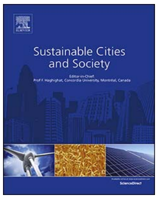
Sustainable Cities and Society 41 (2018) 925–928

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs



Urban water security: Emerging discussion and remaining challenges

Ali Nazemi[a,*], Kaveh Madani[b,c]

[a] Department of Building, Civil and Environmental Engineering, Concordia University, Montreal, Quebec, Canada
[b] Centre for Environmental Policy, Imperial College London, London, UK
[c] Department of Physical Geography, Stockholm University, Stockholm, Sweden

ARTICLE INFO

Keywords:
Water security
Urban hydrology
Integrated water resources management
Coupled human-water systems

ABSTRACT

Human livelihood requires reliable water supply and protection from water-related hazards. Significant growth in population and anthropogenic activities along with unfolding effects of global environmental change have enormously increased the vulnerability of human systems to changes in water quantity and/or quality. Addressing such vulnerabilities has high management priority in urban regions due to the concertation of population and socio-economic activities. This has resulted into emerging various discussions around the concept of "urban water security". Here we provide a brief overview on the water-related threats to human society and the context of water security, with a greater goal of recognizing operational and social challenges along with science needs in urban environments.

1. Water-related threats to human society

Water is among the most prominent elements for human life. Historically, human settlements have developed around areas that enough water has been available to support socio-economic activities. The immense population growth and the irresistible thirst for socio-economic development during the current *Anthropocene* (Crutzen, 2006; Steffen, Crutzen, & McNeill, 2007), however, have created a largely unsustainable global water use. Numbers speak it all: Only during the past century, world's population has increased by around 4-fold, while human water consumption has increased around 5, 18 and 10 times for agricultural, industrial and municipal, respectively (Shiklomanov, 1993, 1997, 2000). This has put water resources under ever-increasing pressure globally. In addition, the unsustainable use of water along with increasing human-induced contaminants in ground and surface water resources have made a wide range of consequences from major decline in water availability and water quality to massive environmental changes – the catastrophic situation of Aral Sea and Lake Urmia (see AghaKouchak et al., 2014; Precoda, 1991) are only two out of many existing examples worldwide.

At the present state, limited water resources has already marked a major global problem: UNESCO (2012) estimates that around 2 billion people currently live in water-stressed areas and over 800 million people have inadequate access to safe drinking water. Such unfolding issues have exacerbated sociopolitical tensions over decreasing water availability, which made the water management and controlling the competition over water allocation extremely complex and sensitive (Madani & Lund, 2011). In addition, water-related hazards account for around 90% of all natural hazards globally, marking floods and droughts as the two most destructive natural threats to human societies. Only throughout 2010 water-related disasters killed nearly 300,000 people, affected around 208 million others and cost nearly $110 billion (UNESCO, 2012). Water-related hazards are continuously present at the local and global news: While California is currently recovering from a major 5-year drought (see Leahy, 17 April 2017), at the time of writing early drafts of this paper (May 2017), southern Quebec was in the State of Emergency due to major flooding in the area, including parts of Montreal (see Turnbull, 13 May 2017). The cost of such flooding events are often high (Wake, 2013): The Alberta's Flood of 2013 has caused more than $5 billion damage to the economy (see Wood, 24 September 2013), marking this few-day incident the second costliest disaster in the Canadian history.

Heightened climate variability and change has started, and will continue, to majorly intensify such water-related threats (Schiermeier, 2014). The most recent model intercomparison study reveals that a 2 °C of global warming will approximately engage 15% of the global population with a severe decrease in water resources and will increase the number of people living under absolute water scarcity by another 40% compared to the effect of population growth alone (Schewe et al., 2014). In addition, various studies show that warming weather can trigger more water use and aggressive extraction from water resources (Elliott et al., 2014; Haddeland et al., 2014; Wheater, 2015a, 2015b; Wheater, 2015a, 2015b; Rosenzweig et al., 2014), which together with changes in operation patterns (Connell-Buck, Medellín-Azuara, Lund,

