From sustainable drinking water to tsunami hazards: modelling water science for impact

Humanities are facing unprecedented water-related challenges towards future sustainable development. These challenges range from droughts, to floods, tsunami, water crises, and extreme precipitation. They are not only linked to climate change, which alters the hydrological cycle, but could also be further amplified due to rapid population growth, socio-economic development and human interventions such as infrastructure construction, land use change and land cover changes (Gleick 2018). To cope with these challenges, scientists have been developing modelling tools to study many aspects of water (e.g. quantity, quality, management) in order to gain a better understanding of its physical mechanisms, identify current existing gaps, as well as design more effective water management policies. With emerging theories, improved datasets and accelerated computational power, water modelling has propelled tremendous progress in the past few decades. But how can we leverage the advances in these modelling tools across disciplines to have impacts beyond their own field? One potential solution (but certainly not the only one) is through applying integrated frameworks given the integrative nature of the above-mentioned water-related challenges. This is what we advocate for the modelling community to consider through this Special Issue (SI) of the Journal of Integrative Environmental Sciences.

This SI aims to present inspiring examples of water modelling research and highlight its role in addressing pertinent environmental challenges. It includes five papers that address key themes such as tsunami hazards, sustainable drinking water, saltwater intrusion, extreme precipitation, and water logging. Although these papers span a wide range of topics, focus on different spatial and temporal scales and utilize different types of modelling tools (theory-based, data-driven, or a combination), they share commonalities in terms of how to leverage modelling advances towards more useful assessments of water-related sustainable development goals as well as more effective disaster risk reduction and management. They are also under the same umbrella of a broader theme of integrative knowledge and thinking (Kroeze et al. 2019), without which the impact of the selected studies may be limited compared to what they are supposed to have.

The SI leads off with a paper on tsunami hazards over fringing reefs (Shao et al. 2019). This study utilized a numerical wave model, validated by newly performed laboratory experiments, to investigate the potential changing characteristics (e.g. wave inundation, momentum flux) of tsunami-like solitary wave with hypothetical scenarios of sea-level rise and reef degradation. Simulation results clearly reveal that, compared to coral bleaching, sea-level rise has a more negative effect on the protective capacity of fringing reefs against tsunami hazards, especially over low-lying areas of reef-fringed coasts, where the increased risk of tsunami will be the highest. These results highlight the challenges
coastal communities will have to face to mitigate future tsunami hazards over fringing reefs.

In the second paper, Van Engelenburg et al. (2019) develop a multi-criteria based integrated framework to facilitate local adaptation planning towards sustainable drinking water abstraction. This conceptual framework first assesses current sustainability levels, on top of which potential future developments (e.g. increased water demand, changing land use and climate, energy transition) are imposed to identify future sustainability challenges. These challenges, together with current practice, are further used to explore adaptation strategies that are able to meet multiple sustainability criteria. Application of this framework to two case studies in the Netherlands highlights the importance of stakeholder involvement in the local adaptation planning processes. The framework proposed by Van Engelenburg et al. (2019) could be upscaled with some modifications to a larger scale (e.g. regional) and fit into a larger picture problem, for example, to identify potential pathways towards United Nations Sustainable Development Goals (SDGs).

Turning to estuarine regions, saltwater intrusion poses a significant threat to water security and environmental sustainability as it contaminates freshwater and disrupts aquatic and ecological systems. Improved understanding of saltwater intrusion is therefore critical for managing freshwater resources and maintaining ecosystem services. The paper by Li et al. (2019) focuses on a ubiquitous saltwater intrusion phenomenon in China’s Qiantang Estuary, where salt is naturally transported into the estuary due to periodic tidal currents. With the aid of high-quality observations (e.g. instantaneous measurements of salinity, tidal levels, flow velocities) at longer time scales (i.e. 10 or more tide cycles) and a flux decomposition model, the authors are able to calculate salt fluxes more accurately as well as attribute the physical drivers of the salt transport. Details aside, modelling results reveal a generally positive correlation between the tidal range and the net flux of landward salt transport. This key finding could be useful for estuarine water management, as decision-makers can utilize the tide information to determine how much freshwater should be released from upstream reservoirs in order to resist saltwater intrusion. This needs to be balanced with the water demand as over release of freshwater will reduce the availability to meet water demand for other sectors and therefore could jeopardize the reliability of freshwater supply. Such trade-offs need to be considered in future work to design more effective and realistic policies.

