Ensuring consideration of water quality in nexus approaches in the science–practice continuum: reply to discussion of "Water quality: the missing dimension of water in the water–energy–food nexus?"

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Abstract We thank Arnbjerg-Nielsen and co-authors for their constructive contribution. We endorse their key comments and suggestions on how to increase awareness of and action water quality interactions in the water‒energy‒food (WEF) nexus. Here, we advance the discussion, commenting on the scope of water quality to embrace ecosystem as well as human needs, and the importance of transdisciplinarity and focussing at the city/aquifer/drainage basin scale in WEF nexus hotspots in ensuring that water quality is considered in WEF nexus approaches. We also identify how recent global events, the COVID-19 pandemic and UNFCCC COP 26, may intensify the WEF nexus and its water quality interlinkages, highlighting the need to weave WEF considerations into addressing the UN Sustainable Development Goals and the climate and biodiversity emergencies.

Keywords: climate change; ecosystem health; nature-based solutions; nexus hotspots; scale; transdisciplinarity

We are grateful to Arnbjerg-Nielsen et al. (2022) for their constructive discussion of our opinion paper (Heal et al. 2021) that highlighted the often overlooked role of water quality within the water‒energy‒food (WEF) nexus. Whilst Arnbjerg-Nielsen et al. (2022) caution that further extension and apparent complication of the WEF nexus may limit its adoption, in accordance with the aims of the *Panta Rhei* opinion paper series (Kreibich et al. 2017), they make constructive suggestions for further developing and operationalizing the WEF nexus with water quality embedded within it.

Arnbjerg-Nielsen et al. (2022) also emphasize the concern that the existing conceptualization of the WEF nexus is overly anthropocentric, focused on meeting human needs, whilst neglecting the importance of ensuring healthy ecosystems. Consequently, the specific inclusion of water quality within the WEF nexus is welcomed as a positive development, since they regard water quality as “a surrogate for ecosystem services, biodiversity, and sustainability” as well as relating to chemical pollution, all aspects that are acknowledged to be complex to assess (Keeler et al. 2012). More practically, Arnbjerg-Nielsen et al. (2022) remark that the WEF nexus is yet to be adopted as a framework for decision-making, although an emerging nexus discourse is contributing to addressing interlinkages between the United Nations Sustainable Development Goals (SDGs) (Cudennec et al. 2018), which are separated for the three WEF dimensions (SDG 2: zero hunger, SDG 6: clean water and sanitation, SDG 7: affordable, and, embracing the wider conceptualization of water quality, SDG 14: life below water (United Nations 2015)).

Arnbjerg-Nielsen et al. (2022) also note the wide diversity of ways in which water quality can be included in the WEF nexus, through both individual and interacting water, energy and food dimensions, and at different spatio-temporal scales. They caution that existing WEF models contain different components (which elaborate on different epistemologies (Cudennec et al. 2018)), but find Fig. 1 in Heal et al. (2021) useful in categorizing diverse spatial scales and helping to provide the increased focus that is needed to support better inclusion of water quality in WEF implementation. In particular, they support the call by Heal et al. (2021) to focus WEF—water quality integrated thinking in “hotspots” where WEF-related stresses are most severe and are anticipated to grow most rapidly. We suggest that the list of case-studies in Table S1 accompanying Heal et al. (2021) is also instructive in illustrating the interactions between water quality and the different WEF dimensions and highlighting the problems that arise if these are not considered. Finally, Arnbjerg-Nielsen et al. (2022) recommend that pushing forward the implementation of the WEF nexus and embedded water quality thinking should target “windows of opportunity”. They highlight two tangible ongoing examples of “windows of opportunity”. Firstly, at the global scale, systemic crosscutting approaches to the SDG targets (Taka et al. 2021), reinforcing the opening paragraph in Heal et al. (2021). Secondly, at the regional scale, implementing sectoral coordination between food and water policies in the EU through the Water Framework Directive, new Common Agricultural Policy, and the European Green Deal. We draw attention to a further window of opportunity presented by the World Water Quality Alliance (WWQA), coordinated by the United Nations Environment Programme (UNEP), in articulation with UN-Water. The WWQA aims to support the achievement of SDG 6 through demonstrating the central role of freshwater quality underpinned by sustainable ecosystems in achieving human health and prosperity, and delivering to governments and other stakeholders methods for assessing baseline water quality and improvements, and solutions for water quality improvement, including building capacity and engagement (UNEP 2021).

