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Original Article

A conceptual framework for assessing the impact of human behaviour on water resource systems performance

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ABSTRACT

The persistent poor performance of water resource systems (WRS) has been reportedly linked to not only climate change and dilapidated water infrastructures but also human unlawful activities. Some of these unlawful activities include unauthorized water abstractions, wastage, excessive losses, discharging untreated wastewater, over-application of chemicals and fraudulent incidences. Despite advances in WRS planning and operational analysis, incorporating such undesirable activities to quantitatively assess their impact on WRS performance remain elusive. This study was then inspired by the need to develop a methodological framework for WRS performance assessment that integrated human impacts with WRS analysis tasks. A conceptual framework for assessing the impact of human behaviour on WRS performance using the concept of socio-hydrology is proposed herein. The framework identifies and coupled four major sources of water values (WRS, goals, managers and users) using three activities serving as the missing links between these values (interactions, outcomes and feedbacks). The framework can be used as a database for choosing relevant social and hydrological variables and to understand the inherent relations between the selected variables to study a specific human-water problem in the context of WRS management.

1. Introduction

Humans are the primary agents for altering natural resources, however, the impacts of their unlawful activities are not incorporated in resources management. According to [1], to achieve sustainable resources utilization, impacts of human behaviour needs to be considered as part of the ecosystem. Hence, sustainable water resource systems (WRS) management can only be realized if a balance between human and environmental needs is attained. Water is an essential resource that sustains life and nothing can viably serve as a substitute for water. Nevertheless, water is increasingly confronted by climatic change, inefficient infrastructures and unlawful activities [2]. Such unlawful activities include unauthorized use, wastages, losses, pollution and fraudulent occurrences [3].

WRS is a system made up of hydrologic, infrastructures and human activities that entangle water management. Although WRSs intertwined human and water, their performance has been evaluated using hydrologic data without incorporating the impact of stakeholders' activities encourage in the concept of socio-hydrology [4]. For example, water conservation measures were implemented in Cape town and a considerable reduction in consumption was recorded from 2011 to 2014 and was presumed that no water development was needed until 2024. However, in

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2015, the city's water consumption increased significantly due to a change in users' behaviour [5]. Unlawful activities occur in almost all parts of the sector as reported by [6] and [3]. Thus, the interplay between human and water is highly uncertain and hence essential to incorporate them into WRS management. There were several occurrences of unlawful water abstractions by irrigation users in South Africa, including those along the Axle and Liebenbergsvlei transfer scheme, Vaal River, Umvoti, Illovo rivers, Olifants River, Western Cape and Hluhluwe Dam ([7]; [8]; [9]). Despite advances in WRS analysis incorporating such unwanted activities to quantitatively assess their impact on WRS remains elusive. This paper presents a socio-hydrological-based framework for the human-water interplay in the context of WRS. The aim of the framework is to facilitate any future effort towards assessing WRS performance under human influences. Section 2 of this paper provide the reviewed theoretical basis for the intended framework. Section 3 describes the seven building blocks of the framework was formed. The coupling of the building blocks and operational principles of the framework is provided in section 4. Lastly, the paper was concluded in section 5.

2. Theoretical Basis for the Conceptual Framework

The intended framework is a product of an extensive review of water-related interdisciplinary studies including; coupled human and natural systems (CHANS) and social-ecological systems (SES) [10] and others in the field of ecology ([11]; [12]; [13]). For example, a stakeholder-centred framework to facilitate catchment-based Integrated Water Resource Management has been developed using strategic adaptive management [15] and applied in the Inkomati Catchment Management Agency and found to be effective. An optimal treatment scenario for field hospital wastewater problem was also developed and found to be effective [14]. The concept of environmental ethics was used to develop a conceptual framework that linked the health and functionality of the South African aquatic ecosystems and human influences [1] based on the belief that aquatic organisms continue to deteriorate amid undeniable advances in South Africa's water management strategies. Moreover, a smart way for managing wastewater from the hospital was developed which is in line with the regulatory standards [16]. Table 1 summarises some of these frameworks.

