IEREK PRESS Academic Research Community
http://www.press.ierek.com
ESSD
ISSN (Print: 2357-0849, online: 2357-0857)
Environmental Science and Sustainable Development
DOI: 10.21625/essd.v5i2.759

Freshwater: Towards a Better Understanding of a Wicked Problem

Tom Sanya[1]

[1] *School of Architecture, Planning and Geomatics, University of Cape Town, South Africa*

Corresponding author email: (tom.sanya@uct.ac.za)

Abstract

Water begets intricate and profound linkages between multiple systems. Quantitative limits to freshwater availability for human needs, variabilities in the water cycle and environmental water requirements interact with water source pollution. The arising tensions are a great challenge of immense contemporary significance that can best be described as a wicked problem – a problem with multiple dimensions that presents unexpected consequences when engaged. Water challenges make vivid the compromises that must be made between the environment and development. These compromises surface in the conflict between ecocentric and technocentric discourse. Globally, there is evidence of numerous disciplinary and interdisciplinary water-related studies both in the past and ongoing. But there is no meta-mapping of various dimensions of such research to give a clear overview of what has been and what needs to be done. Consequences of this oversight may include unnecessary duplication of research, difficulty in articulating knowledge gaps and inability to see beyond disciplinary boundaries. The author suggests an outline of how these difficulties can be engaged. This is done through a wide-ranging literature review to identify a range of issues of focus, which issues are then themed into imperatives for water research. These imperatives are subsequently systematised using four normative descriptors: problem, drivers and mitigation measures. In combination, these descriptors articulate a spectrum of the key issues around water research. The key issues are mapped onto various academic disciplines and societal partners to outline a schema for positioning of water research. The proposed mapping can facilitate interdisciplinary and transdisciplinary (IDTD) research by allowing researchers to benefit from relevant existing bodies of knowledge while also making explicit knowledge gaps and opportunities for collaboration. By locating academic fields within different worldviews, the outlined schema reveals common ground beyond disciplinary confines around which IDTD research can be instigated.

Keywords

freshwater; water scarcity; water pollution; worldviews; interdisciplinary and transdisciplinary (IDTD) research

1. Introduction

The "blue planet", earth, is made habitable by water. But more than 97 percent of planet earth's water is saline (oceans and seas) and hence a mere 2.5 percent is freshwater. Vast volumes of freshwater are locked up in glaciers and polar caps. This leaves only 0.77 percent freshwater available for human use in terranean and subterranean catchments (Kuylenstierna et al, 1998; Shiklomano, 1991). In conditions of freshwater scarcity, tensions arise between human water needs and environmental water requirements. Global freshwater includes renewable and non-renewable water. Non-renewable water, which constitutes 60 percent of the hydrologic cycle, is the water used by plants in evapotranspiration. Though it is important for rainfed agriculture and the natural environment, non-renewable water is generally out of the realm of control of humans and is not included in water scarcity studies. The remaining 40% is renewable water which is framed in reference to the global demands of two categories: (i) anthropogenic water requirements (ii) environmental water requirements (Rijsberman, 2006; Smakhtin et al, 2004). Due to its cyclic nature, water supply and sanitation cannot be delinked.

Water occurs in a continuous hydrological cycle that entangles humans with biotic and abiotic systems in multiple pathways. Water's cyclic occurrence and omnipresence, coupled with its indispensability for the survival of humans and ecosystems, defines myriads of systems with mutual feedback loops. Securing freshwater for growing populations is a grand challenge in the Anthropocene. Rijsberman argues that water is critical to an array of global challenges from health, to malnutrition, poverty, and sustainable natural resources management (2006). Today, this complex challenge is articulated as the water-energy-food-health nexus (Amorim et al, 2018; International Water Management Institute, 2019). It can therefore be argued that the water challenge is a wicked problem. A wicked problem is one which eludes precise definition, whose amelioration demands uncomfortable compromises, and for which intervention in one realm yields unexpected results elsewhere (Webber and Rittel, 1973).

Water-focused research spans ecology, social-sciences, engineering and many more disciplines. Freshwater research is wide in scope and has yielded numerous disciplinary and interdisciplinary studies. Publications have covered such topics as water availability, scarcity and response to scarcity (Falkenmark et al, 1989; Guppy and Anderson, 2017; World Economic Forum [WEF], 2019) 2019; Shiklomanov, 1991; Kuylenstierna et al, 1998); aquatic ecosystem system services (Abell et al, 2019; Vörösmarty et al, 2018; Costanza et al, 2014); water and climate change (Vörösmarty et al, 2000 and Arnel, 1999); wastewater and pollution (Connor et al, 2017; World Health Organization [WHO], 2004; Karr and Dudley, 1981); and the relatively new field of water sensitive design (O'Farrell et al, 2019; Sharma et al., 018; Howe and Mitchell, 2011; Wong and Brown, 2009; Carden et al. 2018). Water research also extends to issues of rights and water, social justice, law and discourse analysis.

Together, these fields outline an impressive spectrum of water-related research. However, critical evaluation of literature reveals that none of these publications provides a strategic overview of water research because they speak to diverse, if overlapping, research fields. The result is that water-related research, though impressive in scope and depth, has not yet, to this author's knowledge, been systematised to relate its diverse fields and subfields. This paper attempts to derive a comprehensive yet non-prescriptive outline to cover the breadth and scope of water-related research. Such an outline can make possible reflexive contextualisation of past, present and future research to facilitate collaborative synergies, identify knowledge gaps, and pre-empt duplication in water-related research. Thus, this paper is aimed at enabling researchers to critically position past and ongoing water research AND to surface collaboration possibilities in future disciplinary, interdisciplinary and transdisciplinary research endeavours.

