Journal of Desert and Environmental Agriculture, 2 (1): 1-11, 2022 JDEA
DOI: 10.21608/jdea.2021.67796.1008

Article

Vulnerability of Oases in Hyper-arid Areas in The Arabian Peninsula and Northern Africa to Climate Change

Hussein, I.S. [1], and Ali, A.M.[2]

1. Division of Ecology and Dry Land Agriculture, Desert Research Center, Cairo, Egypt
2. Division of Water Resources and Desert Soils, Desert Research Center, Cairo, Egypt

The National Committee of Soil Science, Academy of Scientific Research and Technology, Egypt.

Article info.

Received on:7-2-2021

Accepted on: 27-2-2021

Published on: 6-2022

Open Access

Abstract

The United Nations Intergovernmental Panel on Climate Change's (IPCC) Special Report on Climate Change and Land (SRCCL), also known as the "Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems" is a landmark study by 107 experts from 52 countries. The SRCCL provided a comprehensive overview of the entire land-climate system for the first time and decided to enlist land as a "critical resource." On Wednesday, August 7, 2019, in Geneva, Switzerland, the IPCC's 50th session (IPCC-50) adopted the SRCCL's Summary for policymakers (SPM) and approved the report. The report is the second of three Special Reports in the current Sixth Assessment Report (AR6) cycle, which began in 2015 and will be completed in 2022. The third chapter of the special report deals with the relationship between desertification and potential climate change. It reviews research on desertification-affected oases and the impact of climate change in the Kingdom of Saudi Arabia, Egypt, and Tunisia. This review paper discusses oases in hyper-arid climates as affected by climate change. Emphasis has been lent to the Siwa Oasis as an example of the areas impacted by climate change in Egypt. Concluding remarks and recommendations have also been provided to tackle climate change in affected oases.

I S S N : 2 7 3 5 – 4 7 0 9
https://jdea.journals.ekb.eg/

1. Introduction

Much of the arid lands have undergone a considerable anthropogenic change (Scanlon et al., 2006; Bounoua et al., 2009; Georgescu et al., 2009; Fricke et al., 2009; Gao et al., 2010; Xu et al., 2011; Li et al., 2012), mainly via urbanization and land-use changes. Several publications have appeared in recent years documenting that aridification patterns worldwide, especially in oases, have been increased (e.g., Sheffield et al., 2009; D'Odorico et al., 2013; Li et al., 2016). This increase has been detected in Africa, East, South Asia, East Australia, and South Europe since the middle of the 20th century (Dai, 2011). In the same period, the long-term global warming trend has also increased (Ji et al., 2014; Huang et al., 2016), posing a serious effect on arid regions. The aridity associated with rapid warming is attributed to increases in greenhouse gas emissions (Burke et al., 2006; Solomon et al., 2007) due to anthropogenic activities. Zhang et al. (2007) investigated the anthropogenic nature of these changes in terms of the global patterns of precipitation.

About hyperarid areas, Safriel et al. (2006) stated that deserts were warmed-up between 1976 and 2000 at an average rate of 0.2–0.8 ºC per decade. They further stated that global warming is expected to induce an overall increase in rainfall in these areas. Nonetheless, the water loss in evapotranspiration due to the increase in temperature may be greater than the water gained via rainfall. An important implication of climate model simulation by Feng and Fu (2013) showed that the area of global drylands is projected to enlarge by around 10% by 2100. In the same line, Li et al. (2016) reported that desert regions are expected to expand to up to 50% of the global land area by the end of this century.

Since oases are among the most prominent features of the desert in the Arabian Peninsula and North Africa, coupled with their vulnerability to climate change, this review paper aims to shed light on the sensitivity of these regions to different forms of degradation, as well as the aspects of adaptation to climate change. Siwa is discussed in greater depth as an Oasis influenced by climate change in Egypt.

2. The vulnerability of oases in hyper-arid climate

Despite their relatively small size, oases are important sources of fresh water in arid regions. In harsh desert environments where water is scarce, an Oasis can be considered a green patch, where water is found to support life. Moreover, oases are gaining attention nowadays as hot spots of climate change as they are threatened by desertification through various mechanisms. Oasis agriculture has long been the only viable crop production system throughout the hot and arid regions of the Arabian Peninsula and North Africa (Fig. 1). Oases in hyper-arid climates are typically prone to water scarcity as evapotranspiration exceeds rainfall. This often causes salinization of soils. Although several oases have persisted for several thousand years, several others have been abandoned, mostly in response to climate change or hydrological conditions (Jones et al., 2019), providing testimony to societies' vulnerability to climatic shifts raising concerns about similarly severe effects of anthropogenic climate change.

