Water Resilience

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Contributor: María Jaya-Montalvo

Analyze from a holistic and comprehensive perspective the water resource in the water cycle context and its relationships in the various environments for the strategic approach to resilience as a way to sustainability.

Keywords: resilience ; water cycle ; water demand ; climate change ; groundwater ; watershed ; water policy ; environment ; water recycling ; sustainability

1. Introduction

Freshwater represents a small fraction of the available water on earth [1]. With water demand growing approximately 1% per year since the 1980s [2], global demand for the vital resource will continue to increase at a similar rate until 2050 and rise from 20% to 30% above the current use level [3]. Among the leading causes of increased water demand is the growth of the world population (urbanization), changes in consumption patterns (e.g., product preferences based on meat and sugar), improvement of living standards (economic growth, industrialization), and expansion of irrigated agriculture (increased production) [4][5].

Water resource exploitation, in combination with the intersecting effects of climate change [5][6] due to human activity, demarcates a new geological epoch (the Anthropocene) [7][8]. These factors have led to a shortage crisis scenario of unsustainable use of water, a global issue demonstrating that two-thirds of the world population experience severe water shortage conditions at least one month a year [9]. The alarming evidence has led to the creation of strategies to face water scarcity, focusing on its practical and sustainable management [10][11][12].

The first known scientific use in English of the word 'resilience' is attributed to Francis Bacon [13], who used it in the 17th century to describe the way an echo bounces back from a wall. In general, resilience is defined by the Oxford English Dictionary as (i) the capacity to recover quickly from difficulties, and (ii) the ability of a substance or object to spring back into shape [14]. For Timmerman [15], in the domain of engineering and disasters, resilience is the ability of human communities to withstand external shocks or perturbations to their infrastructure and to recover from such perturbations. In the social and ecological domain, Holling [16] defined it as the amount of disturbance that can be sustained by a system before a change occurs in its mechanisms of control or its structure. Regarding groundwater systems, Sharma and Sharma [17] defined resilience as the ability of the system to maintain groundwater reserves despite significant disturbances.

Resilience is known as the adaptive capacity of a system to a change generated by external pressures while maintaining certain vital functions. This concept has gained a prominent place in water policies[18][19], ranging from water resource management at the hydrographic basin scale, to drought and flood management, to climate change adaptation in the water services sector (e.g., [19], [20], [21], [22], [23], [24], [25], [26]). In the human–water interaction context, three types of systems and subsystems in the framework of resilience emerge: (i) the water subsystem, with hydrological resilience to anthropogenic risks; (ii) the human subsystem, with social resilience to hydrological risks; and (iii) the socio-hydrological subsystem, with socio-hydrological resilience [27].

Defining and understanding the system is key to any assessment of resilience [27] [28] [29]. Hence, knowing the system allows examination of its state, evolution, and variables. Thus, the evaluation leads to the proposal of strategies/measures for reaching the desired state.

2. Water Resilience Assessment

Several authors have used numerical methods [30] [31] or the water storage variability in a period [31] to assess the resilience of groundwater systems during droughts. Peters et al. [30] evaluated the performance of groundwater systems in the event of drought using three indicators: resilience, reliability, and vulnerability. In the Pang Basin (United Kingdom), a similar study was carried out by Hugman et al. [31]. In the Querença–Silves aquifer system (Portugal), a quantitative evaluation of aquifer performance and its resilience or recovery capacity was carried out based on four sustainable performance factors: property, recharge, pumping, and distribution of wells in aquifers. Another study, on a larger scale, used remote sensing satellites to assess resilience. The study made use of NASA's Gravity and Recovery and Climate Experiment (GRACE) tool to assess groundwater resilience based on global estimates of groundwater storage and average flow subsurface net storage. The authors defined the total groundwater stress ratio as a measure of groundwater resilience that applies to large aquifers only [32].

Water resilience must be comprehensively evaluated beyond the recharge capacity or economic impact of significant changes in the system. The analysis must include physical, environmental, economic, and social impacts.