---

[*] Corresponding author.
E-mail addresses: ali.nazemi@concordia.ca (A. Nazemi), k.madani@imperial.ac.uk (K. Madani).

http://dx.doi.org/10.1016/j.scs.2017.09.011

Madani, 2011; Gohari, Bozorgi, Madani, Elledge, & Berndtsson, 2014; Guegan, Uvo, & Madani, 2012; Madani, 2011; Mirchi, Madani, Roos, & Watkins, 2013, chap. 6) can pose extra pressure on scarce water resources. In addition, water-related hazards are expected to become more frequent, more intense and more geographically spread under climate change conditions. Recent multi-model studies highlight a likely increase in the global severity of drought by the end of 21st century, in which the frequency of drought increases by more than 20% in highly populated regions such as South America and Central and Western Europe (Prudhomme et al., 2014). On the other hand, an increase in flooding frequency is projected in more than half of the world, particularly in the non-snow dominated regions, which naturally include more population (Dankers et al., 2014). Finally, water quality can also be largely degraded by the climate change (Delpla, Jung, Baures, Clement, & Thomas, 2009; Whitehead, Wilby, Battarbee, Kernan, & Wade, 2009), although a comprehensive global understanding of water quality consequences of climate change is currently lacking.

2. The context of water security

Growing water-related threats to human society has resulted in various debates in both science and governance spheres around possible means for achieving "*an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments, and economies*" (Grey & Sadoff, 2007). Since mid-1990s, these discussions have started to be framed under the new context of "*water security*" (Appelgren & Klohn, 1997; Falkenmark & Lundqvist, 1998; Starr, 1992). Although earlier attempts had mainly noted water quantity concerns, the scope of water security discourse soon expanded to other domains and merged with another newly, yet independently developed context of Integrated Water Resource Management (IWRM; see, Cook & Bakker, 2012 for a comprehensive review). Through this evolution, IWRM has started to engage science and engineering with management, policy and governance through an inclusive discussion around the means of achieving water security. Nonetheless, as the scope of IWRM discussions have mainly been, and still are, defined around specific case studies, the definition of water security have been inevitability case-dependent and become to a large extent geographically influenced. For instance, while in an arid place like Australia, the water security focus has been mainly on water availability (e.g., Government of Australia, 2010), for the UK this has been on flood defence (e.g., Government of UK, 2016), in parts of China on water pollution (e.g., Xia, Zhang, Liu, & Yu, 2007) and in the Middle East and North African regions on allocating limited water resources within a geopolitically tense environment (e.g., Al-Otaibi & Abdel-Jawad, 2007; Amery, 1997; Madani, 2014; Zeitoun, Allan, & Mohieldeen, 2010). Nonetheless, due to the integrative nature of water security, the cross-dependencies between previously assumed disconnected domains were started to be appreciated (Mirchi, Watkins, Madani, 2010). In addition, negative long-term impacts of various human interventions such as water transfer (Gohari et al., 2013; Lund et al., 2007; Madani & Lund, 2012; Madani & Mariño, 2009), extensive dam building (Madani, 2014), aggressive groundwater extraction (Madani, Aghakouchak, & Mirchi, 2016; Shah, 2009), and irrigation expansion (Hassanzadeh et al., 2017; Zekri, Madani, Bazargan-Lari, Kotagama, & Kalbus, 2017) have showed that quick fixes to water security problems can backfire and result in creating whole new set of problems that are often more complicated than the original problem (AghaKouchak, Feldman, Hoerling, Huxman, & Lund, 2015; Mirchi, Watkins, Huckins, Madani, & Hjorth, 2014). Thus, the water resources community has come to a consensus that complex water resource problems require comprehensive solutions that are based on new thinking (Hjorth & Madani, 2014) and improved skills of problem definition, integration, data use, and tool development (Rosenberg & Madani, 2014).