Table 1. Interdisciplinary frameworks for studying human-nature interplays

Interdisciplinary Field	Social and Natural Variables	Author (s)
Social-ecological Systems	River Ecosystem Integrity and Degradation and Socio-economic Development	[11]
Social-ecological Systems	Ecological Resources and Socio-economic Activities	[12]
Social-ecological Systems	Social-ecological Systems Models and Human Behavioural Theories	[13]
Coupled Human and Natural Systems	Natural and Modified Ecosystems	[17]
Coupled Human and Natural Systems	Natural Ecosystem and Environment and Human Socio-economic Development	[18]
Strategic Adaptive Management	Values, Social, Technology, Economy, Environment, and Policy	[15]
Environmental ethics	Health and functionality of aquatic ecosystems; human socio-economic development	[1]

Recently, a concept of socio-hydrology [4] has emerged which consider humans as an inherent part of water systems [19] and used for modelling and coupling human activities and water systems to enable assessing the impact of human behaviour on water systems and vice versa (feedbacks) as depicted in Fig. 1 [20].

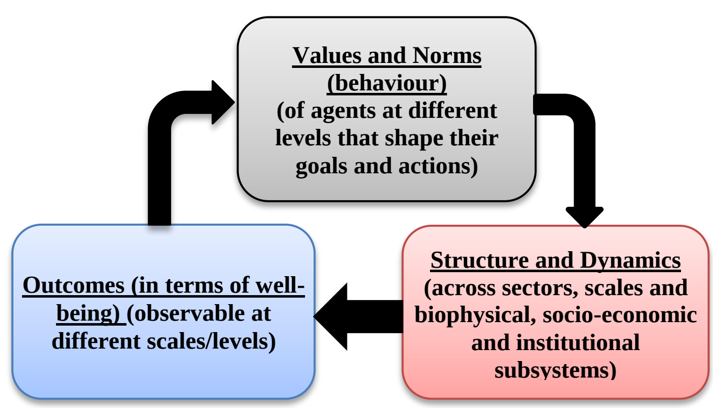


Fig 1. Framework for socio-hydrological system studies

One of the pioneering socio-hydrological studies was the modelling that captured the interactions and feedbacks between socio-economic activities, and flooding events in the flood plain area [21]. The model conceptualised and coupled societal decisions whenever it flooded and how such decisions impacted on flood mitigation. The state drivers of the model (wealth, flooding, distance, awareness, and levees) are represented by a set of differential equations whose variables are upset from time to time by flooding events. These variables are lumped together as a single entity of flooding, societal mental shock, and the decision and coupled to co-evolve dynamically. Similarly, a model that incorporated institutional and co-operative action into a socio-hydrological concept in the context of flood resilience was also developed [22]. [23], coupled socio-economic development, and the state of the land, and water resources in an irrigation catchment. The model is conceptualised based on the concept of "change occurs due to a corresponding change in certain influencing factors", and the paradigm of "exposure–sensitivity–response" as identified in the theory, and literature of resilience [24].

Two human characteristics are coupled to serve as the social aspects of the model: i) Community sensitivity, and awareness (to capture the perceived level of danger to a community's quality of life), and ii) behavioural responses (to capture the state of land and water condition). A slight change in a community's awareness due to the change in social driving variables will change the way in which people are using land, and water in an irrigation settlement, via the behavioural response. Environmental awareness has also been used to develop a mediating strategy model to resolve water competition between agriculture, and ecosystem health [25]. The model is applied and found to perform well in the Murrumbidgee River Basin, Australia. [26], linked political agendas, governance, technology, land and resource use, and societal responses. The model has been operationalized and found to perform well in the downstream use of glacier runoff in Santa River, Peru. [27], developed a catchment water balance model for water sharing between human, and environmental needs. The model has been used to analyse the historical co-evolution of socio-hydrological regimes, and its effect on the environment in the Murray-Darling Basin, Australia for over 100 years. [28]**,** conceptualised a socio-hydrological model for the co-evolution of people, and water in the Tarim River Basin, China. The model captures the community's attitudinal change due to changing ecological health based on water management guidelines.

Historical evidence has been used to analyse the trend of agricultural development, and environmental degradation in the Murrumbidgee River Basin, Australia [29]. A framework that if adopted can moves socio-hydrologic modelling forward by unloading veiled assumptions, model structure and values through engaging with stakeholders. The framework stresses the need for knowledge negotiators that can assist socio-hydrological modellers to work with stakeholders, instead of doing everything themselves [30]. Another framework which provides a collective reflection on the methods to articulate an understanding of social changes within hydrological approaches, based on interdisciplinary insights gained in the field [31]. The socio-hydrological framework was proposed to enable a better understanding of the mechanisms behind human-water dynamics by considering the impacts of social and political decisions on future changes. A study on the role of the model in socio-hydrological studies in predicting socio-hydrological interactions [32]. Socio-hydrological drought processes framework was also conceptualized [33]. Others that have used historical events, and other plausible scenarios to analyse the coupled human-water systems include, [34], [35] and [56].

