Annals of Arid Zone 47(3&4): 457-471, 2008

Climate Change and Urbanization in Arid Regions

Boris A. Portnov[1] and Shlomit Paz[2]

[1] *Department of Natural Resources and Environmental Management, Graduate School of Management, University of Haifa, Haifa, Israel*

[2] *Department of Geography and Environmental Studies, University of Haifa, Haifa, Israel*

Abstract: Ongoing global climate change, which manifests itself in the greater inter-annual variability of precipitation, rising summer temperatures, and increasing periods of droughts, is likely to affect the pace of arid land urbanization in three distinct ways: (a) increasing migration of desert nomads into urban areas; (b) restructuring of regional economies towards reducing the relative share of traditional water-intensive agriculture, and (c) increasing the number of urban settlements in arid regions due to expansion of deserts towards arid land fringes. The present paper looks into the interaction between the climate change and urbanization in arid regions and formulates recommendations for urban and regional development policy aimed at a more sustained urban growth in arid regions.

Key words: Deserts, arid zones, urbanization, climate change.

The Earth's climate is mainly influenced by the solar energy, but also by the amount of greenhouse gases and aerosols in the atmosphere (O'Hare *et al.*, 2005). The concentrations of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) in the atmosphere significantly increased since the beginning of the Industrial Revolution, mostly as a result of human activities, such as fossil fuels burning, biomass utilization and deforestation (Houghton, 2004). The burning of fossil fuels has also resulted in emissions of aerosols that absorb and emit heat, and reflect light. These additions of greenhouse gases and aerosols have changed the composition of the atmosphere and led to climatic changes that influence temperature, precipitation, winds and sea level on global and regional scales (EPA, 2007). It seems that climate change processes are already happening, being one of the greatest environmental, social and economic threats facing the planet (IPCC, 2007a; EU Environment, 2008). According to the prediction results of various global climate models (see inter alia Wigley and Raper, 2001; Stott and Kettleborough, 2002; Knutti *et al.*, 2003; Furrer *et al.*, 2007), without further actions to reduce greenhouse gas emissions, the global average surface temperatures are likely to rise by a further 1.8 to 4.0°C by the end of this century, and by up to 6.4°C in the worst case scenario.

Climate change affects human systems in three principal ways: first, it provides a context for climate-sensitive human activities, such as water shortage for irrigation. Second, it affects the cost of maintaining climate-controlled environments for human life and activity, and, third, it interacts with other types of stresses on human systems, such as rural-urban

migration as a result of drought. In most cases, climate change exacerbates the stress that human activity imposes on the natural environment (IPCC, 2007a).

Rapid urbanization in arid regions, especially susceptive to climate change, is a special concern, because it concentrates people and economic assets in environmentally high-risk areas and thus increases global and regional vulnerability to climate change impacts (Scott *et al.*, 2001). Urban area in developing countries is a good example of this impact, where low capacity drinking water systems are unable to deal with periodic droughts and increased evaporation as a result of climate warming, concomitant with rapid population growth (IPCC, 2007b).

Today, more than a half of the world population lives in urban centers, depending on industry, services and infrastructures for personal income, well-being and day-to-day mobility (UN, 2006). According to the UN's recent estimates, major population growth in the next decades will take place in urban areas, mostly in medium-size cities of 1 to 5 million residents (or even in smaller cities of less than 500,000 people). The majority of these cities are located in the developing countries, especially in Asia and Africa, a sizable part of which are classified as arid and semi-arid countries (UN-Habitat, 2003; IPCC, 2007b).

The present paper looks into the interaction between the climate change and urbanization in arid regions. It starts with a brief review of climate changes on the global scale and in different regions of the world, especially those susceptive to aridity. The analysis is followed by a brief review of potential trends in urban development patterns attributed to both ongoing and potentially forthcoming climate change. In particular, we discuss population movements to and within arid regions and their interaction with the urban environment. Two types of population movements into arid regions are evident today: migration into permanent settlements (urbanization) and short-term visits (tourism); both urbanization and short-term migration increase the pace of population growth in the arid zones. Recommendations for urban and regional development policy conclude the discussion.