Saltwater intrusion is only one of the many factors that hinder coastal environmental sustainability. Another plague to coastal communities is extreme rainfall (mostly caused by typhoons), which can trigger a cascade of natural disasters (such as floods and landslides) and cause significant casualties and economic loss. Recent strides in satellite rainfall products (SRPs) have advanced our capability to develop satellite-based early warning systems (Sheffield et al. 2014, 2018; Wu et al. 2014), yet the accuracy and consistency across different SRPs still need to be quantified and validated against local rain gauges before using them for impact assessment. To this end, Jiang et al. (2019) performed statistical analysis to examine how well multiple SRPs can capture extreme rainfall over the Yangtze River Delta, which is one of the most developed coastal areas in China. They found that it is still challenging for current mainstream SRPs to reproduce gauge-observed extreme rainfall statistics (e.g. magnitude, variability), especially at the high temporal resolution (e.g. hourly). Although their findings are not groundbreaking and have been documented by
previous studies (e.g. Sun et al. 2018), this local analysis reiterate the need to further improve extreme rainfall estimates either through enhanced satellite retrieval algorithms or through post-processing techniques (e.g. bias correction, station merging) in order for more effective disaster risk reduction, coastal water planning and flood management.

Water logging is another example of excess water, which can have much larger socio-economic impacts, given the projection that 68% of the world population will be living in cities by 2050 (DESA 2018). Yet, the changing climate, coupled with burgeoning population growth and rapid economic development, poses unprecedented challenges for cities to boost resilience to water-related hazards (e.g. floods) and mitigate their extreme impact. Focusing on the city scale, the article by Zhu et al. (2019) aims at developing a dynamic framework to provide not only the early warning information of water logging but also its societal impact. This framework builds upon a physically based hydrological model, whose output is dynamically linked with an impact assessment model to evaluate the socio-economic impact of water logging at different spatial and temporal scales. Such an impact-driven integrated framework could potentially strengthen the disaster preparedness and responses at the city level, as decision-makers can utilize the information to provide more targeted and tailored warning and rescue services. There are opportunities to further generalize such a framework to other areas or to a large scale, if detailed physical and socio-economic data become available at impact relevant scales (e.g. city level).

It should be noted that papers collected in this SI are a sampling of water impact related modelling studies. These selections exemplify how advances in modelling approaches can be integrated across disciplines to offer new insights to solve existing challenges at the science-policy interface. These articles also complement topics that are not included in this SI, but are important for consideration as future research priorities. For instance, there is an increased recognition that human and behavioural dimensions should be included in both physical models and impact assessment frameworks (e.g. Nazemi and Wheater 2015a, 2015b; van Loon et al. 2016; He et al. 2017; Aerts et al. 2018; He et al. 2019a). As water science is intertwined with other disciplines, such as those related to food and energy production, it is imperative to model water-food-energy integratively (D’Odorico et al., 2018; Scanlon et al. 2017; Albrecht et al. 2018) through nexus approaches (e.g. Liu et al. 2018; He et al. 2019b; Pastor et al. 2019) so that trade-offs can be minimized and synergies can be achieved. Other important topics in water science not addressed in this SI include water quality (e.g. van Vliet et al. 2017; Tang et al. 2019; Hofstra et al. 2019), climate extremes and compounding events (e.g. Zscheischler et al. 2018), risk assessment and decision-making under deep uncertainties (e.g. Swanson et al. 2010; Simpson et al. 2016; Kwakkel et al. 2016; Hall et al. 2019), water economics, governance and markets (e.g. Rogers and Hall 2003; Huitema et al. 2009; Griffin 2016), among many others. These are areas of water research which can also benefit from integrative modelling tools. Last but not the least, although papers in this collection focus on small scales and are case-specific, concepts and implications from these studies could potentially be extended beyond their own geographical limit to other regions facing similar water challenges. However, as modelling tools and impact assessment are both scale-dependent, cross-scale linkages between them need to be well understood before scaling the existing framework (He et al. 2019a). Taken together, these studies and the SI can guide future research efforts to bridge existing gaps between modelling tools and impact assessment in the field of (but not limited to) water science.
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