Climate change is expected to have significant and complex effects on oasis areas on the Arabian Peninsula and North Africa (Abatzoglou and Kolden, 2011; Guan et al., 2018). For example, hydrological and thermal shifts are predicted to affect oases in southern Tunisia by the 2050s, with an average temperature rise of 2.7 °C, a 29% decline in precipitation, and a 14% increase in evapotranspiration (Ministry of Agriculture and Water Resources of Tunisia and GIZ, 2007). In Morocco, the diminishing aquifer recharge is projected to affect the water supply of the Figuig oasis (Jilali, 2014) and the Draa Valley (Karmaoui et al., 2016). Saudi Arabia is predicted to undergo a 1.8-4.1°C rise in temperatures by 2050, which is estimated to increase agricultural water demand by

5-15% to sustain a level of production comparable to that in 2011 (Chowdhury and Al-Zahrani, 2013). Increased temperatures and a variable pattern of rainfall in the central, northern, and south-western regions of Saudi Arabia could pose challenges to sustainable water resource management (Tarawneh and Chowdhury, 2018). Besides, potential climate scenarios are likely to increase the frequency of floods and flash floods, for example, in coastal areas and the central parts of the Red Sea and the south-southwestern areas of Saudi Arabia (Almazroui et al., 2017).

While many oases are cultivated with highly heat-tolerant crops, such as date palms, such crops eventually lose their productivity when temperatures exceed certain thresholds, or hot conditions prevail for long periods of time. Projections to date do not indicate serious declines in land suitability for date palm for the Arabian Peninsula (Aldababseh et al., 2018). However, it is not clear how reliable the climate response parameters in the underlying models are, and the actual results could differ significantly. Date palms are generally thought to be able to withstand extreme heat. However, recent transcriptomic and metabolic evidence suggests that heat stress reactions begin at 35°C (Safronov et al., 2017), not exceptionally warm for many oases in the area. However, given the current assumptions about the date palm's heat tolerance, the adverse effects are expected to be minimal (Aldababseh et al., 2018). For some other perennial oasis crops, the effect of temperature rises is already evident. Between 2004-2005 and 2012-2013, Oman's Al Jabal Al Akhdar high-mountain oases lost almost all temperate-zone fruit and nut trees, with a surplus of peaches and apricots grapes, figs, pears, apples, and plums dropping by between 86% and 100%. (Al-Kalbani et al., 2016). This means that the local climate will not remain acceptable for species that rely on cool winters to break their dormancy period (Luedeling et al., 2009). Similar impacts are likely to occur in Tunisia and Morocco and other oasis locations in the Arabian Peninsula and North Africa (Benmoussa et al., 2007). These studies predict strong decreases in winter chills, raising concerns that many already well-established species would no longer be viable in areas where they are currently grown. The risk of detrimental chill shortfalls is expected to increase gradually, slowly diminishing the economic prospects to produce such species.

Without appropriate mitigating actions, this development's effects will be very negative for many traditional oasis settlements and other plantations of similar species. Simultaneously, population growth and agricultural expansion in many oasis settlements are leading to substantial increases in water demand for human consumption (Al-Kalbani et al., 2014). For example, a great demand for unmet water was predicted for future scenarios for the Seybouse valley in East Algeria (Aoun-Sebaiti et al., 2014). Similar conclusions were drawn for Wadi El Natrun in Egypt (Switzman et al., 2018). Modeling studies have shown a long-term decrease in available water and a growing likelihood of water scarcity, e.g., in oases in Morocco (Johannsen et al., 2016; Karmaoui et al., 2016), in the Dakhla Oasis in the Western Desert of Egypt (Sefelnasr et al., 2014) and the Large Upper Mega Aquifer of the Arabian Peninsula (Siebert et al., 2016), Mainly due to the risk of water shortages.