In addition, the appreciation of the overlooked role of human behaviour in water management (see Madani, 2010) in conjunction with the growing understanding of the hydrology community about the significance of human activities within hydrologic cycle (see the emerging discussions around "socio-hydrology" e.g., Di Baldassarre, Viglione et al., 2013; Di Baldassarre et al., 2015; Sivapalan, Savenije, & Blöschl, 2012; Sivapalan et al., 2014) have resulted into acknowledging profound interactions between natural and human water systems that can be described under a broader term of "coupled human-water systems" (Di Baldassarre, Kooy, Kemerink, & Brandimarte, 2013; Di Baldassarre, Brandimarte, & Beven, 2016; Srinivasan, Lambin, Gorelick, Thompson, & Rozelle, 2012). The evolving and self-organizing nature of interaction within these systems (Madani, 2013) in addition to the new non-stationarity conditions posed by climate and other sources of global change (Milly et al., 2008, 2015) imply that solutions to stationary problems may not be suitable under new circumstances. These new consensuses have broaden the recognition of enormous challenges in addressing water security threats, particularly under extremely complex and uncertain futures. Recent definitions of water security summarize these new concepts and emphasize on existence of multiple dimensions within the water security discourse and the cross-scale dynamics within and between the coupled human-water systems (see Wheater & Gober, 2013, 2015).

3. Challenges and needs in urban environments

Within the context laid above, achieving water security in urban environments has a particular importance as cities already include more than half of the world's population and accordingly the highest concentration of socio-economic activities (Seto, Sánchez-Rodríguez, & Fragkias, 2010; Seto, Güneralp, & Hutyra, 2012). Nevertheless, complex, and in some cases unknown, dynamics within the coupled human-water systems, combined with existing technological, socio-economic and management obstacles, introduce a new set of scientific challenges in urban regions. Facing these challenges requires pushing the boundary of current advancements within the water security domain. First new insights, tools and methodologies are needed for better representation of complex interactions within coupled human and natural systems in urban regions across a range of temporal and spatial scales. Such attempts should be made with the greater goal of diagnosing water-related threats in urban areas as a result of extreme or gradual changes in natural and anthropogenic conditions, in light of current limitations in future projections – see Jaramillo and Nazemi (2017). Refined decision-making tools are also required for capturing trade-offs in consequences of potential decisions, especially under uncertain future conditions of human-water systems (see Hassanzadeh, Elshorbagy, Wheater, Gober, & Nazemi, 2015; Hassanzadeh, Elshorbagy, Wheater, & Gober, 2016; Nazemi & Wheater, 2014). While still the IWRM context of water security stays the same, particular attention should be made to (i) the notion of risk in design, planning and management of urban water systems; and (ii) the social dimension of urban water security, particularly with respect to the attitudes and values that determine the uptake of new technologies and regulative practices by the public and utilities. Addressing these challenges will be likely achieved again by narrowing the problem within the broader framework of IWRM; however they should aim at opening up a dialogue with management and policy communities. We would like to emphasize that making a collaborative, two-way interaction between science and policy spheres is the key to achieving practicable urban water security solutions.

Scientific contributions, addressing the above mentioned challenges, are emerging (see e.g., Nazemi & Madani, 2017); however much more needs to be done: First, new technologies are required to implement the science solutions particularly with respect to water conservation, treatment, and reuse. While there are practicable water conservation technologies around, much more is needed in the water quality domain, particularly with respect to operational regulation and exotic contaminants. We also note that the uptake of scientific and technological solutions in urban areas requires particular attention to the socio-economic drivers at the managerial and public levels. We would like to emphasize on the importance of social capital in achieving urban water security and the need for having effective multi-channel mechanisms for knowledge delivery to public and policy-making. We envision that due to the role of social processes in urban water security, social processes ultimately embedded in IWRM models as new algorithms. This can lead into new understanding of the complex dynamics between human and natural systems and can pave the way to extend the scope of risk management.