Climate Change Impacts on Arid Regions

Arid regions and their climatic characteristics

Arid regions are one of the largest terrestrial biomes, where the potential evaporation ratio exceeds the amount of precipitation (Nicholson, 2002; Warner, 2004; Smithson *et al.*, 2002). Their types range between regions with sufficient moisture (semi-arid, semi-desert regions), where the precipitation is around 300 mm per year, to hyper-arid regions (extreme deserts), where the rainfall is 50 mm per year or even less (Nicholson, 2002; Warner, 2004; Reid *et al.*, 2005).

The core areas of the drylands are the subtropical high-pressure systems. Sinking air from high altitudes, as a part of the Hadley cell, tends to warm and dry during its subsiding, which minimizes the chance of rainfall (as in the Sahara desert). Mountain ranges may also play a role, causing a "rain shadow" on their lee side. For instance, in Asia, the great Himalayan chain prevents

the summer monsoon flow of the Indian Ocean air from reaching the interior. Other natural factors causing aridity are large distance from water source (one well-known example is the Gobi desert) and the location near a cold ocean current (e.g. Peruvian coasts) (Smithson *et al.*, 2002).

Due to their low agricultural productivity, the deserts support no more that 10 people per km^2, with the lowest population density across all eco-regions of the world (Reid *et al.*, 2005).

Drought

Drought, commonly associated with aridity, is a complex, multifaceted phenomenon which is difficult to define precisely. According to O'Hare *et al.* (2005) and Heim (2002), it is a prolonged period of abnormally dry weather, which causes a serious hydrological imbalance. It has number of facets: "meteorological drought," which is mainly a prolonged deficit of precipitation; "hydrological drought," which is related to below-normal stream flow, lake and groundwater levels, and "agricultural drought" that relates to moisture deficits in the topmost layer of soil (the root zone) that impacts crops (ibid). Droughts occur in most countries, in both dry and humid regions alike, and their spatial extent and severity vary on seasonal and annual timescales (WMO, 2006). Following the Palmer Severity Drought Index-PSDI (Palmer, 1965; Heim, 2002), evapotranspiration and drying are important factors that contribute to droughts. Climatic models predict that drought processes are encouraged by an increase in temperatures associated with a decrease in precipitation (IPCC, 2007a).

Desertification

The transition zones surrounding deserts have very fragile, delicately balanced ecosystems. In these marginal areas, human activities may stress the ecosystem beyond its tolerance (or carrying capacity) limits. By pounding the soil with their hooves, livestock compact the substrate, increase the proportion of fine material, and reduce the percolation rate of the soil, thus encouraging erosion by wind and water. Grazing and the collection of firewood reduce or eliminate plants that help to bind the soil. The result is degradation of the land, causing desertification, which leads to the expansion of desert-like conditions into non-desert area (USGS, 1997; Tarbuck and Lutgens, 2005). Recent studies estimate that between 10-20% of the drylands are degraded because of human intervention, creating an imbalance between demand and supply of ecosystem services. These critical services include water for humans and livestock, water for sanitation and irrigation, fuel, building materials, wild food sources, forage and grazing, and genetic resources, particularly of arid-adapted species (Adeel *et al.*, 2005; Hassan *et al.*, 2005).

Desertification is a global phenomenon that is spurred by climate variations, especially by drought (Houghton, 2004; O'hare *et al.*, 2005). The progress of desertification in drylands is likely to increase in the next decades due to more frequent and intense droughts, as a result of expected climate change (Houghton, 2004).