Continuous water depletion, increasing soil salinization, and soil contamination are currently threatening the maintenance of oasis systems and their communities' livelihoods (Besser et al., 2017). Waterlogging and soil salinization due to increasing saltwater tables and inadequate drainage systems have become common to all the mainland oases in Tunisia, most of which are clustered around salt depressions, locally known as chotts (Ben Hassine et al., 2013). Due to agricultural developments, inefficient water use for irrigation, and drainage system failures, similar salinization processes also occur in

Egypt's oases (Abo-Ragab, 2010; Masoud and Koike, 2006).

Many oases in North Africa and the Arabian Peninsula are thought to be vulnerable to climate change. While it is difficult to distinguish the effects of recent climate change from those of other change processes, water supplies have already deteriorated in many areas, and the suitability of the local climate for many crops, especially perennial crops, has already decreased. This decline of water supplies and thermal suitability of oasis locations for conventional crops is very likely to continue throughout the 21st century. People living in oasis regions worldwide will face problems in the coming years as the effects of global environmental change intensify (Chen et al., 2018). Hence, efforts to increase their adaptive capacity to climate change can facilitate the sustainable development of oasis regions globally. This will require addressing the trade-offs between environmental restoration and agricultural livelihoods in particular (Chen et al., 2018). Ultimately, sustainability in oasis regions will rely on policies that integrate ecosystem services and social and human welfare needs.

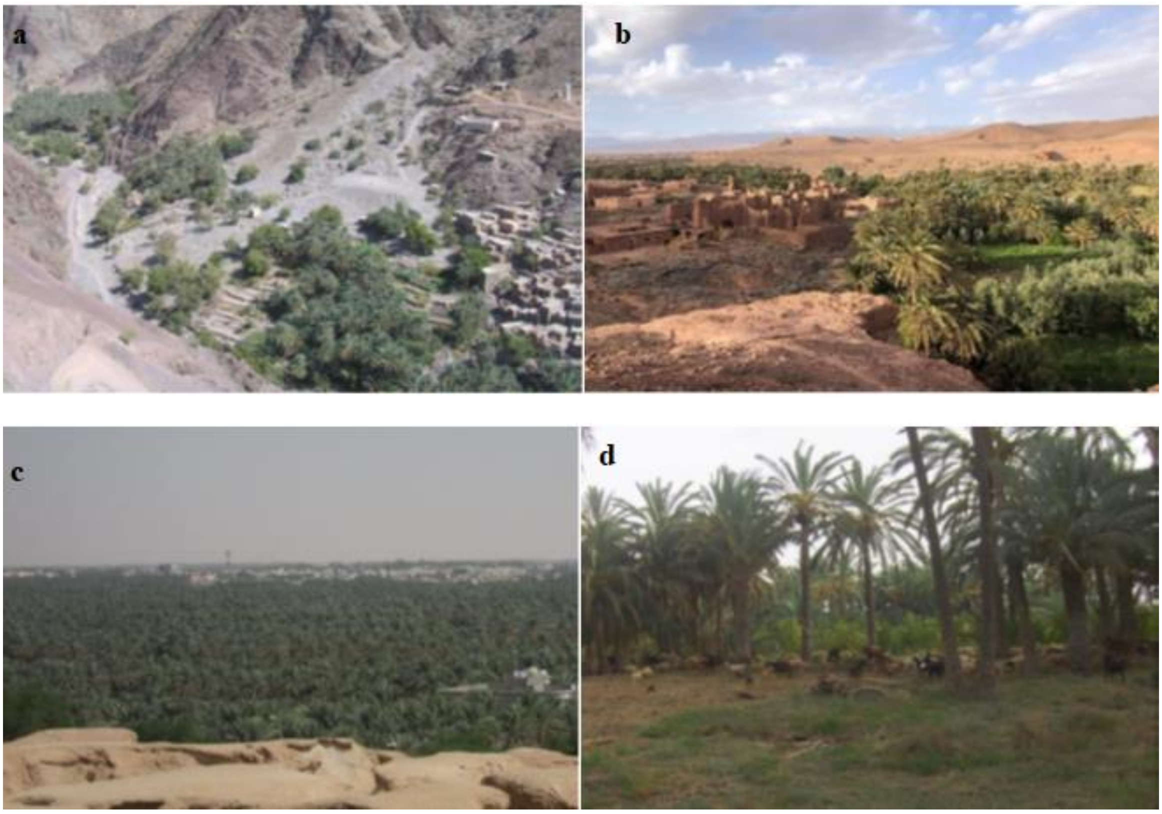

Figure 1Oases across the Arabian Peninsula and North Africa (alphabetically by country): (a) Masayrat ar Ruwajah oasis, Ad Dakhiliyah Governorate, Oman. Photo: Eike Lüdeling; (b) Tasselmanet oasis, Ouarzazate Province, Morocco. Photo: Abdellatif Khattabi. (c) Al