References

AghaKouchak, A., Norouzi, H.-R., Madani, K., Mirchi, A., Azarderakhsh, M., Nazemi, A., ... Hasanzadeh, E. (2014). Aral sea syndrome desiccates lake urmia: Call for action. *Journal of Great Lakes Research*. http://dx.doi.org/10.1016/j.jglr.2014.12.007.

AghaKouchak, A., Feldman, D., Hoerling, M., Huxman, T., & Lund, J. (2015). Water and climate: Recognize anthropogenic drought. *Nature, 524*, 409–411.

Al-Otaibi, A., & Abdel-Jawad, M. (2007). Water security for Kuwait. *Desalination, 214*(1–3), 299–305.

Amery, H. A. (1997). Water security as a factor in Arab-Israeli wars and emerging peace. *Studies in Conflict & Terrorism, 20*(1), 95–104.

Appelgren, B., & Klohn, W. (1997). Management of transboundary water resources for water security; principles, approaches and state practice. *Natural Resources Forum, 21*(2), 91–100 Blackwell Publishing Ltd.

Connell-Buck, C. R., Medellín-Azuara, J., Lund, J. R., & Madani, K. (2011). Adapting California's water system to warm vs. dry climates. *Climatic Change, 109*(1), 133–149.

Cook, C., & Bakker, K. (2012). Water security: Debating an emerging paradigm. *Global Environmental Change, 22*(1), 94–102.

Crutzen, P. J. (2006). *The anthropocene. Earth system science in the anthropocene*. Berlin, Heidelberg: Springer13–18.

Dankers, R., Arnell, N. W., Clark, D. B., Falloon, P. D., Fekete, B. M., Gosling, S. N., ... Stacke, T. (2014). First look at changes in flood hazard in the Inter-Sectoral Impact Model Intercomparison Project ensemble. *Proceedings of the National Academy of Sciences, 111*(9), 3257–3261.

Delpla, I., Jung, A. V., Baures, E., Clement, M., & Thomas, O. (2009). Impacts of climate change on surface water quality in relation to drinking water production. *Environment International, 35*(8), 1225–1233.

Di Baldassarre, G., Viglione, A., Carr, G., Kuil, L., Salinas, J. L., & Blöschl, G. (2013). Socio-hydrology: Conceptualising human-flood interactions. *Hydrology and Earth System Sciences, 17*(8), 3295.

Di Baldassarre, G., Kooy, M., Kemerink, J. S., & Brandimarte, L. (2013). Towards understanding the dynamic behaviour of floodplains as human-water systems. *Hydrology and Earth System Sciences, 17*(8), 3235.

Di Baldassarre, G., Viglione, A., Carr, G., Kuil, L., Yan, K., Brandimarte, L., & Blöschl, G. (2015). Debates—Perspectives on socio-hydrology: Capturing feedbacks between physical and social processes. *Water Resources Research, 51*(6), 4770–4781.

Di Baldassarre, G., Brandimarte, L., & Beven, K. (2016). The seventh facet of uncertainty: Wrong assumptions, unknowns and surprises in the dynamics of human-water systems. *Hydrological Sciences Journal, 61*(9), 1748–1758.

Elliott, J., Deryng, D., Müller, C., Frieler, K., Konzmann, M., Gerten, D., ... Eisner, S. (2014). Constraints and potentials of future irrigation water availability on agricultural production under climate change. *Proceedings of the National Academy of Sciences, 111*(9), 3239–3244.

Falkenmark, M., & Lundqvist, J. (1998). Towards water security: Political determination and human adaptation crucial. *Natural Resources Forum, 22*(1), 37–51 Blackwell Publishing Ltd.

Gohari, A., Bozorgi, A., Madani, K., Elledge, J., & Berndtsson, R. (2014). Adaptation of surface water supply to climate change in Central Iran. *Journal of Water and Climate Change, 5*(3), 391–407.

Government of Australia (2010). *Water for the future.* Canberra: Government of Australia. Available at http://155.187.2.69/water/publications/action/pubs/water-for-the-future.pdf.