Global climate change impacts on arid regions

Global climate change is likely to affect arid regions in several ways. According to IPCC (2007b), theses influences, together

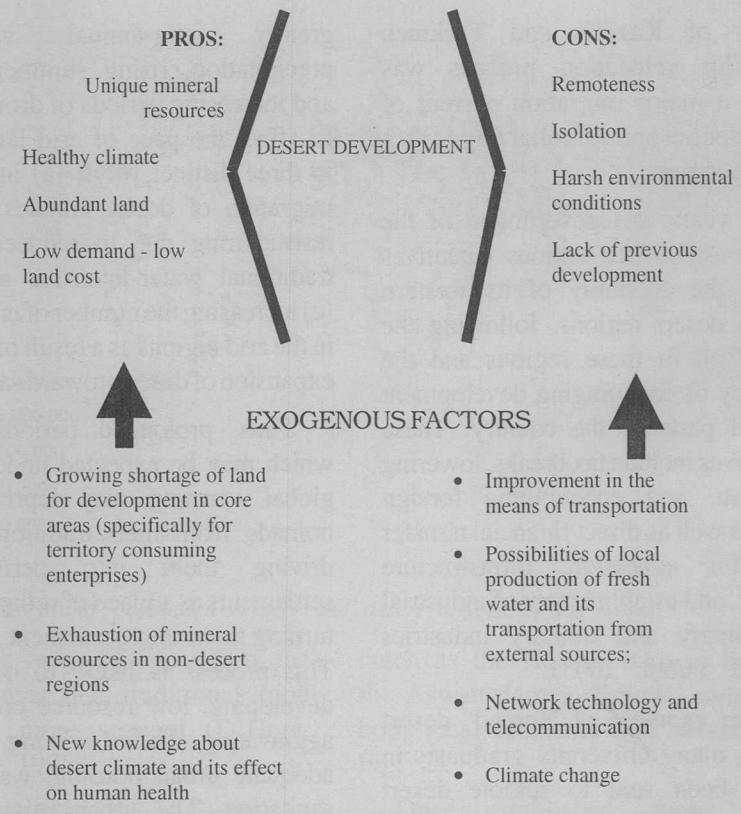

Fig. 2. Factors affecting urbanization in desert regions (after: Portnov and Safriel, 2004)

resources are concerned. The "low-resource" societies will thus require substantial exogenous aid to achieve the economy-transformation goal or will otherwise sink even deeper into the vicious circle of famine and poverty.

The expected global warming may also accelerate the pace of desertification or the process of geographic expansion of deserts, which is already evident today (Middleton and Thomas, 1997). This process will draw the desert frontier closer to many existing population centers, located today in semi-arid zones, thus bringing more cities currently located in desert fringes closer to the desert; some of them will become desert cities eventually. Thus, as a result of climate change more non-desert people of today are likely to become desert dwellers of tomorrow, not by their own free choice, but by the merciless forces of nature.

Conclusions

Two major factors hamper the attractiveness of desert settlements for newcomers - limited employment opportunities and remoteness from major cities outside desert regions, which are major national foci of employment, services and cultural life. However, if these drawbacks

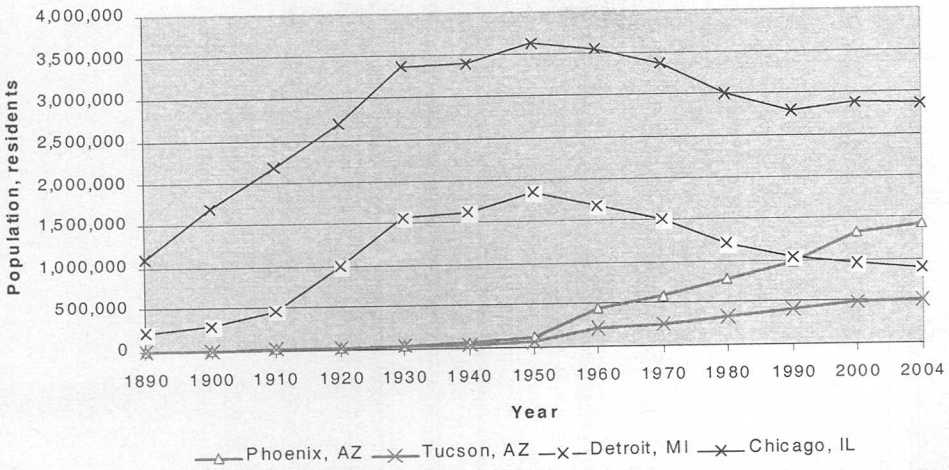

Fig. 3. Comparative trends of population growth of selected cities in the United States (Source: Assembled from publications of the US Census Bureau)