There are many ways to assess sustainable development; indicators are among the most commonly used approaches [33]. Studies have been presented in the water context based on the development of indicators to measure the sustainability and resilience of different aspects of these systems. Some examples are the development of the water provision resilience indicator, a measure of the capacity of the water system to maintain or improve the percentage of the population with access to safe water in the water supply sector (supply, infrastructure, service provision, finance, water quality, and governance) [34]; the application of a framework of nine indicators of water resource management at the level of the watershed (water quality, water quantity, system stability, water-use efficiency, user-sector productivity, institutional preparedness, equitable water services, water-related well-being, public participation) [35]; the use of indicators of wastewater treatment systems for sustainability assessment, highlighting key indicators such as organic matter, nutrients, cost, heavy metals, and land area [36], the work proposed by Polonenko et al. [37] studying indicators within the role of institutions and communities in urban water systems, as well as indicators for various areas such as social, institutional, governance, economic, technological, and environmental, especially in such systems [38], [39], [40], [41]. Finally, GRAM matrix for assessing water resilience based on indicators in the Sustainable Development Goals (SDGs) and the four axes of development (political, social, environmental, and cultural) in a communal coastal aquifer system proposed by Herrera-Franco et al., [42].

3. Conclusions

For groundwater sustainability, it is essential to know the factors that influence recharge: (i) climate, (ii) geology and topography, and (iii) land cover and use, adapting them to the four axes of sustainability: (i) political and economic, (ii) environmental, (iii) social, and (iv) cultural. The positive interaction of all these aspects makes the socio-hydrological system resilient, satisfying the demand for water in the face of demographic explosion and climate change.

Resilience can be taught and improved if there is a methodology that benchmarks, measures, and indicates its strengths, good practices, and acute problems. Therefore, it will be possible to implement long-term measures that solve system problems.

References

1. Sandra L. Postel; G. C. Daily; Paul R. Ehrlich; Human Appropriation of Renewable Fresh Water. *Science* **1996**, *271*, 785-788, 10.1126/science.271.5250.785.
2. AQUASTAT—FAO's Global Information System on Water and Agriculture . FAO Food and Agriculture Organization of the United Nations. Retrieved 2020-10-19
3. Burek, P.; Satoh, Y.; Fischer, G.; Kahil, M.T.; Scherzer, A.; Tramberend, S.; Nava, L.F.; Wada, Y.; Eisner, S.; Flörke, M.; et al. Water Futures and Solution. Fast Track Initiative; IIASA: Laxenburg, Austria, 2016.
4. A. Ertug Ercin; Arjen Ysbert Hoekstra; Water footprint scenarios for 2050: A global analysis. *Environment International* **2014**, *64*, 71-82, 10.1016/j.envint.2013.11.019.
5. C. J. Vorosmarty; Global Water Resources: Vulnerability from Climate Change and Population Growth. *Science* **2000**, *289*, 284-288, 10.1126/science.289.5477.284.
6. Grant Ferguson; Tom Gleeson; Vulnerability of coastal aquifers to groundwater use and climate change. *Nature Climate Change* **2012**, *2*, 342-345, 10.1038/nclimate1413.
7. Paul J. Crutzen; Will Steffen; How Long Have We Been in the Anthropocene Era?. *Climatic Change* **2003**, *61*, 251-257, 10.1023/b:clim.0000004708.74871.62.
8. Will Steffen; Wendy Broadgate; Lisa Deutsch; Owen Gaffney; Cornelia Ludwig; The trajectory of the Anthropocene: The Great Acceleration. *The Anthropocene Review* **2015**, *2*, 81-98, 10.1177/2053019614564785.
9. Mesfin M. Mekonnen; Arjen Ysbert Hoekstra; Four billion people facing severe water scarcity. *Science Advances* **2016**, *2*, e1500323, 10.1126/sciadv.1500323.

10. Karen Bakker; Cynthia Morinville; The governance dimensions of water security: a review. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* **2013**, *371*, 20130116, 10.1098/rsta.2013.0116.

11. G. Dunn; R. R. Brown; J. J. Bos; K. Bakker; Standing on the shoulders of giants: Understanding changes in urban water practice through the lens of complexity science. *Urban Water Journal* **2016**, *14*, 758-767, 10.1080/1573062x.2016.1241284.

12. M. Farrelly; R. Brown; Rethinking urban water management: Experimentation as a way forward?. *Global Environmental Change* **2011**, *21*, 721-732, 10.1016/j.gloenvcha.2011.01.007.

13. D. E. Alexander; Resilience and disaster risk reduction: an etymological journey. *Natural Hazards and Earth System Sciences* **2013**, *13*, 2707-2716, 10.5194/nhess-13-2707-2013.