Government of UK (2016). *New plan for stronger flood defences.* London: Government of UK. Available at https://www.gov.uk/government/news/new-plan-for-stronger-flood-defences.

Grey, D., & Sadoff, C. W. (2007). Sink or swim? Water security for growth and development. *Water Policy, 9*(6), 545–571.

Guegan, M., Uvo, C. B., & Madani, K. (2012). Developing a module for estimating climate warming effects on hydropower pricing in California. *Energy Policy, 42*, 261–271.

Haddeland, I., Heinke, J., Biemans, H., Eisner, S., Flörke, M., Hanasaki, N., ... Stacke, T. (2014). Global water resources affected by human interventions and climate change. *Proceedings of the National Academy of Sciences, 111*(9), 3251–3256.

Hassanzadeh, E., Elshorbagy, A., Wheater, H., & Gober, P. (2016). A risk-based framework for water resource management under changing water availability, policy options, and irrigation expansion. *Advances in Water Resources, 94*, 291–306.

Hassanzadeh, E., Elshorbagy, A., Wheater, H., Gober, P., & Nazemi, A. (2015). Integrating supply uncertainties from stochastic modeling into integrated water resource management: Case study of the Saskatchewan River Basin. *Journal of Water Resources Planning and Management, 142*(2) 05015006.

Hassanzadeh, E., Elshorbagy, A., Nazemi, A., Jardine, T. D., Wheater, H., & Lindenschmidt, K. E. (2017). The ecohydrological vulnerability of a large inland delta to changing regional streamflows and upstream irrigation expansion. *Ecohydrology*. http://dx.doi.org/10.1002/eco.1824 (in press).

Hjorth, P., & Madani, K. (2014). Sustainability monitoring and assessment: New challenges require new thinking. *Journal of Water Resources Planning and Management, 140*(2), 133–135.

Jaramillo, P., & Nazemi, A. (2017). Assessing urban water security under changing climate: Challenges and ways forward. *Sustainable Cities and Society*. http://dx.doi.org/10.1016/j.scs.2017.04.005 (in press).

Leahy, K. (2017). *From moonscape to lush: Photographs capture California drought's story.* NPR. April 17, Available at http://www.npr.org/2017/04/17/523969466/from-moonscape-to-lush-photographs-capture-california-droughts-story.

Lund, J., Hanak, E., Fleenor, W., Howitt, R., Mount, J., & Moyle, P. (2007). *Envisioning futures for the Sacramento-San Joaquin delta.* San Francisco: Public Policy Institute of California285.

Madani, K., & Lund, J. R. (2011). A Monte-Carlo game theoretic approach for multi-criteria decision making under uncertainty. *Advances in Water Resources, 34*(5), 607–616.

Madani, K., & Lund, J. R. (2012). California's Sacramento-San Joaquin Delta conflict: From cooperation to chicken. *ASCE Journal of Water Resources Planning and Management, 138*(2), 90–99. http://dx.doi.org/10.1061/(ASCE)WR.1943-5452.0000164.

Madani, K., & Mariño, M. A. (2009). System dynamics analysis for managing Iran's Zayandeh-Rud river basin. *Water Resources Management, 23*(11), 2163–2187. http://dx.doi.org/10.1007/s11269-008-9376-z.

Madani, K., Aghakouchak, A., & Mirchi, A. (2016). Iran's socio-economic drought: Challenges of a water-bankrupt nation. *Iranian Studies, 49*(6), 997–1016. http://dx.doi.org/10.1080/00210862.2016.1259286.

Madani, K. (2010). Game theory and water resources. *Journal of Hydrology, 381*(3), 225–238.

Madani, K. (2011). Hydropower licensing and climate change: Insights from cooperative game theory. *Advances in Water Resources, 34*(2), 174–183.

Madani, K. (2013). Modeling international climate change negotiations more responsibly: Can highly simplified game theory models provide reliable policy insights? *Ecological Economics, 90*, 68–76.