3. Siwa oasis as an example of the areas affected by climate change in Egypt.

The oases in Egypt are the most prominent features of the Western Desert as green patches. The five inhabited Egyptian oases in the Western Desert are Siwa, Bahariya, Farafra, Dakhla, and Kharga, which contain the largest underground water reservoir. Siwa Oasis is located in the northern part of the Western Desert of Egypt, 300 km south of the Mediterranean coast and near the Libyan border as a natural deep depression about 20 m below sea level (Fig. 1). It is one of the most isolated Egyptian settlements in the Western Desert with people who have developed a unique culture. The people of Siwa, with a population of 28300 individuals (DRC, 2016), speak their own language, which is closer to the Berber people of the desert.

Groundwater is one of Siwa's most valuable resources. Agriculture has been and continues to be the most important economic activity in Siwa by cultivating dates and olives, which play a significant role in rural livelihoods. Currently, some 280,000 date palms produce some 25.000 t of dates per year, corresponding to approximately 2% of Egypt's total date production. Siwa is also a major national olive producer with a total annual production of 27,500 t (DRC, 2016). Tourism has recently become a vital source of income, and attention has been paid to building hotels with local materials that exhibit unique local styles (El-Ramady et al., 2018). Siwa oasis has been recognized as a Globally Important Agricultural Heritage Site (GIAHS) by FAO as an in-situ repository of plant genetic resources, in particular the uniquely adapted varieties of the date palm, olive and secondary crops that are highly valued for their quality and continue to play a significant role in rural livelihoods and diets (FAO, 2016).

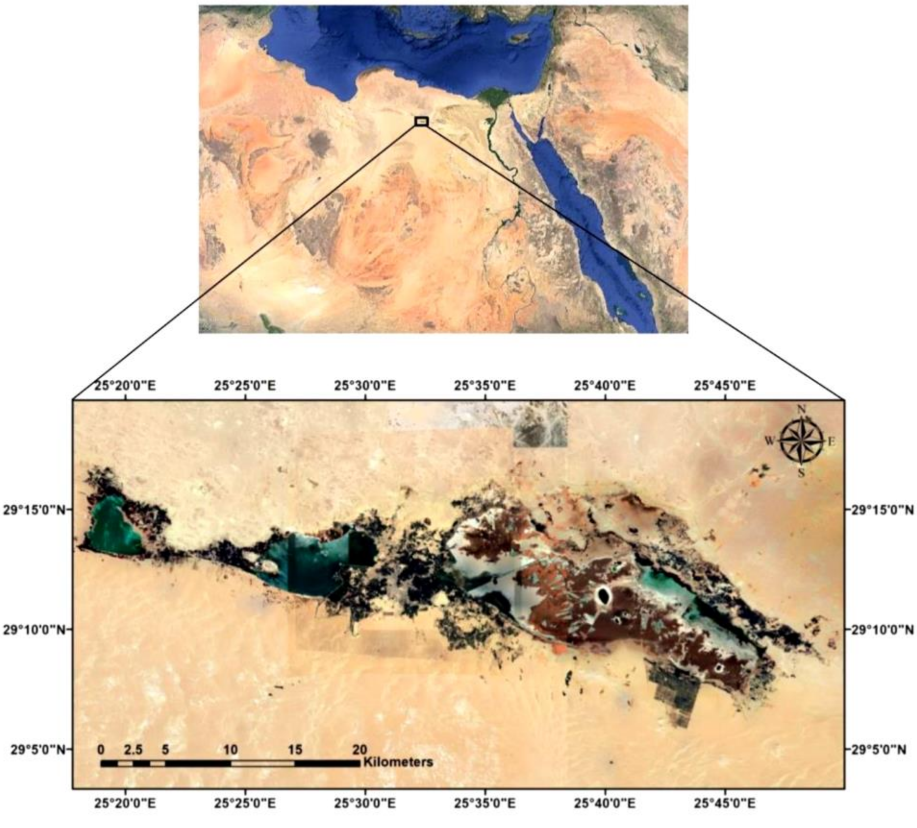

FIGURE 2THE SATELLITE IMAGE OF THE SIWA OASIS, EGYPT. SOURCE: GOOGLE EARTH.