Since the opinion paper was published, two major global events and their aftermath have resulted in ongoing reconfiguration of the context and relevance of the WEF nexus: the COVID-19 pandemic, and the 26th Conference of the Parties of the UN Framework Convention on Climate Change (UNFCCC COP 26) and the Glasgow Climate Pact in November 2021. The COVID-19 pandemic has intensified WEF interactions, particularly where there were existing vulnerabilities, highlighting the ongoing necessity for sectoral coordination. Examples of intensification within the WEF nexus due to COVID-19 that particularly relate to water quality include: increasing demands for water of a suitable quantity and quality for sanitation and washing to reduce virus transmission (Anim and Ofori-Asenso 2020), and food contamination arising from a shift to more local food production using chemically and/or bacteriologically contaminated water (Keulertz et al. 2020). Freshwater quality deterioration (in terms of chemical and bacteriological composition) has been attributed to the indirect impact of COVID-19 on human activities and consumption, such as increased domestic sewage outputs (Patel et al. 2020), mass use (and discard) of single-use plastics and personal protective equipment (Patrício Silva et al. 2021), and use of chlorine-based disinfectants (Chu et al. 2021), although reduction in industrial polluting activities improved water quality during lockdowns (Liu et al. 2022). The drivers of pandemics are regarded to be the same as those that underlie climate change and biodiversity loss ─ land-use change, agricultural extension and intensification, and human consumption (Ortiz et al. 2021) ─ and which by extension also give rise to WEF nexus tensions. During the UNFCCC COP 26 meeting, increased prominence was given to the role of indigenous peoples and local communities and to nature-based solutions in climate adaptation and mitigation (UNFCCC 2021). The latter is also highly relevant to improving security in water quantity and quality and is the subject of the 2018 World Water Development Report (WWAP/UN-Water 2018), in which Chapter 3 focuses on nature-based solutions for managing water quality. Nevertheless, the transition to cleaner energy systems will increase demand for critical minerals, such as lithium for battery storage and copper for expanding electricity networks, by 400% by 2040 compared to today to meet the goals of the Paris Agreement to limit global warming to well below 2 °C compared to pre-industrial levels (IEA 2021). Since critical minerals are predominantly sourced from mining at the moment, rising demand is expected to result in increased pressures on water and land resources and increased water pollution, amongst other adverse impacts (such as inadequate worker safety, human rights abuses and corruption), unless environmental performance is improved.

Both the global events discussed above serve to demonstrate the inherent connectivity of the challenges facing Earth and humanity and the need for coordinated cross-sectoral thinking and policy-making to address them at a variety of scales. They highlight further the relevance of the Anthropocene concept, which Heal et al. (2021) and Arnbjerg-Nielsen et al. (2022) identify as a framing for the WEF nexus. Elaborations of the Anthropocene concept to enhance its utility in addressing Earth System challenges are also helpful in operationalizing the WEF nexus, such as calls for integrative collaborative research (Brondizio et al. 2016), and scaling down the notion of the Anthropocene to analyze issue-based problems in regional settings within the context of a global understanding (Biermann et al. 2016).

The WEF nexus with water quality embedded is one of the tools at the science–practice continuum that can contribute to addressing these challenges. We suggest that improving the operationalization of water quality embedded within the WEF nexus necessitates two foci. The first focus should be on WEF nexus hotspots of which four were identified in Heal et al. (2021): areas of intensive groundwater use for agricultural food and/or energy production (e.g., the North China Plain, the Indo-Gangetic basin); cities; semi-arid and arid areas (e.g., the Mediterranean region, Australia, south-west USA); and drainage basins heavily dependent on meltwater from snow and glaciers. Within these hotspots, the second focus should be on the intermediate scale of the city/aquifer/drainage basin, in which examples of WEF–water quality nexus interactions include hydropower dams, wastewater treatment, wastewater irrigation, and water supply for agriculture from surface water and groundwater. Supporting these operational foci for the WEF–water quality nexus, transdisciplinary analytical tools and methods are needed that integrate agriculture (food), water (quantity and quality) and energy, which are often developed in isolation (Albrecht et al. 2018). Practical benefits of such integrated analytical systems include, for example, engaging stakeholders and decision-makers through communicating WEF axis metrics in a combined way.

The overall aim of our opinion paper and its discussion has been achieved in raising the profile of water quality within the WEF nexus and contributing to the uptake and operationalization of the WEF nexus in sustainable development. The key action to effect sustainable change in interacting challenges across sectors is to embed the WEF nexus incorporating water quality in transdisciplinary thinking and policy-making at the drainage basin scale focusing initially on hotspots. We trust that these contributions and Fig. 1 and Table S1 in Heal et al. (2021) can help advance this impactful discussion in sectors beyond water and in the science–practice continuum.

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