Table 2. Human characteristics used in the previous socio-hydrological models

Case studies	Human characteristics	Author(s)
Santa River, Peru	Societal Response	[26]
Hypothetical Floodplain	Societal Risk Awareness and Response	[21], [36]
Murrumbidgee Catchment, Australia	Community Sensitivity & Behavioural Response	[23]
New Mexico, USA	Societal Culture and Identity; Community Resilience and Cohesion	[37], [38]
Saskatchewan River Basin, Canada	Fragmented and Overlapping Governance	[39]
Tarim River Basin, China	Evolving Community Awareness	[40]
Chennai city, India	Emergency Response	[30], [41]
Murrumbidgee River Basin, Australia	Environmental Awareness	[25], [27]
Hypothetical Catchment	Community Risk Coping Culture, collective memory and trust	[42]
Other hypothetical cases	Water-human conceptual frameworks	[16], [22], [30]–[32]

3. Development of the Conceptual Framework

The framework was developed using four-values operating in WRS (water systems, goals, managers and users) and three-activities as the missing links between the four-values (interactions, outcomes and feedbacks). Other variables are characterized under the four-values and three missing links. Basically, each variable may interact with one or more variables to co-evolve dynamically thereby resulting in new behaviour and outcome. These outcomes can provide insights into how stakeholders impact on WRS, and how this could, in turn, affect stakeholders' well-being and decisions over time as enclosed in the concept of socio-hydrology [20].

3.1. Water systems

WRS is made up of interconnected hydrologic, infrastructures and human activities that entangle water management [43]. WRS comprised reservoir system, rainwater harvesting system, wastewater re-use system and desalination system and each of these systems as made up of many components. Example, reservoir system is made up of runoff catchment, rivers, pumping units, treatment plants and conveyance systems [44]. Such system components are organised to supply water to various demand sectors. Most of these water systems are designed, constructed, operated and managed by a human, hence human can adversely or favourably impact on WRS performance significantly.

3.2. Water goals

The values operating in WRS management as stated under the definition of integrated water resource management (IWRM) include social, economic, technology, political, laws, institutions and environmental [45]. The social benefits include; affordable and reliable water supply whereas economic gains entail irrigation, power generation and industrial uses [46]. Ecological needs entail attaining ecosystem health (environmental flow requirements, discharging well-treated wastewater and minimizing the application of chemicals). The hierarchical managerial order, political agendas and affiliations affect WRS significantly. Laws enacted to serve as the guide to water managers is also an important value [47]. It is therefore, vital to realistically incorporate these values in the management of WRS by developing an approach that integrated them holistically.

3.3. Water managers

WRS custodians involved public and private institutions, national and international organisations, civil societies, users' associations and traditional leaders. They had a collective responsibility to manage WRS under the agreed rules. The public wing includes the minister of water affairs, directors, engineers, technical, security and administrative staff. Private organizations include multinational agencies (United Nations, World Bank), national and international organisations, civil societies and traditional leaders [48]. How these water custodians are structured, what belongs to who (property right), water sharing rules, licensing and means of sharing information can result in conflicts [49]. Compliance monitoring and enforcement strategies, legal proceedings, employment, promotion, incentives and other benefits of staff can affect WRS performance. Interventions such as awareness campaigns, participation and dialogues are essential for tackling unlawful activities [50]. Respect for indigenous people and community-based associations can offer a significant role in tackling undesirable activities. Thus, creating a self-organised management strategy that co-opted all parties is essential [15].

3.4. Water users

Managing open-access resources such as WRS involved numerous stakeholders with diverse values which posed a unique challenge to the managers [51]. These values are the factors that affect stakeholders' moral awareness and propensity to compliant or unlawful activities. Moral awareness is the ability of an individual to identify his deliberate action and understand what consequences that action could cause to others. Thus, for an individual to make an ethically accepted action depends on a person’s moral awareness and motives which largely depends on value-related factors such as culture, knowledge and religious beliefs [52]. Others include participation, public trust and social well-being including access to good health, education, electricity, water, sanitation and transportation [15]. These factors can affect individuals’ propensity toward compliant or unlawful activities. Issues related to prioritizing some users over others and controversies due to users’ geographical location can also lead to conflicts. External factors (drought, floods and crop water requirement) can also affect users’ compliance. Thus, coordinating stakeholders to act towards a common goal is desirable.

