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Nature-based solutions for flood-drought risk mitigation in vulnerable urbanizing parts of East-Africa

Zahra Kalantari[1], Carla Sofia Santos Ferreira[2], Saskia Keesstra[3] and Georgia Destouni[1]

Abstract
Urbanization and climate changes have direct impacts on ecosystems and the services they provide to society, thus influencing human well-being and health. Urban sprawl may conflict with ecosystem services, e.g. enhancing water-related stresses and risks of, e.g., droughts and floods, with significant economic, environmental and societal impacts. Such hydro-climatic extremes and their societal impacts are evident around the world. East Africa is a region with highly vulnerable populations to frequent floods and droughts. To achieve long-term sustainable solutions to such water-related risks and problems, we need to understand and plan for the feedback mechanisms between population expansion and associated land-use changes and their impacts on ecosystem services. The potential of nature-based solutions to mitigate these risk and problems in urban development under climate change needs to be considered and accounted for in spatial planning and management strategies.

Addresses
[1] Stockholm University, Department of Physical Geography and Bolin Centre for Climate Research, SE-106 91 Stockholm, Sweden
[2] CERNAS, Agrarian School of Coimbra, Polytechnic Institute of Coimbra, Coimbra, Portugal
[3] Soil, Water and Land Use Team, Wageningen Environmental Research, Wageningen UR, 6708PB Wageningen, The Netherlands

Corresponding author: Kalantari, Zahra. (zahra.kalantari@natgeo.su.se)

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Introduction

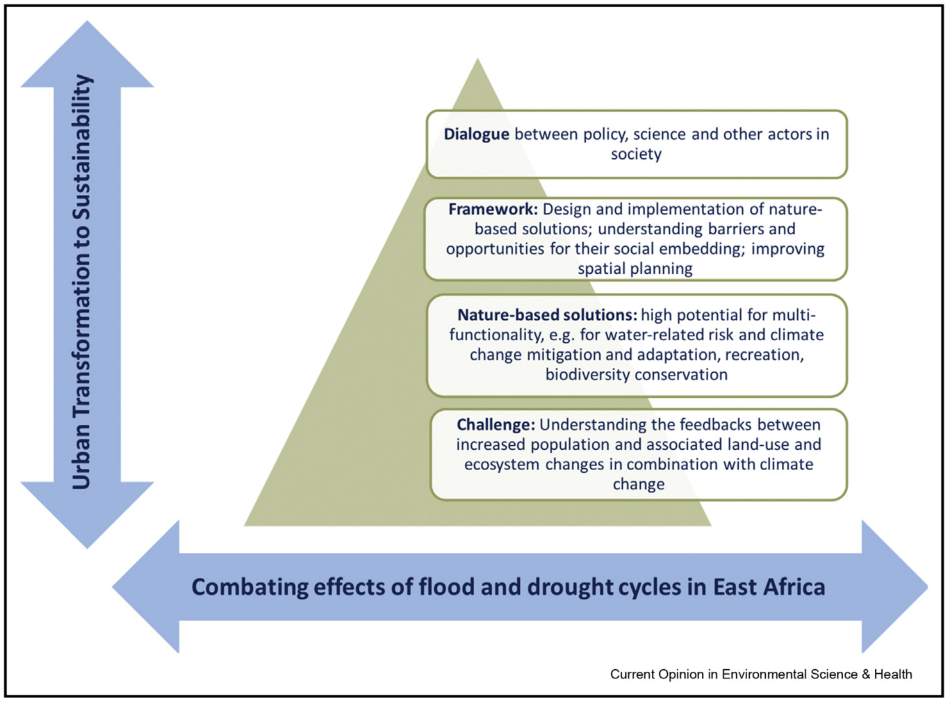
Ecosystem services and goods (ES) represent the direct and indirect benefits humanity derives from ecosystems [1]. The ES concept is considered a useful approach to highlight the dependence of human well-being on ecosystems, bridging the gaps between ecology, economics and society in order to achieve sustainable resource management [2]. A particular strength of this concept is its ability to spatially integrate multiple biophysical conditions, thereby facilitating collaboration between science and policy in finding solutions for global challenges, recognition of human-nature interactions, and more informed exploration of feedback loops [3,4]. This is not least useful for our ability to handle water-related disasters, such as floods and droughts, as these are governed by the feedbacks that potentially also hold a key to efficient flood-drought risk reduction (see Scheme 1).