14. David V. Rosowsky; Defining resilience. *Sustainable and Resilient Infrastructure* **2019**, *5*, 125-130, 10.1080/23789689.2019.1578166.

15. Timmerman, P. Vulnerability Resilience and Collapse of Society. A Review of Models and Possible Climatic Applications; University of Toronto: Toronto, ON, Canada, 1981

16. C. S. Holling; Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics* **1973**, *4*, 1-23, 10.1146/annurev.es.04.110173.000245.

17. Sharma, U.C.; Sharma, V. Groundwater sustainability indicators for the Brahmaputra basin in the northeastern region of India. In Sustainability of Groundwater Resources and Its Indicators; Webb, B., Hirata, R., Kruse, E., Vrba, J., Eds.; International Association of Hydrological Sciences: Wallingford, UK, 2006; p. 43. ISBN 1-901502-43-0.

18. R. R. Brown; N. Keath; T. H. F. Wong; Urban water management in cities: historical, current and future regimes. *Water Science and Technology* **2009**, *59*, 847-855, 10.2166/wst.2009.029.

19. Carlos N. A. Salinas Rodriguez; Richard Ashley; Berry Gersonius; Jeroen Rijke; A. Pathirana; Chris Zevenbergen; Incorporation and application of resilience in the context of water-sensitive urban design: linking European and Australian perspectives. *Wiley Interdisciplinary Reviews: Water* **2014**, *1*, 173-186, 10.1002/wat2.1017.

20. Julia Baird; Angela Dzyundzyak; Ryan Plummer; Ryan Bullock; Diane Dupont; Marilyne Jollineau; Wendee Kubik; Gary Pickering; Liette Vasseur; Ecosystem Perceptions in Flood Prone Areas: A Typology and Its Relationship to Preferences for Governance. *Water* **2016**, *8*, 191, 10.3390/w8050191.

21. Julia Baird; Ryan Plummer; Michele-Lee Moore; Oliver Brandes; Introducing Resilience Practice to Watershed Groups: What Are the Learning Effects?. *Society & Natural Resources* **2016**, *29*, 1214-1229, 10.1080/08941920.2015.1107788.

22. J. Rijke; M. Farrelly; R. Brown; C. Zevenbergen; Configuring transformative governance to enhance resilient urban water systems. *Environmental Science & Policy* **2012**, *25*, 62-72, 10.1016/j.envsci.2012.09.012.

23. Johan Rockstrom; Malin Falkenmark; T M Allan; Carl Folke; Line Gordon; Anders Jagerskog; Matti Kummu; Mats Lannerstad; Michel Meybeck; D. Molden; et al. The unfolding water drama in the Anthropocene: towards a resilience-based perspective on water for global sustainability. *Ecohydrology* **2014**, *7*, 1249-1261, 10.1002/eco.1562.

24. Sangmin Shin; Seungyub Lee; David R. Judi; Masood Parvania; Erfan Goharian; Timothy McPherson; Steven J. Burian; A Systematic Review of Quantitative Resilience Measures for Water Infrastructure Systems. *Water* **2018**, *10*, 164, 10.3390/w10020164.

25. E. K. White; T. J. Peterson; J. Costelloe; Andrew W. Western; E. Carrarra; Can we manage groundwater? A method to determine the quantitative testability of groundwater management plans. *Water Resources Research* **2016**, *52*, 4863-4882, 10.1002/2015wr018474.

26. Li Xu; Yuya Kajikawa; An integrated framework for resilience research: a systematic review based on citation network analysis. *Sustainability Science* **2017**, *13*, 235-254, 10.1007/s11625-017-0487-4.

27. Feng Mao; Julian Clark; Timothy Karpouzoglou; Art Dewulf; Wouter Buytaert; David M. Hannah; HESS Opinions: A conceptual framework for assessing socio-hydrological resilience under change. *Hydrology and Earth System Sciences* **2017**, *21*, 3655-3670, 10.5194/hess-21-3655-2017.

28. Stephen R Carpenter; Barbara Louise Endemano Walker; J. Marty Anderies; Nick Abel; From Metaphor to Measurement: Resilience of What to What?. *Ecosystems* **2001**, *4*, 765-781, 10.1007/s10021-001-0045-9.