3.5. Interactions between different water values

This is the hub of the framework where all variables (system, goals, managers and users) interact with each other which involves conflict and conflict resolution, compliant and unlawful activities. It also reveals the WRS managers' integrity, credibility, expertise/skills, experience and welfare as these can affect the overall WRS managers’ performance and competence. Depending on the outcomes of such controversies the final decision reached can either positively or negatively affect WRS. The level of users' participation and compliance with the rules is also important and such corporation from stakeholders depends on many factors including socio-cultural values and other situational factors [53]. Other interactions that require urgent intervention include corruption such as inflating contract, fraudulent operation and employing unskilled labours. Unethical behaviour such as water wastage, unlawful water use and adulterating meters are also detrimental to WRS [54]. Dialogues, self-organising and networking activities are vital to the success of WRS.

3.6. Outcomes due to complex interactions

Outcomes are the positive or negative consequences on water users, managers and the WRS due to complex interactions. Outcomes can be measured using the performance indices from different perspectives (social, economic, environmental and institutional performance). The social and economic measures include equity, quality and quantity assurances, affordability, reliability, accountability, income per capita and GDP among others. The institutional performance measures include adequacy, equity, reliability, efficiency and sustainability of supply.

3.7. Feedbacks as correction interventions

In this framework, feedbacks are the appropriate actions taken by the WRS stakeholders as a response to the consequences due to unfavourable outcomes. Examples of such interventions include; i) monitoring and law enforcement (surveillance systems and legal actions), ii) dialogues and policy alterations (deliberating with all parties to reach a consensus, awareness campaigns and imposing supply restrictions), iii) re-enforcement strategy (incentive, recognition or reward to those who abide by the water laws), iv) management restructuring (staff training, promotion, transfer, employment, retirement, demotion, sacking) and v) users' positive response (whistleblowing, lodging complaints, retrofitting appliances and fixing/reporting leaks). These responses from water stakeholders can improve WRS. Hence, human behaviour can serve as a surrogate to materials in achieving efficient and sustainable WRS management.

4. Coupling and Operational Principles of the Framework

WRS stakeholders aimed at achieving one or more water-related goals. Users are known to maximize socio-economic benefits and these objectives can be achieved when water demands are met. Water users are known to maximise socio-economic benefits at individual or societal levels as explained in the consequentialist ethical theories of egoism and homo economicus [55]. When water demand is not met, this could drive users to unlawfully abstract water not allocated to satisfy their goals, especially during water scarcity periods. Such aggressive behaviour can gradually be manifested to new social norms. Thus, for users to achieve their goals, variables from users' module will interact with other variables within the framework.

Unlike users, managers are working toward achieving socio-economic and other objectives at institutional and national levels and environmental needs. The institutional values may include supplying water equitably, efficiently and sustainably. Other objectives comprised reducing unnecessary losses and licensing thereby minimising the unlawful use. Whereas, national values is attaining the objectives of the national development plans of a given country [55]. Thus, users' activities and management strategies can be shaped by WRS values and subsequently impact on the performance of WRS. Also, the performance of the WRS (outcomes) can, in turn, impact on the WRS stakeholders in terms of their well-being and decisions as coupled using visual systems model (graphical abstract) figure 2.

Variables from users, managers and system modules can interact thereby creating an interaction dynamics via interaction hub and continue to co-evolve dynamically as illustrated in figure 2. Depending on the interdependencies between the variables from the users, managers and the system, the co-evolving dynamics can result in new and unexpected outcomes. Such outcomes are the results of interest in the field of socio-hydrology and can favourably or unfavourably impact on the WRS which can influence WRS goals via feedback variables. Such changes in the WRS performance are expected to change the way water stakeholders are behaving, and this is observable via the interaction and outcomes. Also, intervention measures are usually employed as a response to unfavourable outcomes to change the way stakeholders behaves. Such interventions may include conservation campaigns, supply restrictions, improving infrastructures, law enforcement, participation, dialogues and whistleblowing. Thus, WRS performance (outcomes) can, in turn, influence stakeholders by reshaping their behaviour (feedbacks). Such changes in interaction variables observable via outcomes and informed via feedbacks and tackled by reshaping stakeholders' behaviour are expected to change WRS performance substantially. This is the perceived and conceptualised operational principles of the conceptual framework for assessing WRS performance under human behavioural impacts.

5. Conclusions

This paper presented a conceptual framework for assessing the impact of human behaviour on WRS performance. The framework is aiming to guide any future socio-hydrological studies toward a better understanding of the dynamics and complexities of WRS management under the inevitable human influences. At the current level of socio-hydrological research, the framework can help in gaining insights into the complex interactions and co-evolutionary dynamics between various human activities and WRS performance, thereby developing models that can predict the future trajectories of the coupled human behaviour-WRS performance. Practical application of this framework requires the measurement and/or realistic estimate of the selected variables. The perceived interdependencies and the conceptual basis of the causal relationship between the selected variables need to be clearly and accurately described and modelled.