are mitigated (e.g., as in Tucson and Phoenix, AZ), desert cities may exhibit impressive growth, outranking even long-established non-desert communities (Fig. 3). Although successful desert cities such as Tucson and Phoenix are rather unique cases, their success factors (that is, the combination of infrastructure development and employment creation) may be emulated in other desert areas, thus leading to more sustained urbanization trends in the arid zones.

Achieving this goal will, however, require a major change in the existing regional development paradigm.

In our view, a main reason for the failure of regional policy to achieve a desirable interregional population shift towards urban areas in arid zones is the so called "compensatory approach" to selecting development incentives. For instance, regional policy makers may try to compensate relative disadvantages of arid regions (e.g., a lack of previous urban development, harsh environment, inferior infrastructure and communication networks) by tax benefits or more affordable public housing. These measures may, however, have only a limited effect on the interregional population change.

In contrast, the "counter-balanced" approach we advocate assumes that relative disadvantages of peripheral regions should be counter-balanced rather than compensated (Portnov and Etzion, 2000). For instance, a lack of previous urban development in a peripheral arid region can be reduced by creating dense urban clusters in which small urban settlements share some essential urban functions - employment, educational, cultural and recreational services and facilities - where each of the small localities cannot individually sustain (Portnov and Safriel, 2004).

In order to diversify the employment base of peripheral areas, another strategy

- the strategy of redirecting priorities - can also be employed. Such a strategy assumes that development resources should be primarily concentrated on a limited number of selected urban communities in the frontier areas (Portnov and Erell, 1998). This should be done until these communities become sufficiently attractive to both migrants and private developers. Such support can then be redirected, on a stage-by-stage basis, to other frontier settlements. Combined with traditional compensatory policy measures (provision of public housing, tax incentives, etc.), the aforementioned development strategies may improve substantially the quality of urban life in arid regions by attracting more migrants and private developers there.

References

Abu-Taleb, M.F. 2000. Impacts of global climate change scenarios on water supply and demand in Jordan. *Water International* 25: 457-463.

Adeel, Z., Safriel, U., Niemeijer, D., White, R., de Kalbermatten, G., Glantz, M., Salem, B., Scholes, R., Niamir-Fuller, M., Ehui, S. and Yapi-Gnaore, V. (Eds.) 2005. *Ecosystems and Human Well-being: Desertification Synthesis*. Island Press, Washington, District of Columbia, 36 pp.

Alpert, P., Ben-Gai, T., Bahrahad, A., Benjamini, Y., Yekutieli, D., Colacino, M., Diodato, L., Ramis, C., Homar, V., Romero, R., Michaelides, S. and Manes, A. 2002. The paradoxical increase of Mediterranean extreme daily rainfall in spite of decrease in total values. *Geophysical Research Letters* 29(11): doi:10.1029/2001GL013554

Barlow, M., Cullen, H. and Lyon, B. 2002. Drought in central and southwest Asia: La Niña, the warm pool, and Indian Ocean precipitation. *Journal of Climate* 15: 697-700.

Biggs, R., Bohensky, E., Desanker, P.V., Fabricius, C., Lynam, T., Misselhorn, A.A., Musvoto, C., Mutale, M., Reyers, B., Scholes, R.J., Shikongo, S., and van Jaarsveld, A.S. 2004. *Nature Supporting People: The Southern African Millennium Ecosystem Assessment Integrated Report*. Millennium Ecosystem Assessment, Council for Scientific and Industrial Research, Pretoria, 68 pp.