The population growth in Siwa is leading to rapid agricultural expansion and land reclamation. The Siwan farmers are transforming the surrounding desert to reclaimed land by applying their old traditional heritage practices. However, agricultural expansion in the oasis depends primarily on non-renewable groundwater. Soil salinization and vegetation degradation (Fig. 3) have accelerated since 2000 due to water mismanagement and insufficient drainage systems (Masoud and Koike, 2006). Between 1990- 2008, the cultivated area increased from 53 to 88 km2, lakes from 60 to 76 km2, sabkhas (salt flats) from 335 to 470 km2, and the urban area from 6 to 10 km2 (Abo-Ragab, 2010). Climate change intensified rising groundwater tables (Askri et al., 2010; Gad and Abdel-Baki, 2002; Marlet et al., 2009).

Masoud and Koike (2006) advocated acceleration in the rate of soil salinization and vegetation death in the Siwa oasis after the year 2000. Satellite images were analyzed and concluded that 85 km2 of land in the Oasis had been salinized during 1987–2003, with a vegetation loss of some 21 km2. Besides, they argued that this rise in salinization is positively linked to relative climate warming and insufficient drainage systems, combined with the lack of an effective strategy for managing water supplies. In support of this, Gad and Abdel-Baki (2002), Marlet et al.(2009), and Askri et al.(2010) stated that inefficiency in water use by farmers is a major cause of secondary salinization in the Oasis. Prevention of soil salinization has been proposed in several studies in similar areas in India, China, and Pakistan (e.g., Boumans et al., 1988; Ghassemi et al., 1995; Morris and Collopy, 1999; Qadir and Oster, 2002; Wang and Li, 2013). These recommendations revolve around reducing water inflow into the lakes, subsoil, and shallow water-table and using means for removing excess water from the subsoil.

FIGURE 3A PHOTOGRAPH SHOWING TOPSOIL SALINIZATION AND VEGETATION DEATH DUE TO THE INCREASE IN WATER-TABLE IN SIWA OASIS (TAKEN FROM MASOUD AND KOIKE, 2006).

4. Concluding remarks and recommendations

Desertification and climate change would decrease dryland ecosystem resources and ecosystem protection, including biodiversity losses, both separately and in conjunction. Desertification worsens climate change by various processes, including changes in vegetation cover, sand and dust aerosols, and other factors. Integrated crop, soil and water management strategies can be used to reduce soil degradation and improve agricultural production systems' sensitivity to the effects of climate change. Crop diversification and the use of drought-tolerant crops, reduced tillage, the implementation of advanced irrigation techniques and moisture management methods (e.g., rainwater harvesting using indigenous and local practices), and the maintenance of vegetation and mulch cover are all examples of these strategies. Furthermore, rural households' resistance to desertification and severe weather events, such as droughts, is strengthened by on-farm and off-farm livelihood diversification strategies.

Regarding oases, the water supply for agriculture is likely to become much more limited in the future due to changing climate, and feasible solutions are difficult to come through. Although some authors emphasize the possibility of using desalinated water for irrigation, the economics of such options is debatable, particularly given the Arabian Peninsula's and North Africa's high evapotranspiration rates. Many oases are situated far away from water supplies appropriate for desalination, further complicating the situation. As a result, most authors emphasize the importance of restricting water use, e.g., increasing irrigation efficiency, reducing agricultural areas, or enforcing water-use limits, as well as closely monitoring desertification. Whether the adoption of low-water crops, such as sorghum or jojoba, could be a viable choice for some oases remains to be seen, but given their comparatively low-profit margins compared to currently grown oases, there are reasons for doubting the economic viability of such proposals. While it is currently uncertain to what degree oasis farming can be sustained in hot locations in the area, cooler sites potentially shift to new species and cultivars, especially for tree crops, which have particular climatic needs across seasons. Resilient options can be established, but procedures to fit tree species and cultivars with a site environment need to be strengthened to promote successful adaptation.

5. References

Abatzoglou, J.T. and Kolden, C.A., 2011. Climate change in western US deserts: potential for increased wildfire and invasive annual grasses. *Rangeland Ecology & Management*, *64*(5), pp.471-478.

Abo-Ragab, S., 2010. A desertification impact on Siwa Oasis: Present and future challenges. *Research Journal of Agriculture and Biological Sciences*, *6*(6), pp.791-805.