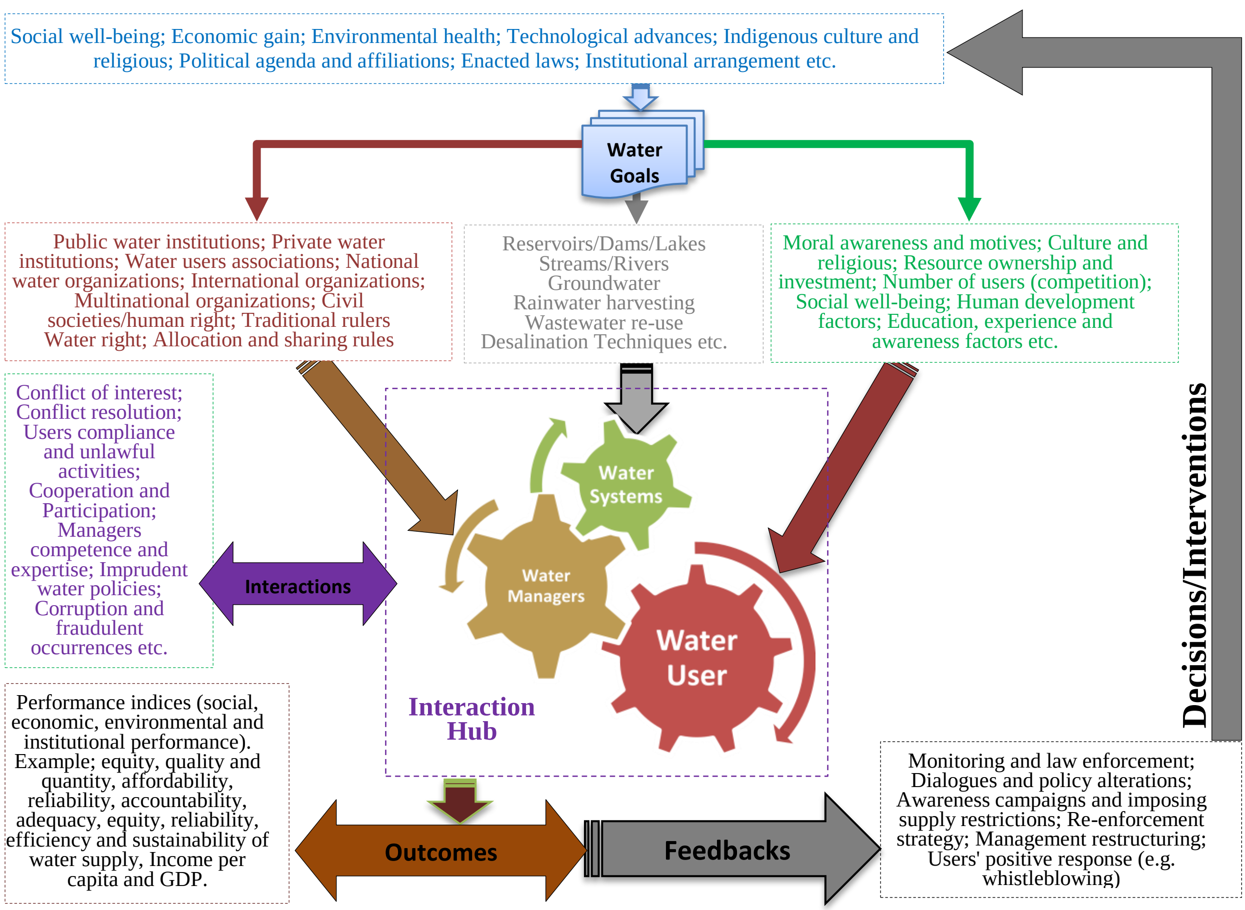
References

1. Odume ON, De Wet C. The role of environmental ethics in social-ecological systems and water resource management. WRC report; 2016. *http://www.wrc.org.za/wp-content/uploads/mdocs/2342-1-15.pdf*
2. Wood J, Antonowicz L. Fighting Corruption in the Education Sector: Methods Tools, and Good Practices. United Nations Development Programme. 2011. *https://anti-corruption.org/fighting-corruption-in-the-water-sector-methods-tools-and-good-practices/*
3. Hermann-friede J, Kropac M, Achermann S, Heeb J, Feuerstein L. Integrity Management Toolbox for Water Service Providers: Manual for Facilitators - Water Integrity Network (WIN). 2014; 56. *https://sswm.info/node/12490*
4. Sivapalan M, Savenije HH, Blöschl G. Socio-hydrology: A new science of people and water. *Hydrol. Process.* 2012;26(8):1270-1276.
5. Muller M. Understanding the origins of Cape Town's water crisis: By Social Science Research Network (SSRN) in Civil Engineering of June, 2017. *https://papers.ssrn.com/sol3/Delivery.cfm/SSRN_ID2995937_code739318.pdf?abstractid=2995937&mirid=1*
6. IPCA. (Information Portal on Corruption in Africa) Lesotho Highlands Water Project - Information Portal on Corruption in Africa. 2010**.** *https://media.africaportal.org/documents/No-22.-The-Lesotho-Highlands-Water-Project-and-Sustainable-Livelihoods.pdf*
7. Ginster M, Gouws C, Gouws CM, Maki H, Mathipa R, Motloung S, Nyandoro M, Tempelhoff JW. Views on unlawful water abstractions along the Liebenbergsvlei River, South Africa. TD: *The Journal for Transdisciplinary Research in Southern Africa.* 2010;6(1):1-24.
8. Ndiritu J, Odiyo J, Makungo R, Mwaka B, Mthethwa N, Ntuli C, Andanje A. Development of probabilistic operating rules for Hluhluwe Dam, South Africa. *Physics and Chemistry of the Earth, Parts A/B/C*. 2017;100:343-352.
9. DWA. Liability of the Responsible Authority for Changes in Yield Assessment: Development of a Reconciliation Strategy for the Olifants River Water Supply System. 2011. *https://docplayer.net/24032509-Development-of-a-reconciliation-strategy-for-the-olifants-river-water-supply-system-wp10197-preliminary-reconciliation-strategy-report.html*
10. An L. Modeling human decisions in coupled human and natural systems: Review of agent-based models. *Ecological Modelling*. 2012;229:25-36.
11. Karr JR. Defining and measuring river health. *Freshwater biology*. 1999;41(2):221-34.
12. Ostrom E. A general framework for analyzing sustainability of social-ecological systems. *Science*. 2009;325(5939):419-422.