Water-related disasters are largely created by people living in conflict with their environment [5]. As such, changes in environmental conditions can have enormous consequences on *people* and *places* experiencing such changes [6]. Climate change effects may further accelerate and exacerbate such environmental impacts on society [7]. For water-based disasters in particular, climate change implies altered average temperatures and precipitation patterns that may lead to more intense and frequent floods and droughts [6]. It is essential to develop more effective strategies, methods and tools for incorporating water-based analysis into spatial planning aiming to mitigate water-related natural hazards and their societal impacts, especially in the most vulnerable societies [8].

The potential feedbacks (positive and negative) of water-related ES to water-related risks and their possible reduction should be considered in spatial planning. Water-related ES can be structured in three categories: provisioning services (e.g., drinking water, fish), regulating services (e.g., flood and drought regulation) [6,7], and cultural services (e.g., for recreation) [9]. Commonly, ES are not well understood and quantified and, in some regions, may have deteriorated severely due to poor urban planning and, e.g., land degradation, which includes physical and chemical soil and water impairments, and loss of biodiversity [10] Mismanagement of water resources and their potential may provide negatively impacts, both on freshwater provisioning and food provisioning services [10].

In regions with increasing population density, water-related stresses, such as droughts and floods, have increasingly negative economic, environmental and

Scheme 1



Integrated approach to interconnected societal and environmental challenges confronting rapidly developing regions.

societal consequences [12]. Shifting frequency and severity of such hydrological extremes are already evident in terms of their impacts on civil society [7], expected to be exacerbated in the future with two-thirds of the world's population predicted to reside in cities by 2030 [13] and 80% of this urban growth taking place in Africa and Asia. The problems created by such shifts tend to be aggravated by poor economics and high population density that may prevail in cities of developing regions [14]. This manuscript aims to discuss current status of water-related problems with focus on floods and droughts in East Africa, and the potential of nature-based solutions to mitigate such problems driven by urban sprawl and climate changes. To achieve long-term sustainable solutions to such water-related risks and problems, we need to understand and plan for the feedback mechanisms between population expansion and associated land-use changes and their impacts on ecosystem services. The potential of nature-based solutions to mitigate these risk and problems in urban development under climate change needs to be considered and accounted for in spatial planning and management strategies.