Madani, K. (2014). Water management in Iran: What is causing the looming crisis? *Environmental Studies and Sciences, 4*(4), 315–328. http://dx.doi.org/10.1007/s13412-014-0182-z.

Milly, P. C., Betancourt, J., Falkenmark, M., Hirsch, R. M., Kundzewicz, Z. W., Lettenmaier, D. P., & Stouffer, R. J. (2008). Stationarity is dead: Whither water management? *Science, 319*(5863), 573–574.

Milly, P. C. D., Betancourt, J., Falkenmark, M., Hirsch, R. M., Kundzewicz, Z. W., Lettenmaier, D. P., ... Krysanova, V. (2015). On critiques of stationarity is dead: Whither water management? *Water Resources Research, 51*(9), 7785–7789.

Mirchi, A., Watkins, D. W., Jr., & Madani, K. (2010). Modeling for watershed planning, management, and decision making. In J. C. Vaughn (Ed.). *Watersheds: Management, restoration and environmental impact* (pp. 1–25). Hauppauge, New York: Nova Science Publishers ISBN 978-1-61668-667-3.

Mirchi, A., Madani, K., Roos, M., & Watkins, D. W. (2013). *Climate change impacts on California's water resources. Drought in arid and semi-arid regions*. Netherlands: Springer301–319.

Mirchi, A., Watkins, D. W., Huckins, C. J., Madani, K., & Hjorth, P. (2014). Water resources management in a homogenizing world: Averting the growth and under-investment trajectory. *Water Resources Research, 50*(9), 7515–7526.

Nazemi, A., & Madani, K. (2017). Toward addressing urban water security: Searching for practicability. *Sustainable Cities and Society*. http://dx.doi.org/10.1016/j.scs.2017.09.010.

Nazemi, A., & Wheater, H. S. (2014). Assessing the vulnerability of water supply to changing streamflow conditions. *Eos, Transactions American Geophysical Union, 95*(32) 288–288.

Nazemi, A., & Wheater, H. S. (2015a). On inclusion of water resource management in Earth system models–Part 1: Problem definition and representation of water demand. *Hydrology and Earth System Sciences, 19*(1), 33–61.

Nazemi, A., & Wheater, H. S. (2015b). On inclusion of water resource management in Earth system models–Part 2: Representation of water supply and allocation and opportunities for improved modeling. *Hydrology and Earth System Sciences, 19*(1), 63–90.

Precoda, N. (1991). Requiem for the Aral Sea. *Ambio*, 109–114.

Prudhomme, C., Giuntoli, I., Robinson, E. L., Clark, D. B., Arnell, N. W., Dankers, R., ... Hagemann, S. (2014). Hydrological droughts in the 21st century, hotspots and uncertainties from a global multimodel ensemble experiment. *Proceedings of the National Academy of Sciences, 111*(9), 3262–3267.

Rosenberg, D. E., & Madani, K. (2014). Water resources systems analysis: A bright past and a challenging but promising future. *Journal of Water Resources Planning and Management, 140*(4), 407–409.

Rosenzweig, C., Elliott, J., Deryng, D., Ruane, A. C., Müller, C., Arneth, A., ... Neumann, K. (2014). Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. *Proceedings of the National Academy of Sciences, 111*(9), 3268–3273.

Schewe, J., Heinke, J., Gerten, D., Haddeland, I., Arnell, N. W., Clark, D. B., ... Gosling, S. N. (2014). Multimodel assessment of water scarcity under climate change. *Proceedings of the National Academy of Sciences, 111*(9), 3245–3250.

Schiermeier, Q. (2014). Water risk as world warms. *Nature, 505*(7481), http://dx.doi.org/10.1038/505010a.

Seto, K. C., Sánchez-Rodríguez, R., & Fragkias, M. (2010). The new geography of contemporary urbanization and the environment. *Annual Review of Environment and Resources, 35*, 167–194.