13. Schlüter M, Baeza A, Dressler G, Frank K, Groeneveld J, Jager W, Janssen MA, McAllister RR, Müller B, Orach K, Schwarz N. A framework for mapping and comparing behavioural theories in models of social-ecological systems. *Ecological Economics*. 2017;131:21-35.
14. Khan NA, Ahmed S, Vambol S, Vambol V, Farooqi IH. Field hospital wastewater treatment scenario. *Ecological Questions*. 2019;30(3):57-69.
15. Rogers KH, Luton R. Strategic adaptive management as a framework for implementing integrated water resource management in South Africa. *WRC Report No. KV*. 2011;245(10).
16. Khan NA, Khan SU, Ahmed S, Farooqi IH, Hussain A, Vambol S, Vambol V. Smart ways of hospital wastewater management, regulatory standards and conventional treatment techniques. *Smart and Sustainable Built Environment*. 2019. *https://www.emerald.com/insight/content/doi/10.1108/SASBE-06-2019-0079/full/html*
17. Wallace JS, Acreman MC, Sullivan CA. The sharing of water between society and ecosystems: from conflict to catchment–based co–management. Philosophical Transactions of the Royal Society of London. *Series B: Biological Sciences*. 2003;358(1440):2011-2026.
18. Liu J, Dietz T, Carpenter SR, Alberti M, Folke C, Moran E, Pell AN, Deadman P, Kratz T, Lubchenco J, Ostrom E. Complexity of coupled human and natural systems. *Science*. 2007;317(5844):1513-1516.
19. Montanari A, Young G, Savenije HH, Hughes D, Wagener T, Ren LL, Koutsoyiannis D, Cudennec C, Toth E, Grimaldi S, Blöschl G. "Panta Rhei—everything flows": change in hydrology and society—the IAHS scientific decade 2013–2022. *Hydrological Sciences Journal*. 2013;58(6):1256-1275.
20. Sivapalan M, Konar M, Srinivasan V, Chhatre A, Wutich A, Scott CA, Wescoat JL, Rodríguez‐Iturbe I. Socio‐hydrology: Use‐inspired water sustainability science for the Anthropocene. *Earth's Future*. 2014;2(4):225-230.
21. Di Baldassarre G, Viglione A, Carr G, Kuil L, Salinas JL, Blöschl G. Socio-hydrology: conceptualising human-flood interactions. *Hydrology and Earth System Sciences.* 2013;17(8):3295.
22. David JY, Sangwan N, Sung K, Chen X, Merwade V. Incorporating institutions and collective action into a sociohydrological model of flood resilience. *Water Resources Research*. 2017;53(2):1336-1353.
23. Elshafei Y, Sivapalan M, Tonts M, Hipsey MR. A prototype framework for models of socio-hydrology: identification of key feedback loops with application to two Australian case-studies. *Hydrology and Earth System Sciences*. 2014;11(1):629-689.
24. Dale A, Ling C, Newman L. Community vitality: The role of community-level resilience adaptation and innovation in sustainable development. *Sustainability*. 2010;2(1):215-31.