Bou-Zeid, E. and El-Fadel, M. 2002. Climate change and water resources in Lebanon and the Middle East. *Journal of Water Research Planning and Management* 128: 343-355.

Burke, E.J., Brown, S.J. and Christidis, N. 2006. Modelling the recent evolution of global drought and projections for the 21st century with the Hadley Centre climate model. *Journal of Hydrometeorology* 7: 113-125

Confalonieri, U. 2003. Variabilidade climática, vulnerabilidade social e saúde no Brasil. Terra Livre, San Paulo, 19-I, 20, 193-204.

Dai, A., Lamb, Trenberth, P.J., Hulme, K.E., Jones, M., Pingping Xie, P.D. 2004. The recent Sahel drought is real. *International Journal of Climatology* 24: 1323-1331.

D'Hont, O. 1989. The population of the squatter districts of Nouakchott, or 'Kebe'. *Mauritania, Cahiers d'Outre Mer* 42(165): 73-96.

Divon H. and Abou Hadab F. 1996 Collaborative Agricultural and Rural Development of Settlement in the Nubariya Region, Egypt (http://www.jewishvirtuallibrary.org/jsource/Peace/egmashav.html)

Duraiappah, A., Naeem, S., Agardi, T., Ash, N., Cooper, D., Diaz, S., Faith, D.P., Mace, G., McNeilly, J.A., Mooney, H.A., Oteng-Yeboah, A.A., Pereira, H.M., Polasky, S., Prip, C., Reid, W.V., Samper, C., Schei, P.J., Scholes, R., Schutyser, F. and van Jaarsveld, A. (Eds.) 2005. *Ecosystems and HumanWell-being: Biodiversity Synthesis*. Island Press, Washington, District of Columbia, 100 pp.

ECA (Economic Commission for Africa) 2005. Assessing sustainable development in Africa. *Africa's Sustainable Development Bulletin*. Economic Commission for Africa, Addis Ababa, 59 pp.

ECF (European Climate Forum) and Potsdam Institute 2004. What is dangerous climate change? *Initial Results of a Symposium on Key Vulnerable Regions, Climate Change and Article 2 of the UNFCCC*, Buenos Aires. Beijing, 39 pp. Available: http://www.european-climate-forum.net/.

EEA 2004. *Impacts of Europe's Changing Climate: An Indicator-Based Assessment.* EEA Report No 2/2004, European Environment Agency, Copenhagen (or: Luxembourg, Office for Official Publications of the EC), 107 pp.

EPA 2007. Climate change. Available: http://www.epa.gov/climatechange/index.html

EU environment, 2008. Climate change. Available: http://ec.europa.eu/environment/climat/home_en.htm

FAO 2004. Seguridad alimentaria como estrategia de Desarrollo rural. *Proc. 28ava Conferencia Regional de la FAO para América Latina y el Caribe*, Ciudad de Guatemala, Guatemala.

Furrer, R., Sain, S.R., Nychka, D. and Meehl, G.A. 2007. Multivariate Bayesian analysis of atmosphere-ocean general circulation models. *Environmental and Ecological Statistics* 14: 249-266.

Golany, G. 1978. Planning urban sites in arid zones: The basic considerations. In *Urban Planning for Arid Zones* (Ed. G. Golany), pp. 3-21. John Wiley & Sons, New York.

Gonzalez, P. 2001. Desertification and a shift of forest species in the West African Sahel. *Climate Research* 17: 217-228.

Hardy, J.T. 2003. *Climate Change Causes, Effects and Solutions*. Wiley, Chichester, 247 pp.

Hassan, R., Scholes, R. and Ash, N. (Eds.) 2005. *Ecosystems and Human Wellbeing*: Volume 1: Current State and Trends. Island Press, Washington, District of Columbia, 917 p.

Heim, R.R. 2002. A review of twentieth-century drought indices used in the United States. *Bulletin of the American Meteorological Society* 83: 1149-1165.