29. Brad Evans; Julian Reid; Dangerously exposed: the life and death of the resilient subject. *Resilience* **2013**, *1*, 83-98, 10.1080/21693293.2013.770703.

30. E. Peters; H.A.J. Van Lanen; P.J.J.F. Torfs; G. Bier; Drought in groundwater—drought distribution and performance indicators. *Journal of Hydrology* **2005**, *306*, 302-317, 10.1016/j.jhydrol.2004.09.014.

31. Rui Hugman; Tibor Y. Stigter; José Paulo Monteiro; Luis Alfredo Pinheiro Leal Nunes; Influence of aquifer properties and the spatial and temporal distribution of recharge and abstraction on sustainable yields in semi-arid regions. *Hydrological Processes* **2011**, *26*, 2791-2801, 10.1002/hyp.8353.

32. Alexandra S. Richey; Brian F. Thomas; Min-Hui Lo; James S. Famiglietti; Sean Claude Swenson; Matthew Rodell; Uncertainty in global groundwater storage estimates in a T otal G roundwater S tress framework. *Water Resources Research* **2015**, *51*, 5198-5216, 10.1002/2015wr017351.

33. Ramos, T.; Pires, S.M. Sustainability Assessment: The Role of Indicators. In Sustainability Assessment Tools in Higher Education Institutions; Springer International Publishing: Cham, Switzerland, 2013; pp. 81–99. ISBN 9783319023755.

34. Anita Milman; Anne Short; Incorporating resilience into sustainability indicators: An example for the urban water sector. *Global Environmental Change* **2008**, *18*, 758-767, 10.1016/j.gloenvcha.2008.08.002.

35. Antonio A.R. Ioris; Colin Hunter; Susan Walker; The development and application of water management sustainability indicators in Brazil and Scotland. *Journal of Environmental Management* **2008**, *88*, 1190-1201, 10.1016/j.jenvman.2007.06.007.

36. Aj Annelies Balkema; Ha Heinz Preisig; Ralf Otterpohl; Fred J.D Lambert; Indicators for the sustainability assessment of wastewater treatment systems. *Urban Water* **2002**, *4*, 153-161, 10.1016/s1462-0758(02)00014-6.

37. Leah McMillan Polonenko; Mohamed A. Hamouda; Mohamed M. Mohamed; Essential components of institutional and social indicators in assessing the sustainability and resilience of urban water systems: Challenges and opportunities. *Science of The Total Environment* **2020**, *708*, 135159, 10.1016/j.scitotenv.2019.135159.

38. Cornelis J. Van Leeuwen; Jos Frijns; Annemarie Van Wezel; Frans H. M. Van De Ven; City Blueprints: 24 Indicators to Assess the Sustainability of the Urban Water Cycle. *Water Resources Management* **2012**, *26*, 2177-2197, 10.1007/s11269-012-0009-1.

39. Staddon, C.; Sarkozi, R.; Langberg, S. Urban Water Governance as a Function of the ‘Urban Hydrosocial Transition’. In Freshwater Governance for the 21st Century; Karar, E., Ed.; Springer: Berlin/Heidelberg, Germany, 2017; Volume 6, pp. 81–102. ISBN 9783319433486.

40. Willems, S.; Baumert, K. Institutional Capacity and Climate Actions; Organisation for Economic Co-operation and Development International Energy Agency (OECD): Paris, France, 2003.

41. Angela J. Dean; Kelly S. Fielding; Fiona J. Newton; Community Knowledge about Water: Who Has Better Knowledge and Is This Associated with Water-Related Behaviors and Support for Water-Related Policies?. *PLOS ONE* **2016**, *11*, e0159063, 10.1371/journal.pone.0159063.

42. Gricelda Herrera-Franco; Paúl Carrión-Mero; Maribel Aguilar-Aguilar; Fernando Morante-Carballo; María Jaya-Montalvo; M.C. Morillo-Balsera; Groundwater Resilience Assessment in a Communal Coastal Aquifer System. The Case of Manglaralto in Santa Elena, Ecuador. *Sustainability* **2020**, *12*, 8290, 10.3390/su12198290.

43. D. E. Alexander; Resilience and disaster risk reduction: an etymological journey. *Natural Hazards and Earth System Sciences* **2013**, *13*, 2707-2716, 10.5194/nhess-13-2707-2013.