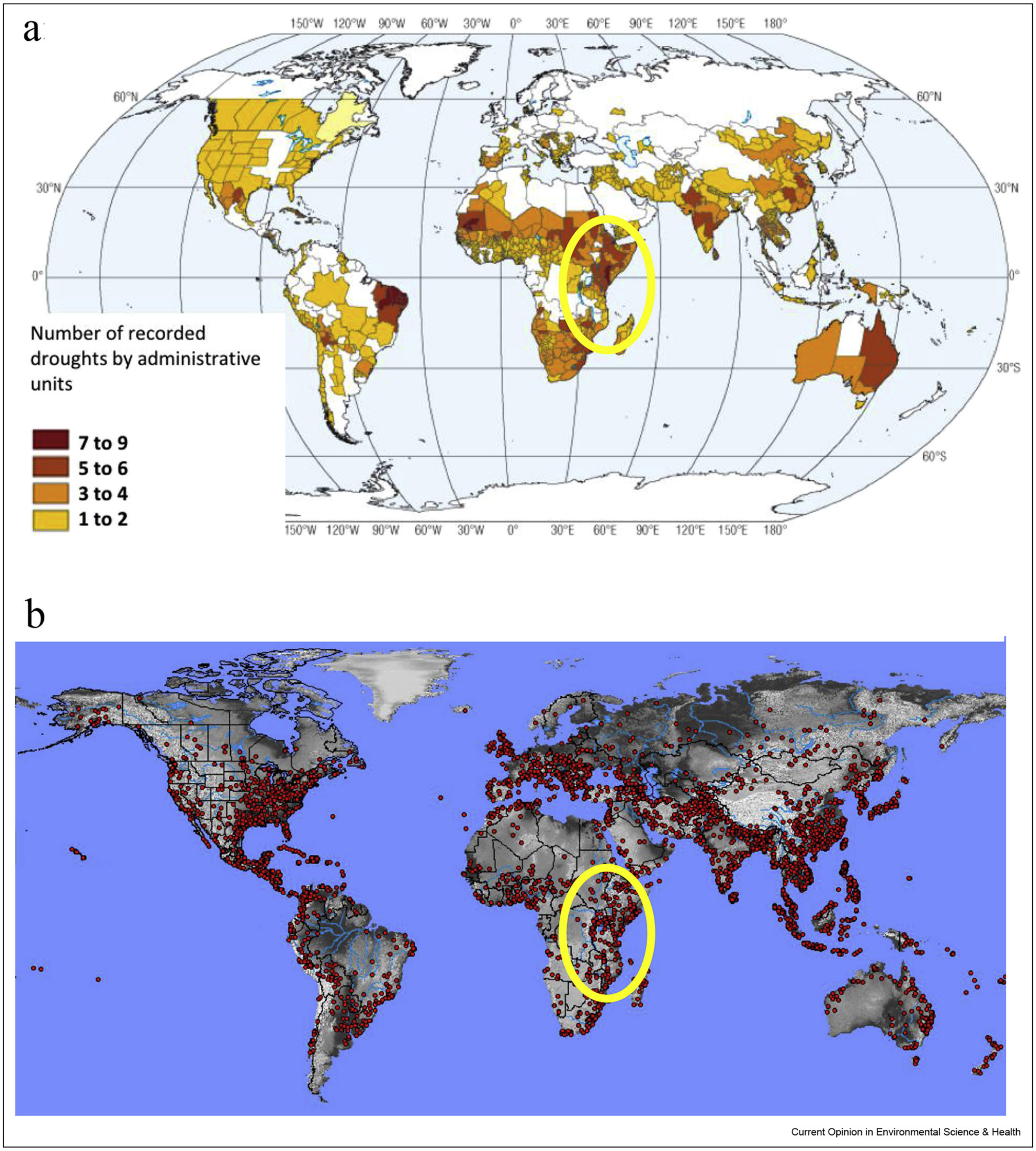
Urbanization and ES conflicts in East Africa

Urbanization and sustainable development are at the core of political debates, not least concerning poverty reduction and food security and safety in East African countries [15,16]. The rapid urbanization of this region has brought people into direct conflict with nature, particularly regarding water resources, where the delicate balance between too much water (flooding) and too little water (drought) is a matter of life and death for millions.

As population centers expand and become more interlaced with rural landscapes, ecosystems and the services they provide are being pushed to their limits. Without a clear understanding of the feedbacks between urban sprawl and associated land-use changes on ES, it is impossible to work towards sustainability [17]. According to FAO and World Bank development indicators, agriculture sector contributes to 43% of the total GDP in East Africa and livelihood of about 80% of the population in rural area is dependent on agriculture [18]. In this region, the economic dependence from agriculture sector and the competition for land and water resources dictates livelihood development nowadays and in the foreseeable future [19].

