(3):541-566.

Potter RB, Darmame K, Barham K, Nortcliff S (2007). An Introduction to Urban Geography of Amman, Jordan: University of Reading, Geographical. P. 182.

Potter RB, Darmame K, Nortcliff S (2010). Issues of water supply and contemporary urban society: the case of Greater Amman, Jordan. Philosophical Trans. Royal Society, A, 368:5299-5313.

Raddad K (2005). Water Supply and Water Use Statistics in Jordan; IWG-Env International Work Session on Water Statistics: Vienna, June 20-22.

Rosenberg DE, Lund JR (2009). Modelling integrated decisions for a municipal water system with recourse and uncertainties: Amman, Jordan. Water Resour Manage. 23:85-115.

Royal Commission for Water (2009). *Water for life; Jordan's Water strategy, 2008-2022:* Royal Commission for Water the Hashemite Kingdom of Jordan, Amman.

Salameh E, Alawi, M, Batarseh M, Jiries A (2002). Determination of trihalomethanes and the ionic composition of groundwater at Amman City, Jordan. Hydrogeol. J. 10:332-339.

Ta'any A, Tahboub AB, Saffarini GA (2009). Geostatistical analysis of spactiotemporal variability of groundwater level fluctuations in Amman-Zarqa basin, basin Jordan: A case study. Environ. Geol. 57:525-535.