Houghton, J. 2004. *Global Warming*. 3rd edition, Cambridge University Press, 351 pp.

ICBS 2005. Statistical Abstract of Israel #55. Israel Central Bureau of Statistics, Jerusalem.

IPCC 2007a. Working Group I Report - The Physical Science Basis. Available: http://www.ipcc.ch/ipccreports/ar4-wg1.htm

IPCC 2007b. Working Group II Report - Impacts, Adaptation and Vulnerability. Available: http://www.ipcc.ch/ipccreports/ar4-wg2.htm

Issar, A. 1999. 'The Past as a Key for the Future in Resettling the Desert', in B.A. Portnov and A.P. Hare, Desert Regions: Population, Migration, and Environment, Springer Verlag, Heidelberg, pp. 241-248.

Johansen, R.J. 2001. Impacts of fire on biological soil crusts. *Biological Soil Crusts: Structure, Function, and Management* (Eds. J. Belnap and O.L. Lange), pp. 386-397. Springer, Berlin.

Kates, R.W., Johnson, D.L. and Johnson-Haring, K. 1977. *Population, Society and Desertification, in Desertification: Its Causes and Consequences*. Pergamon Press, Oxford, pp. 261-318.

Knutti, R., Stocker, T.F., Joos, F. and Plattner, G.-K. 2003. Probabilistic climate change projections using neural networks. *Climate Dynamics* 21: 257-272.

Lauenroth, W.K., Epstein, H.E., Paruelo, J.M., Burke, I.C., Aguiar, M.R. and Sala, O.E. 2004. Potential effects of climate change on the temperate zones of North and South America. *Revista Chilena de Historia Natural* 77: 439-453.

Lin, E.D., Xu, Y.L., Ju, H. and Xiong, W. 2004. Possible adaptation decisions from investigating the impacts of future climate change on food and water supply in China. Paper presented at the 2ndAIACC Regional Workshop for Asia and the Pacific, 2-5 November 2004, Manila, Philippines. Available: http://www.aiaccproject.org/meetings/Manila_04/Day2/erda_nov3.doc.

Lioubimtseva, E. and Adams, J.M. 2004. Possible implications of increased carbon dioxide levels and climate change for desert ecosystems. *Environmental Management* 33: S388-S404.

Malheiros, J.O. 2004. 17 puntos que ajudam a explicar o que é la desertificação, a convenção da ONU e o processo de construção do PAN-LCD Brasileiro. RIOD BRASIL, 11 pp.

McLeman, R. and Smit, B. 2005. Assessing the security implications of climate change-related migration. Preprint, *Human Security and Climate Change: An International Workshop*, Oslo, 20 pp.

Middleton, N. and Thomas, D. (Eds.) 1997. *World Atlas of Desertification*. Arnold, London.

Morrow A. Tourism in Egypt still booming despite militant attacks (http://www.dawn.com/2005/05/01/int13.htm)

Mutangadura, G., Ivens, S. and Donkor, S.M. 2005. Assessing the progress made by southern Africa in implementing the MDG target on drinking water and sanitation. *Assessing sustainable development in Africa*, Africa's Sustainable

Development Bulletin, Economic Commission for Africa, Addis Ababa, 19-23.

Myers, N. 2002. Environmental refugees: a growing phenomenon of the 21st century. *Philosophical Transactions of the Royal Academy of London, Series B - Biological Sciences* 357: 609-613.

Niasse, M., Afouda, A. and Amani, A. (Eds.) 2004. Reducing West Africa?s Vulnerability to Climate Impacts on Water Resources, Wetlands and Desertification: Elements for a Regional Strategy for Preparedness and Adaptation. International Union for Conservation of Nature and Resources (IUCN), Cambridge, 84 pp.

Nicholson, S.E. 2002. What are the key components of climate as a driver of desertification? *Global Desertification: Do Humans Cause Deserts?* (Eds. J.F. Reynolds and D.M. Stafford-Smith), pp. 41-57. Dahlem University Press, Berlin.