East Africa is a good example of human-nature conflicts, as it is a region with large populations vulnerable to frequent floods and droughts (Figure 1a and b). For example, Tanzania's Dar es Salaam is one of the fastest growing cities in sub-Saharan Africa and approximately 70% of its population reside in unplanned settlements

Figure 1



a: Global archive of large flood events 1985–2010 (East Africa circled) [22]. b: Number of drought disasters recorded by EMDAT (1974–2004) (East Africa circled) [23].

and flood-prone areas [20]. A particular concern is that the amount and intensity of rainfall reaching the city have been increasing for the last 15 years [21]. This is expected to continue, with serious impacts on resources, such as land and water, and the provision of ES.

The city council of Dar es Salaam in Tanzania is currently exploring potential plans for increased climate resilience and improved land use planning, water and sanitation systems, and public transportation, both now and in the future [24]. Among other heavily populated and fast-growing countries in East Africa, Mozambique, Kenya, Ethiopia and Malawi are also vulnerable to direct and indirect effects of climate related risks, including storms, floods, temperature extremes and land degradation [25]. In response to the twin threats of population growth and climate change, the Ethiopian government has developed a national strategy for a Climate-Resilient Green Economy (CRGE) [26]. The CRGE vision seeks to achieve climate resilience by coupling Ethiopia's economy with available ES, while at the same time securing these ES to reduce environmental risks. Zambia is also working in this strategic area and has developed a National Climate Change Response Strategy [27] focusing on key socio-economic priorities for adaption and mitigation actions. These include implementation of climate-resilient adaptation activities and mainstreamed disaster risk reduction.

On reviewing the strategies in place and being developed across East Africa, one open (and fundamental) issue remains: How can nature-based solutions in urban areas and their rural surroundings be accounted for and identified, and associated management recommendations and activities be developed for efficient spatial targeting and implementation of climate change mitigation and adaptation measures that are also acceptable to stakeholders?

ES approach to mitigate water-related risks in East Africa

ES related to water are essential for human well-being. In addition to human sustenance, water-based ES contribute to a multitude of economic sectors, including agriculture, industry and tourism. Therefore, changes in water availability and quality driven by urbanization [28], affect societal health and economy, including flood and drought risks and associated regulating ES. Water-related disasters, such as floods and droughts, are typically analyzed in separate hydrological and statistical approaches, reflecting their distinct underlying processes and causes. To be truly useful in a planning sense, however, spatial assessments of such risks should consider all types of hazards, through a multi-hazard or multi-risk approach considering all spatial levels (local to regional). Flood and drought frequency cycles have been considered in numerous projects funded by the European Commission (e.g., CORFU, DEWFORA and IMPRINT). However, these projects have focused on isolated analysis of risks of floods or water scarcity and did not consider possible benefits of addressing trade-offs between flood and drought risk management, or combined ES-based risk-mitigation practices and techniques that may in synergy reduce both of these (and/or other) types of risks.

ES-based mitigation measures and their spatial locations should be considered and accounted for as they can, e.g., retain water and reduce peak flows while the areas involved are still functionally "in use" also for other purposes [8]. Using such nature-based solutions, their possible multi-functionality needs to be quantified in order to optimize their potential benefits for human well-being [29]. For instance, measures for water harvesting can be developed to satisfy a dual-purpose of flood prevention in addition to the water harvesting. Such dual/multi-functional measures may range from local and city–district scale (e.g., green infrastructure, such as green roofs, green walls, rain gardens) [30] to whole–catchment scale (e.g., using natural and constructed wetlands for flood control) [31]. More specifically, the African nature-based solutions include, e.g., the use of grass strips for trapping sediments in Ethiopia, restoration of mangroves in Kenya, protection of water sources and enhancing water availability in Kenya by providing more watering points in national parks and community areas, pioneering climate resilient marine protected area management in Madagascar, and forest protection in Nigeria [32].