Aldababseh, A., Temimi, M., Maghelal, P., Branch, O. and Wulfmeyer, V., 2018. Multi-criteria evaluation of irrigated agriculture suitability to achieve food security in an arid environment. *Sustainability*, *10*(3), p.803.

Al-Kalbani, M.S., Price, M.F., Abahussain, A., Ahmed, M. and O'Higgins, T., 2014. Vulnerability assessment of environmental and climate change impacts on water resources in Al Jabal Al Akhdar, Sultanate of Oman. *Water*, *6*(10), pp.3118-3135.

Al-Kalbani, M.S., Price, M.F., O'Higgins, T., Ahmed, M. and Abahussain, A., 2016. Integrated environmental assessment to explore water resources management in Al Jabal Al Akhdar, Sultanate of Oman. *Regional Environmental Change*, *16*(5), pp.1345-1361.

Almazroui, M., Islam, M.N., Balkhair, K.S., Şen, Z. and Masood, A., 2017. Rainwater harvesting possibility under climate change: A basin-scale case study over western province of Saudi Arabia. *Atmospheric research*, *189*, pp.11-23.

Aoun-Sebaiti, B., Hani, A., Djabri, L., Chaffai, H., Aichouri, I. and Boughrira, N., 2014. Simulation of water supply and water demand in the valley of Seybouse (East Algeria). *Desalination and Water Treatment*, *52*(10-12), pp.2114-2119.

Askri, B., Bouhlila, R. and Job, J.O., 2010. Development and application of a conceptual hydrologic model to predict soil salinity within modern Tunisian oases. *Journal of Hydrology*, *380*(1-2), pp.45-61.

Ben Hassine, H., Slimane, A.B., Mlawah, M., Albouchi, L. and Gandouzi, A., 2013. Effects of underground water on soil salinity and dates production in Kebili Oases Area (Tunisia): The case of El Bahaier Oasi. *Journal Of Environmental Science, Toxicology And Food Technology*,*(4)*, pp.51-58.

Benmoussa, H., Luedeling, E., Ghrab, M., Yahmed, J.B. and Mimoun, M.B., 2017. Performance of pistachio (Pistacia vera L.) in warming Mediterranean orchards. *Environmental and experimental botany*, *140*, pp.76-85.

Besser, H., Mokadem, N., Redhouania, B., Rhimi, N., Khlifi, F., Ayadi, Y., Omar, Z., Bouajila, A. and Hamed, Y., 2017. GIS-based evaluation of groundwater quality and estimation of soil salinization and land degradation risks in an arid Mediterranean site (SW Tunisia). *Arabian Journal of Geosciences*, *10*(16), pp.1-20.

Boumans, J.H., Van Hoorn, J.W., Kruseman, G.P. and Tanwar, B.S., 1988. Water table control, reuse and disposal of drainage water in Haryana. *Agricultural Water Management*, *14*(1-4), pp.537-545.

Bounoua, L., Safia, A., Masek, J., Peters-Lidard, C. and Imhoff, M.L., 2009. Impact of urban growth on surface climate: A case study in Oran, Algeria. *Journal of applied meteorology and climatology*, *48*(2), pp.217-231.

Burke, E.J., Brown, S.J. and Christidis, N., 2006. Modeling the recent evolution of global drought and projections for the twenty-first century with the Hadley Centre climate model. *Journal of Hydrometeorology*, *7*(5), pp.1113-1125.

Chen, J., Yin, S., Gebhardt, H. and Yang, X., 2018. Farmers' livelihood adaptation to environmental change in an arid region: A case study of the Minqin Oasis, northwestern China. *Ecological Indicators*, *93*, pp.411-423.

Chowdhury, S. and Al-Zahrani, M., 2013. Implications of climate change on water resources in Saudi Arabia. *Arabian Journal for Science and Engineering*, *38*(8), pp.1959-1971.

D'Odorico, P., Bhattachan, A., Davis, K.F., Ravi, S. and Runyan, C.W., 2013. Global desertification: drivers and feedbacks. *Advances in water resources*, *51*, pp.326-344.

Dai, A., 2011. Drought under global warming: a review. *Wiley Interdisciplinary Reviews: Climate Change*, *2*(1), pp.45-65.