25. Van Emmerik TH, Li Z, Sivapalan M, Pande S, Kandasamy J, Savenije HH, Chanan A, Vigneswaran S. Socio-hydrologic modeling to understand and mediate the competition for water between agriculture development and environmental health: Murrumbidgee River basin, Australia. *Hydrology and Earth System Sciences*. 2014;18, 4239–4259
26. Carey M, Baraer M, Mark BG, French A, Bury J, Young KR, McKenzie JM. Toward hydro-social modeling: Merging human variables and the social sciences with climate-glacier runoff models (Santa River, Peru). *Journal of Hydrology*. 2014;518:60-70.
27. Zhou S, Huang Y, Wei Y, Wang G. Socio-hydrological water balance for water allocation between human and environmental purposes in catchments. *Hydrology & Earth System Sciences*. 2015;19(8).
28. Liu D, Tian F, Lin M, Sivapalan M. A conceptual socio-hydrological model of the co-evolution of humans and water: case study of the Tarim River basin, western China. *Hydrology & Earth System Sciences*. 2015;19(2).
29. Kandasamy J, Sounthararajah D, Sivabalan P, Chanan A, Vigneswaran S, Sivapalan M. Socio-hydrologic drivers of the pendulum swing between agricultural development and environmental health: a case study from Murrumbidgee River basin, Australia. *Hydrology and Earth System Sciences*. 2014;18(3), 1027–1041.
30. Srinivasan V, Sanderson M, Garcia M, Konar M, Blöschl G, Sivapalan M. Moving socio-hydrologic modelling forward: unpacking hidden assumptions, values and model structure by engaging with stakeholders: reply to "What is the role of the model in socio-hydrology?". *Hydrological Sciences Journal*. 2018;63(9):1444-1446.
31. Massuel S, Riaux J, Molle F, Kuper M, Ogilvie A, Collard AL, Leduc C, Barreteau O. Inspiring a broader socio-hydrological negotiation approach with interdisciplinary field-based experience. *Water Resources Research*. 2018;54(4):2510-2522.
32. Melsen LA, Vos J, Boelens R. What is the role of the model in socio-hydrology? Discussion of "Prediction in a socio-hydrological world". *Hydrological Sciences Journal*. 2018;63(9):1435-1443.
33. Kuil L, Carr G, Viglione A, Prskawetz A, Blöschl G. Conceptualizing socio-hydrological drought processes: The case of the Maya collapse. *Water resources research*. 2016;52(8):6222-6242.
34. Sivapalan M, Blöschl G. The growth of hydrological understanding: Technologies, ideas, and societal needs shape the field. *Water Resources Research*. 2017;53(10):8137-8146.
35. Jr Wescoat JL. Reconstructing the duty of water: a study of emergent norms in socio-hydrology. *Water Resources Research*. 2013; 54, 1–16.
36. Di Baldassarre G, Viglione A, Carr G, Kuil L, Yan K, Brandimarte L, Blöschl G. Debates—Perspectives on socio-hydrology: Capturing feedbacks between physical and social processes. *Water Resources Research*. 2015;51(6):4770-4781.
37. Fernald A, Guldan S, Boykin K, Cibils A, Gonzales M, Hurd B, Lopez S, Ochoa C, Ortiz M, Rivera J, Rodriguez S. Linked hydrologic and social systems that support resilience of traditional irrigation communities. *Hydrology and earth system sciences.* 2015;19.
38. Fernald A, Tidwell V, Rivera J, Rodríguez S, Guldan S, Steele C, Ochoa C, Hurd B, Ortiz M, Boykin K, Cibils A. Modeling sustainability of water, environment, livelihood, and culture in traditional irrigation communities and their linked watersheds. *Sustainability*. 2012;4(11):2998-3022.
39. Gober P, Wheater HS. Socio-hydrology and the science-policy interface: a case study of the Saskatchewan River basin. *Hydrology and Earth System Sciences.* 2014;18(4):1413.
40. Liu Y, Tian F, Hu H, Sivapalan M. Socio-hydrologic perspectives of the co-evolution of humans and water in the Tarim River Basin, Western China: the Taiji--Tire Model. *Hydrology & Earth System Sciences Discussions*. 2013;10, 12753-12792.
41. Srinivasan V. Reimagining the past–use of counterfactual trajectories in socio-hydrological modelling: the case of Chennai, India. *Hydrology and Earth System Sciences.* 2015;19(2):785-801.
42. Viglione A, Di Baldassarre G, Brandimarte L, Kuil L, Carr G, Salinas JL, Scolobig A, Blöschl G. Insights from socio-hydrology modelling on dealing with flood risk–roles of collective memory, risk-taking attitude and trust. *Journal of Hydrology*. 2014;518:71-82.
43. Brown CM, Lund JR, Cai X, Reed PM, Zagona EA, Ostfeld A, Hall J, Characklis GW, Yu W, Brekke L. The future of water resources systems analysis: Toward a scientific framework for sustainable water management. *Water resources research*. 2015;51(8):6110-6124.
44. Loucks DP, Van Beek E, Stedinger JR, Dijkman JP, Villars MT. Water resources systems planning and management–An introduction to methods, models and applications, *Studies and Reports in Hydrology series*. 2005 *https://unesdoc.unesco.org/ark:/48223/pf0000143430*
45. Agarwal A, delos Angeles MS, Bhatia R, Chéret I, Davila-Poblete S, Falkenmark M, Villarreal FG, Jønch-Clausen T, Kadi MA, Kindler J, Rees J. Integrated water resources management. Global water partnership. 2000; Paper No. 4. *https://www.scirp.org/(S(351jmbntvnsjt1aadkposzje))/reference/ReferencesPapers.aspx?ReferenceID=1320536*
46. Srinivasan V, Lambin EF, Gorelick SM, Thompson BH, Rozelle S. The nature and causes of the global water crisis: Syndromes from a meta-analysis of coupled human-water studies. *Water Resources Research*. 2012;48(10).
47. Bergström U, Sundblad G, Downie AL, Snickars M, Boström C, Lindegarth M. Evaluating eutrophication management scenarios in the Baltic Sea using species distribution modelling. *Journal of Applied Ecology*. 2013;50(3):680-690.
48. Jaspers FG. Institutional arrangements for integrated river basin management. *Water policy*. 2003;5(1):77-90.