Applying such nature-based solutions can offer significant potential for risk reduction; realization of this potential requires enhanced planning, implementation and assessment efforts for integrated land and water management [33,29,4], and analysis and decision support systems that can relatively simply and transparently account for natural–human interactions [34] and for possible multi-functionality solutions, such as in flood-drought as well as energy-use and CO_2-emissions management [30].

An nature-based solution approach may also assist East African countries in making cities and human settlements more inclusive, safe, resilient and sustainable, thus supporting governments to reach the UN sustainable development goal (SDG) [11]. Such solutions may further assist the region to reach other SDGs, such as protecting, restoring and promoting sustainable use of terrestrial ecosystems, halting and reversing land degradation, and mitigating biodiversity loss (SDG 15); combating climate change and its impacts (SDG 13); and strengthening means to implement and revitalize the global partnership for sustainable development (SDG 17). In addition, consideration of nature-based solutions in East Africa may also indirectly support fulfillment of SDG 2 and SDG 8, focusing on food security and sustainable agriculture, and economic growth, respectively.

Furthermore, to exploit the possible advantages and benefits of nature-based solutions, it is necessary to understand barriers and opportunities for social embedding of best management practices, and for policy and regulatory frameworks that can drive implementation of such solutions and practices in collaboration with stakeholders. A main barrier to the implementation of e.g., blue and green infrastructure as part of nature-based solutions, relates to the requirement for space to accommodate such solutions. Claiming new land for nature-based solutions may conflict with existing land uses, raising questions related to land use planning, land ownership and benefit-sharing. These barriers may be overcome to some degree by multi-functionality, i.e., by combining primary ES solution functions, e.g., for water retention and purification, with other benefits, such as recreation and biodiversity conservation. Gray infrastructures may be also developed to help reducing and controlling land requirements, while enhancing water supply for human consumption and safety [35]. In general, nature-based solutions require new protocols for planning, implementation, and maintenance [33,29], and understanding the barriers and opportunities of such new requirements is essential for overcoming the former and realizing the latter towards achieving long-term sustainable solutions.

Concluding remarks

East Africa is one of the most rapidly developing regions globally. Here, the balance of too much water (flood) or too little water (drought) is a matter of life and death for millions of people. As population centers expand and become more interlaced with rural landscapes, ecosystems are pushed to their limits. Thus, it is critically important to develop effective methods and tools for assessing and identifying sustainable solutions to mitigate water-related risk hazards and problems. This requires improved understanding of the feedbacks between increased population and associated land-use and ecosystem changes, in combination with ongoing climate changes. There is a particular need to explore opportunities for vulnerable urbanizing regions to employ nature-based solutions for water-related risk mitigation and enhanced climate resilience. Such exploration and employment require in turn improved spatial planning and management strategies that can drive implementation and maintenance of effective solutions. It is then essential to understand barriers and opportunities for efficient nature-based solutions, the social embedding of best management practices for these, and policy and regulatory frameworks that can drive their implementation in collaboration with stakeholders.

Conflict of interest statement

None declared.

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References

Papers of particular interest, published within the period of review, have been highlighted as:

* of special interest
* * of outstanding interest

1. MEA: *Ecosystems and human well-being: synthesis*. Washington DC: Island Press; 2005.

2. Braat LC, de Groot R: **The ecosystem services agenda: bridging the worlds of natural science and economics, conservation and development, and public and private policy**. *Ecosystem Services* 2012, **1**:4–15.

3. Goldenberg R, Kalantari Z, Cvetkovic V, Mörtberg U, Deal B, Destouni G: **Distinction, quantification and mapping of potential and realized supply-demand of flow-dependent ecosystem services**. *Sci Total Environ* 2017, **593–594**: 599–609.

4. * Thorslund J, Jarsjo J, Jaramillo F, Jawitz JW, Manzoni S, Basu NB, Chalov SR, Cohen MJ, Creed IF, Goldenberg R, *et al.*: **Wetlands as large-scale nature-based solutions: status and challenges for research, engineering and management**. *Ecol Eng* 2017, **108**:489–497.
This work survey research on Wetlands as large-scale nature-based solutions by experts and in literature.