DRC, 2016. Analysis of Globally Important Agricultural Heritage Systems in Siwa Oasis, Egypt. Desert Research Center, Cairo, Egypt. Final Report, April 2016. Mimeograph, 153 p.

El-Ramady, H., Alshaal, T., Bakr, N., Elbana, T., Mohamed, E. and Belal, A.A. eds., 2018. The Soils of Egypt.

FAO. (2016). Trees, forests and land use in drylands: The first global assessment Preliminary findings 9 (First). Rome: FAO.

Feng, S. and Fu, Q., 2013. Expansion of global drylands under a warming climate. *Atmospheric Chemistry and Physics*, *13*(19), pp.10081-10094.

Fricke, K., Sterr, T., Bubenzer, O. and Eitel, B., 2009. The oasis as a megacity: Urumqi's fast urbanisation in a semiarid environment: Megacity research. *Erde*, *140*(4), pp.449-463.

Gad, M.I.M. and Abdel-Baki, A.A., 2002, April. Estimation of salt balance in the soil-water of the old cultivated lands in Siwa oasis, western desert, Egypt. In *Proceedings of the International Symposium on Optimum Resources Utilization in Salt-Affected Ecosystems in Arid and Semi-Arid Regions* (pp. 16-23).

Gao, Q., Kang, M., Xu, H., Jiang, Y. and Yang, J., 2010. Optimization of land use structure and spatial pattern for the semi-arid loess hilly–gully region in China. *Catena*, *81*(3), pp.196-202.

Georgescu, M., Miguez-Macho, G., Steyaert, L.T. and Weaver, C.P., 2009. Climatic effects of 30 years of landscape change over the Greater Phoenix, Arizona, region: 1. Surface energy budget changes. *Journal of Geophysical Research: Atmospheres*, *114*(D5).

Ghassemi, F., Jakeman, A.J. and Nix, H.A., 1995. *Salinisation of land and water resources: human causes, extent, management and case studies*. CAB international.

Guan, C., Li, X., Zhang, P. and Li, C., 2019. Effect of global warming on soil respiration and cumulative carbon release in biocrust-dominated areas in the Tengger Desert, northern China. *Journal of Soils and Sediments*, *19*(3), pp.1161-1170.

Huang, J., Ji, M., Xie, Y., Wang, S., He, Y. and Ran, J., 2016. Global semi-arid climate change over last 60 years. *Climate Dynamics*, *46*(3-4), pp.1131-1150.

Ji, F., Wu, Z., Huang, J. and Chassignet, E.P., 2014. Evolution of land surface air temperature trend. *Nature Climate Change*, *4*(6), pp.462-466.

Jilali, A., 2014. Impact of climate change on the Figuig aquifer using a numerical model: Oasis of Eastern Morocco. *Journal of Biology and Earth Sciences*, *4*(1), pp.E16-E24.

Johannsen, I.M., Hengst, J.C., Goll, A., Höllermann, B. and Diekkrüger, B., 2016. Future of water supply and demand in the Middle Drâa Valley, Morocco, under climate and land use change. *Water*, *8*(8), p.313.

Jones, M.D., Abu-Jaber, N., AlShdaifat, A., Baird, D., Cook, B.I., Cuthbert, M.O., Dean, J.R., Djamali, M., Eastwood, W., Fleitmann, D. and Haywood, A., 2019. 20,000 years of societal vulnerability and adaptation to climate change in southwest Asia. *Wiley Interdisciplinary Reviews: Water*, *6*(2), p.e1330.

Karmaoui, A., Ifaadassan, I., Babqiqi, A., Messouli, M. and Khebiza, M.Y., 2016. Analysis of the water supply-demand relationship in the Middle Draa Valley, Morocco, under climate change and socio-economic scenarios. *Journal of Scientific Research and Reports*, pp.1-10.

Li, A., Wu, J. and Huang, J., 2012. Distinguishing between human-induced and climate-driven vegetation changes: a critical application of RESTREND in inner Mongolia. *Landscape ecology*, *27*(7), pp.969-982.

Li, X., Yang, K. and Zhou, Y., 2016. Progress in the study of oasis-desert interactions.

Luedeling, E., Gebauer, J. and Buerkert, A., 2009. Climate change effects on winter chill for tree crops with chilling requirements on the Arabian Peninsula. *Climatic Change*, *96*(1), pp.219-237.