49. Dietrich J. Scaling issues in multi-criteria evaluation of combinations of measures for integrated river basin management. *Proceedings of the International Association of Hydrological Sciences* 373 (2016). 2016;373:19-24.
50. World Bank. World development report 2015: Mind, society, and behavior. 2015. https://www.worldbank.org/en/publication/wdr2015
51. Ostrom EE, Dietz TE, Dolšak NE, Stern PC, Stonich SE, Weber EU. The drama of the commons. National Academy Press; 2002. *https://www.nap.edu/read/10287/chapter/2*
52. Treviño LK, Weaver GR, Reynolds SJ. Behavioral ethics in organizations: A review. *Journal of management*. 2006;32(6):951-990.
53. Berkes F, Hughes TP, Steneck RS, Wilson JA, Bellwood DR, Crona B, Folke C, Gunderson LH, Leslie HM, Norberg J, Nyström M. Globalization, roving bandits, and marine resources. *Science*. 2006; 17;311(5767):1557-1558.
54. Rogers P, Bhatia R, Huber A. Water as a social and economic good: How to put the principle into practice. Stockholm: Global Water Partnership; 1998. *https://www.ircwash.org/resources/water-social-and-economic-good-how-put-principle-practice*
55. Monroe KR. Paradigm shift: from rational choice to perspective. *International Political Science Review*. 2001;22(2):151-172.
56. Shanono NJ. Assessing the Impact of Human Behaviour on Reservoir System Performance Using Dynamic Co-evolution - A PhD Thesis Submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg. 2019. *http://wiredspace.wits.ac.za/handle/10539/29043*

Graphical abstract



Graphical abstract of the conceptual interplay between the four key values of WRS management (goals, systems, managers and users) and three human activities which serves as the missing links (interactions, outcomes and feedbacks)

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