Seto, K. C., Güneralp, B., & Hutyra, L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences, 109*(40), 16083–16088.

Shah, T. (2009). Climate change and groundwater: India's opportunities for mitigation and adaptation. *Environmental Research Letters, 4*(3), 035005.

Shiklomanov, I. A. (1993). *World water resources.* Paris: UNESCO, 1998 http://www.ce.utexas.edu/prof/mckinney/ce385d/Papers/Shiklomanov.pdf. (Last Accessed 6 May 2014).

Shiklomanov, I. A. (1997). *Assessment of water resources and water availability in the world, comprehensive assessment of the freshwater resources of the world.* Geneva: WMO and SEI.

Shiklomanov, I. A. (2000). World water resources and water use: Present assessment and outlook for 2025. In F. R. Rijsberman (Ed.). *World water scenarios* (pp. 160–203). London: Earthscan.

Sivapalan, M., Savenije, H. H., & Blöschl, G. (2012). Socio-hydrology: A new science of people and water. *Hydrological Processes, 26*(8), 1270–1276.

Sivapalan, M., Konar, M., Srinivasan, V., Chhatre, A., Wutich, A., Scott, C. A., ... Rodríguez-Iturbe, I. (2014). Socio-hydrology: Use-inspired water sustainability science for the Anthropocene. *Earth's Future, 2*(4), 225–230.

Srinivasan, V., Lambin, E. F., Gorelick, S. M., Thompson, B. H., & Rozelle, S. (2012). The nature and causes of the global water crisis: Syndromes from a meta-analysis of coupled human-water studies. *Water Resources Research, 48*(10).

Starr, J. (1992). Water security: The missing link in our mideast strategy. *Canadian Journal of Development Studies/Revue canadienne d'études du développement, 13*(4), 35–48.

Steffen, W., Crutzen, P. J., & McNeill, J. R. (2007). The Anthropocene: Are humans now overwhelming the great forces of nature. *AMBIO: A Journal of the Human Environment, 36*(8), 614–621.

Turnbull, J. (2017). *'We are trying to survive': Floods wash away Montreal business owners' life's work.* CBC. May 13, Available at http://www.cbc.ca/news/canada/montreal/pierrefonds-businesses-floodwaters-2017-1.4113642.

UNESCO (2012). *The 4th edition of the UN world water development report*Paris: UNESCO Available at http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/wwdr4-2012/. (Last Accessed 16 December 2014).

Wake, B. (2013). Flooding costs. *Nature Climate Change, 3*(9) 778–778.

Wheater, H., & Gober, P. (2013). Water security in the Canadian Prairies: Science and management challenges. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences, 371*(2002), 20120409.

Wheater, H. S., & Gober, P. (2015). Water security and the science agenda. *Water Resources Research, 51*(7), 5406–5424.

Whitehead, P. G., Wilby, R. L., Battarbee, R. W., Kernan, M., & Wade, A. J. (2009). A review of the potential impacts of climate change on surface water quality. *Hydrological Sciences Journal, 54*(1), 101–123.

Wood, J. (2013). *Province boosts cost of Alberta floods to $6 billion.* Calgary Herald. September 24, Available at http://www.calgaryherald.com/news/Province+boosts+cost+Alberta+floods+billion/8952392/story.html.

Xia, J., Zhang, L., Liu, C., & Yu, J. (2007). Towards better water security in North China. *Water Resources Management, 21*(1), 233–247.

Zeitoun, M., Allan, J. T., & Mohieldeen, Y. (2010). Virtual water 'flows' of the Nile Basin, 1998-2004: A first approximation and implications for water security. *Global Environmental Change, 20*(2), 229–242.

Zekri, S., Madani, K., Bazargan-Lari, M. R., Kotagama, H., & Kalbus, E. (2017). Feasibility of adopting smart water meters in aquifer management: An integrated hydro-economic analysis. *Agricultural Water Management, 181*, 85–93.