Marlet, S., Bouksila, F. and Bahri, A., 2009. Water and salt balance at irrigation scheme scale: a comprehensive approach for salinity assessment in a Saharan oasis. *Agricultural Water Management*, *96*(9), pp.1311-1322.

Masoud, A.A. and Koike, K., 2006. Arid land salinization detected by remotely-sensed landcover changes: A case study in the Siwa region, NW Egypt. *Journal of arid environments*, *66*(1), pp.151-167.

Ministry of Agriculture and Water Resources of Tunisia, & GIZ. (2007). Stratégie nationale 44 d'adaptation de l'agriculture tunisienne et des écosystèmes aux changements climatiques.

Morris, J.D. and Collopy, J.J., 1999. Water use and salt accumulation by Eucalyptus camaldulensis and Casuarina cunninghamiana on a site with shallow saline groundwater. *Agricultural Water Management*, *39*(2-3), pp.205-227.

Qadir, M. and Oster, J., 2002. Vegetative bioremediation of calcareous sodic soils: history, mechanisms, and evaluation. *Irrigation Science*, *21*(3), pp.91-101.

Safriel, U., Ezcurra, E., Tegen, I., Schlesinger, W.H., Nellemann, C., Batjes, N.H., Dent, D., Groner, E., Morrison, S., Resenfeld, D. and Avner, U., 2006. Deserts and the planet-linkages between deserts and non-deserts. In *Global Deserts Outlook* (pp. 50-72). UNEP.

Safronov, O., Kreuzwieser, J., Haberer, G., Alyousif, M.S., Schulze, W., Al-Harbi, N., Arab, L., Ache, P., Stempfl, T., Kruse, J. and Mayer, K.X., 2017. Detecting early signs of heat and drought stress in Phoenix dactylifera (date palm). *PLoS One*, *12*(6), p.e0177883.

Scanlon, B.R., Keese, K.E., Flint, A.L., Flint, L.E., Gaye, C.B., Edmunds, W.M. and Simmers, I., 2006. Global synthesis of groundwater recharge in semiarid and arid regions. *Hydrological Processes: An International Journal*, *20*(15), pp.3335-3370.

Sefelnasr, A., Gossel, W. and Wycisk, P., 2014. Three-dimensional groundwater flow modeling approach for the groundwater management options for the Dakhla oasis, Western Desert, Egypt. *Environmental earth sciences*, *72*(4), pp.1227-1241.

Sheffield, J., Andreadis, K.M., Wood, E.F. and Lettenmaier, D.P., 2009. Global and continental drought in the second half of the twentieth century: Severity–area–duration analysis and temporal variability of large-scale events. *Journal of Climate*, *22*(8), pp.1962-1981.

Siebert, C., Rödiger, T., Schulz, S., Horovitz, M., Merz, R., Friesen, J., Dietrich, P., Michelsen, N., Kallioras, A., Rausch, R. and Engelhardt, I., 2016. New tools for coherent information base for IWRM in arid regions: the upper mega aquifer system on the Arabian Peninsula. In *Integrated Water Resources Management: Concept, Research and Implementation* (pp. 85-106). Springer, Cham.

Solomon, S., Manning, M., Marquis, M. and Qin, D., 2007. *Climate change 2007-the physical science basis: Working group I contribution to the fourth assessment report of the IPCC* (Vol. 4). Cambridge university press.

Switzman, H., Salem, B., Gad, M., Adeel, Z. and Coulibaly, P., 2018. Conservation planning as an adaptive strategy for climate change and groundwater depletion in Wadi El Natrun, Egypt. *Hydrogeology Journal*, *26*(3), pp.689-703.

Tarawneh, Q.Y. and Chowdhury, S., 2018. Trends of climate change in Saudi

Arabia: Implications on water resources. *Climate*, *6*(1), p.8.

Wang, Y. and Li, Y., 2013. Land exploitation resulting in soil salinization in a desert–oasis ecotone. *Catena*, *100*, pp.50-56.

Xu, Y., Tang, B.S. and Chan, E.H., 2011. State-led land requisition and transformation of rural villages in transitional China. *Habitat International*, *35*(1), pp.57-65.

Zhang, X., Zwiers, F.W., Hegerl, G.C., Lambert, F.H., Gillett, N.P., Solomon, S., Stott, P.A. and Nozawa, T., 2007. Detection of human influence on twentieth-century precipitation trends. *Nature*, *448*(7152), pp.461-465.