5. Dadson S, Hall JW, Garrick D, Sadoff C, Grey D, Whittington D: **Water security, risk, and economic growth: insights from a dynamical systems model**. *Water Resour Res* 2017, **53**:6425–6438.

6. Lehner B, Döll P, Alcamo J, Henrichs T, Kaspar F: **Estimating the impact of global change on flood and drought risks in Europe: a continental, integrated analysis**. *Climatic Change* 2006, **75**:273–299.

7. * * Di Baldassarre G, Martinez F, Kalantari Z, Viglione A: **Drought and flood in the Anthropocene: feedback mechanisms in reservoir operation**. *Earth Syst. Dynam.* 2017, **8**:225–233.
This study investigates the dynamics from the interplay between human impacts on drought and flood events and human responses to hydrological extremes.

8. Michielsen A, Kalantari Z, Lyon SW, Liljegren E: **Predicting and communicating flood risk of transport infrastructure based on watershed characteristics**. *J Environ Manag* 2016, **182**: 505–518.

9. Kalantari Z, Khoshkar S, Falk H, Cvetkovic V, Mörtberg U: **Accessibility of water-related cultural ecosystem services through public transport—a model for planning support in the Stockholm region**. *Sustainability* 2017, **9**:346.

10. * * Li P, Omani N, Chaubey I, Wei X: **Evaluation of drought implications on ecosystem services: freshwater provisioning and food provisioning in the upper Mississippi river basin**. *Int J Environ Res Publ Health* 2017, **14**:496.
The paper provides very sound results on evaluating the effect of drought on ecosystem services such as freshwater and food provisioning.

11. Ferreira CSS, Walsh RPD, Nunes JPC, Steenhuis TS, Nunes M, de Lima JLMP, Coelho COA, Ferreira AJD: **Impact of urban development on streamflow regime of a Portuguese peri-urban Mediterranean catchment**. *J Soils Sediments* 2016, **16**: 2580–2593.

12. Van Loon AF, Gleeson T, Clark J, Van Dijk AIJM, Stahl K, Hannaford J, Di Baldassarre G, Teuling AJ, Tallaksen LM, Uijlenhoet R, *et al.*: **Drought in the anthropocene**. *Nat Geosci* 2016, **9**:89.

13. Grimm NB, Faeth SH, Golubiewski NE, Redman CL, Wu J, Bai X, Briggs JM: **Global change and the ecology of cities**. *Science* 2008, **319**:756–760.

14. Abeygunawardena P, Vyas Y, Sperling F: *Poverty and climate change : reducing the vulnerability of the poor through adaptation*. Washington, DC: World Bank; 2009. http://documents.worldbank.org/curated/en/534871468155709473/Poverty-and-climate-change-reducing-the-vulnerability-of-the-poor-through-adaptation.

15. United Nations Economic Commission for Africa: *Africa regional report on the sustainable development goals, Summary*. 2015. https://www.uneca.org/sites/default/files/uploaded-documents/SDG/africa_regional_report_on_the_sustainable_development_goals_summary_english_rev.pdf.

16. Tacoli C: **Food (in) security in rapidly urbanising, low-income contexts**. *Int J Environ Res Publ Health* 2017, **14**:1554.

17. McDonald RI, Marcotullio P: **Global effects of urbanization on ecosystem services**. In *Handbook of urban ecology*. Edited by Niemelä J, Oxford, UK: Oxford University Press; 2011.

18. OECD, Food, Nations AOotU: *OECD-FAO agricultural outlook 2016-2025*. 2016.

19. Scheba A: **Conservation agriculture and sustainable development in Africa: insights from Tanzania**. *Nat Resour Forum* 2017, **41**:209–219.