O'hare, G., Sweeny, J. and Wilby, R. 2005. *Weather, Climate and Climate Change - Human Perspectives, Pearson Education Limit*. London, 403 pp.

Oropeza, O. 2004. Evaluación de la vulnerabilidad a la desertificación. Cambio Climático: Una Visión Desde México, J.Martínez andA. Fernández Bremauntz, Eds., SEMARNAT e INE, México, 301-311.

Palmer, W.C. 1965. Meteorological Drought. Research Paper 45, US Department of Commerce, Weather Bureau, Washington, DC, 58 pp. [Available from NOAA Library and Information Services Division, Washington, DC 20852.]

Paz, S., Tourre, Y. and Planton, S. 2003. North Africa-West Asia (NAWA) Sea-Level Pressure Patterns and its Linkages with the Eastern Mediterranean (EM) Climate. Geophysical Research Letters, 30(19): 1999-2002, doi: 10.1029/2003GL01786.

Paz, S., Tourre, Y.M. and Brolley, J. 2008. Multi-temporal Climate Variability over the Atlantic Ocean and Eurasia: Linkages with Mediterranean and West African Climate. Atmospheric Science Letters, DOI: 10.1002/asl.181.

Pedersen, J. 1995 Drought, migration and population growth in the Sahel: The case of the Malian Gourma: 1900-1991. *Population Studies* 49(1), pp. 111-126.

Portnov B.A. and Safriel, U. 2004. Combating desertification in the Negev: dryland agriculture vs. dryland urbanization. *Journal of Arid Environments* 56(4): 659-680.

Portnov, B.A. and Erell, E. 1998. Long-term Development Peculiarities of Peripheral Desert Settlements: The Case of Israel. *International Journal of Urban and Regional Research* 22(2): 216-32.

Prospero, J.M. and Lamb, P.J. 2003. African droughts and dust transport to the Caribbean: climate change implications. *Science* 302: 1024-1027.

Ragab, R. and Prudhomme, C. 2002. Climate change and water resources management in arid and semi-arid regions: prospective and challenges for the 21st century. *Biosystems Engineering* 81: 3-34.

Reason, C.J.C. and Keibel, A.2004. Tropical cyclone Eline and its unusual penetration and impacts over the southern African mainland. *Weather Forecast* 19: 789-805.

Reich, P.F., Numbem, S.T., Almaraz, R.A. and Eswaran, H. 2001. Land resource stresses and desertification in Africa. *Agro-Science* 2: 1-10.

Reid, W.V., Mooney, H.A., Cropper, A., Capistrano, D., Carpenter, S.R., Chopra, K., Dasgupta, P., Dietz, T., Duraiappah, A.K., Hassan, R., Kasperson, R., Leemans, R., May, R.M., McMichael, A.J., Pingali, P., Samper, C., Scholes, R., Watson, R.T., Zakri, A.H., Shidong, Z., Ash, N.J., Bennett, E., Kumar, P., Lee, M.J., Raudsepp-Hearne, C., Simons, H., Thonell, J. and Zurek, M.B. (Eds.) 2005. *Ecosystems and Human Well-being: Synthesis*. Island Press, Washington, District of Columbia, 155 pp.

Saini, B.S. 1980. *Building in Hot Dry Climates*, John Wiley & Sons, Chichester.

Schreider, G. and Knerr, B. 2000. Labor migration as a social security mechanism for smallholder households in sub-Saharan Africa: the case of Cameroon. *Oxford Development Studies* 28: 223-236.

Schwinning, S. and Sala, O.E. 2004. Hierarchy of responses to resource pulses in arid and semi-arid ecosystems. *Oecologia* 141: 211-220.

Scott, M.J., Gupta, S., Jauregui, E., Nwafor J., Satterthwaite, D., Wanasinghe, Y., Wilbanks, T., Yoshino, M. and Kelkar, U. 2001. Human settlements, energy, and industry. In *Climate Change 2001: Impacts, Adaptation, and*

Vulnerability. Contribution of Working Group to the Third Assessment Report of the Intergovernmental Panel on Climate Change (Eds. J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken and K.S. White), pp. 381-416. Cambridge University Press, Cambridge.