20. Mutanga SS, Mwiruki B, Ramoelo A: **Spatial analysis of human exposure and vulnerability to coastal flooding in Dar es Salaam, Tanzania**. *Afr Insight* 2014, **43**:171–186.

21. Congedo L, Macchi S: **The demographic dimension of climate change vulnerability: exploring the relation between population growth and urban sprawl in Dar es Salaam**. *Current Opinion in Environmental Sustainability* 2015, **13**:1–10.

22. Brakenridge, G.R. "Global Active Archive of Large Flood Events", Dartmouth Flood Observatory, University of Colorado, http://floodobservatory.colorado.edu/Archives/index.html.

23. EMDAT: *The OFDA/CRED International disaster database*. 2009. GIS analysis: IRI, Columbia University; Cartography: UNEP/GRID-Europe, www.emdat.net. http://www.emdat.be/database. http://preventionweb.net/go/10600.

24. Shemdoe R, Kassenga G, Mbuligwe S: **Implementing climate change adaptation and mitigation interventions at the local government levels in Tanzania: where do we start?** *Current Opinion in Environmental Sustainability* 2015, **13**:32–41.

25. Eckstein D, Kunzel V, Schafer L: *Global Climate Risk Index 2018: Who Suffers Most From Extreme Weather Events? Weather-related Loss Events in 2016 and 1997 to 2016*. Germanwatch e.V. 2017. https://germanwatch.org/en/download/20432.pdf.

26. CRGE: *The federal democratic republic of Ethiopia*. Ethiopia's Green Economy Strategy; 2011.

27. NCCRS: *National climate change response strategy*. Government of the Republic of Zambia; 2010.

28. Elmhagen B, Destouni G, Angerbjörn A, Borgström S, Boyd E, Cousins SAO, Lindborg R: **Interacting effects of change in climate, human population, land use, and water use on biodiversity and ecosystem services**. *Ecol Soc* 2015, **20**.

29. ** Keesstra S, Nunes J, Novara A, Finger D, Avelar D, Kalantari Z, Cerdà A: **The superior effect of nature based solutions in land management for enhancing ecosystem services**. *Sci Total Environ* 2018, **610–611**:997–1009.
In this work the authors did a very good review on showing the potential of nature-based solutions as effective measures against water-related disasters and land degradation.

30. Engström RE, Howells M, Destouni G, Bhatt V, Bazilian M, Rogner H-H: **Connecting the resource nexus to basic urban service provision – with a focus on water-energy interactions in New York City**. *Sustainable Cities and Society* 2017, **31**: 83–94.

31. ECDG: *Towards an EU research and innovation policy agenda for nature-based solutions & Re-Naturing cities final report of the horizon 2020 expert group on nature-based solutions and Re-Naturing cities*. 2015. Luxembourg.

32. Fischborn M, Herr D. *African solutions in a rapidly changing world: nature-based solutions to climate change by african innovators in protected areas*. Gland, Switzerland: IUCN; 2015. 36pp.

33. Mörtberg U, Goldenberg R, Kalantari Z, Kordas O, Deal B, Balfors B, Cvetkovic V: **Integrating ecosystem services in the assessment of urban energy trajectories – a study of the Stockholm Region**. *Energy Pol* 2017, **100**:338–349.

34. Mazi K, Koussis AD, Destouni G: **Quantifying a sustainable management space for human use of coastal groundwater under multiple change pressures**. *Water Resour Manag* 2016, **30**:4063–4080.

35. Koussis AD, Georgopoulou E, Kotronarou A, Mazi K, Restrepo P, Destouni G, Prieto C, Rodriguez JJ, Rodriguez-Mirasol J, Cordero T, *et al.*: **Cost-efficient management of coastal aquifers via recharge with treated wastewater and desalination of brackish groundwater: application to the Akrotiri basin and aquifer**. *Cyprus. Hydrological Sciences Journal* 2010, **55**: 1234–1245.