Seely, M.K., Klintenberg, P. and Kruger, A.S. 2009. The unmet challenge of connecting scientific research with community action. In *The Future of Drylands* (Eds. Cathy Lee and Thomas Schaaf), pp. 687-697. Springer Netherlands & UNESCO.

Smith, S.D., Huxman, T.E., Zitzer, S.F., Charlet, T.N., Housman, D.C., Coleman, J.S., Fenstermaker, L.K., Seemann, J.R. and Nowak, R.S. 2000. Elevated CO_2 increases productivity and invasive species success in an arid ecosystem. *Nature* 408: 79-82.

Smithson, P., Addison, K. and Atkinson, K. 2002. *Fundamental of the Physical Environment.* 3rd edition, Routledge Press: London and New York., pp. 546-564.

Stott, P.A. and Kettleborough, J.A. 2002. Origins and estimates of uncertainty in predictions of twenty-first century temperature rise. *Nature* 416: 723-726.

Tarbuck, E.J. and Lutgens, F. 2005. *Earth - an Introduction to Physical Geology.* Pearson Education Limit, New Jersey, pp. 567-589.

Thomas, D.S.G. and Leason, H.C. 2005. Dunefield activity response to climate variability in the southwest Kalahari. *Geomorphology* 64: 117-132.

Tiffen, M. 2003. Transition in sub-Saharan Africa: agriculture, urbanization and income growth. *World Development* 31: 1343-1366.

Tourre, Y., Paz, S., Cassou, C. and Kutiel, H. 2006. Atmospheric Dynamics over Northwest Africa and Linkages with Sahelian Rainfall. Geophysical Research Letters, 33, L14808, doi:10.1029/2006GL026695.

UN Habitat. 2003. *Water and Sanitation in the World's Cities.* Earthscan, London 274 pp.

UNEP (United Nations Environment Programme) 2002. *Global Environment Outlook 3*, Earthscan, London, 426 pp.

United Nations 2006. World Urbanization Prospects: the 2005 Revision. United Nations Department of Economic and Social Affairs, Population Division, CDROM Edition - Data in digital form (POP/DB/WUP/Rev.2005), United Nations, New York.

United Nations Environment Programme (UNEP) 2007. Environmental Degradation Triggering Tensions and Conflict in Sudan. Available: http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=512&ArticleID=5621&l=en

USGS 1997. Desertification. Available: http://pubs.usgs.gov/gip/deserts/desertification/

Wang, F.T. 2002. Advances in climate warming impacts research in China in recent ten years. *Journal of Applied Meteorological Science* 13: 766.

Warner, T.T. 2004. *Desert Meteorology.* Cambridge University Press, Cambridge, 595 pp.

Wenhui, Z. and Yubin, Z. 2005. On four regional policy readjustments since reform and an assessment. Discussion paper, Beijing: China Development Institute.

Wigley, T.M.L. and Raper, S.C.B. 2001. Interpretation of high projections for global-mean warming. *Science* 293: 451-454.

Wittig, R., König, K., Schmidt, M. and Szarzynski, J. 2007. A Study of Climate Change and Anthropogenic Impacts in West Africa. *Environmental Science and Pollution Research* 14(3): 182-189.

WMO (World Meteorological Organization) 2006. Drought monitoring and early warning: concepts, progress and future challenges. WMO-No. 1006; ISBN 92-63-11006-9, 24 pp.

World Research Institute 2003. *Earth Trends.* Washington, DC.

Yousif, H.M. 2005. Rapid urbanisation in Africa: impacts on housing and urban poverty. In *ECA, 2005, Assessing Sustainable Development in Africa. Assessing Sustainable Development in Africa, Africa?s Sustainable Development Bulletin*, Economic Commission for Africa, Addis Ababa, 55-59.