2. Method

This paper uses systematic literature review to uncover and characterise different aspects of water-related research. The literature reviewed includes articles in peer-reviewed academic journals, some books and publications from multilateral organisations. *Endnote* is used as a software to organise and theme the literature.

After Beker (2003), the paper adapts a three part approach to the literature review to cover analytical, normative and operational level literature. Analytical level literature focuses on worldviews. Normative literature covers definitions, goals, criteria and indicators. And operational literature proposes particular strategies and actions to deal with specific problem situations.

First, normative and operational level literature is analysed. Referencing the postulate that problems are "the fountainhead" of research (Becker, 2006), the paper takes water-related disutilities to society and the environment as a starting point. These disutilises are captured in a set of problems: societal water scarcity; environmental water scarcity; temporal variations in the water cycle (drought and flooding); and water pollution. Each problem is discussed in turn.

Normative and operational level water literature results in a three-part systematisation: problems, causes and mitigation measures. This becomes the *vertical dimension* of the outline schema for water related research.

Apart from the water-related problems, there is emergent discourse which problematises the dominant quantitative water discourse. This is covered separately as part of normative and operational level literature.

The next part of the paper is at the analytical level. It focuses on a higher level framing of the normative and operational literature. This part specifically draws from O'riordan (1981), Drysek (2013), Groat and Wang (2002) and Naess (1990 and 1973) to situate normative and operational literature within different worldviews.

The final part references a classification of different academic fields and locates them within different worldviews. The worldviews together with the academic fields become the *horizontal dimension* in the outlined schema for water research.

Mapping the vertical and horizontal dimensions together outlines a schema for systemisation of water related research.

3. Water Research Literature

3.1. Societal Water Scarcity

Globally, humans abstract over 4 000 Km^3 (4000 billion m^3) of available freshwater annually. 12 percent of abstracted freshwater is *municipal water* for domestic and commercial purposes (Food and Agricultural Organisation [FAO], 2016) such as drinking, food preparation, personal hygiene and sanitation and watering of ornamental landscapes. Domestic water scarcity is evidenced by the 844 million people worldwide who lack access to safe water and the 2.4 billion people without access to improved sanitation (United Nations International Children Education Fund [UNICEF] and World Health Organisation [WHO], 2015). Domestic water scarcity, which occurs mostly in poverty stricken rural areas and urban informal settlements (Center for Disease Control and Prevention [CDC], 2015; Hou et al, 2014), significantly reduces wellbeing and is associated with a range of health risks. Contaminated water and poor sanitation are linked to transmission of diseases such as cholera, diarrhoea, dysentery, hepatitis A, typhoid, and polio (WHO, 2019b). More than 820 000 people die each year from diarrhoea as a result of unsafe drinking-water, poor sanitation, and due to poor hygiene (WHO, 2019b; UNICEF and WHO, 2015). The majority of the world's population is already urbanised and, driven by population growth and migration from rural areas. The rate of urbanisation is accelerating – particularly in the resource challenged Global South (United Nations, Department of Economic and Social Affairs Population Division, 2019a and 2019b). Therefore, inadequate water and poor sanitation will continue to be a significant challenge. This challenge is proactively acknowledged in Sustainable development Goal 6 (Clean Water and Sanitation) (United Nations, 2017). The research imperative that emerges here is *secure safe water and sanitation for those who lack access*.

At 69 percent, the largest freshwater consumer is agriculture (irrigation, livestock and aquaculture) (FAO, 2016). Global projections are that, due to growing population, agricultural water demand will continue to grow (Conforti, 2011). Seventy times more food will be needed by 2050 (Conforti, 2011). About 20 percent of freshwater abstracted by humans is used for industrial purposes and energy production (FAO, 2016). Taken together agricultural and industrial water use is expressed in GDP/m^3 of water. That is, like embodied energy, every product contains "virtual water" (Hoekstra, 2003; Chapagain and Hoekstra, 2004). Generally, as populations grow and standards of living increase, water use increases proportionately (Conforti, 2011). However, others have argued that an efficiency revolution, similar to the energy revolution is possible. Indeed, recent evidence suggests that there is not necessarily a linear mapping of population growth and standards of living with water consumption (Gleick, 2003). That is, increase of water productivity is possible (Gleick, 2003). Research into *increasing water productivity is paramount*.

Often, water for human use is scarce despite its abundance in natural systems – a phenomenon known as economic water scarcity (Rijsberman, 2006). At a macro-level, *economic water scarcity* is caused by lack of capacity in terms of capital, technology and infrastructure to deliver the water for human consumption. At a micro-level economic water scarcity is faced by poor households that cannot afford to be connected to infrastructure e.g. in informal settlements. Poverty and water scarcity, coupled with malnutrition and ill health, result in a vicious poverty-water-food-health nexus that poses a critical global challenge (Amorim et al, 2018; Weitz et al, 2014). Clearly, SDG 6 (clean water and sanitation) is key to achievement of many other SDGs, such as: no poverty, zero hunger, good health and well-being, reduced inequalities, sustainable cities and communities, life below water, and life on land. Economic water scarcity may also be due to governance failure whereby poor institutions, institutional fragmentation, and lack of transparency and accountability result in societal water scarcity despite its abundance in natural systems (Akhmouch and Clavreul, 2016). Research imperatives emerging here are about: securing clean water and sanitation for *vulnerable populations and households.*

The above biophysical characterisation of water scarcity is extended by critical perspectives that position water availability in rights and social justice. Arguing that water cannot be substituted, Shiva (2006) posits that water must be free for all people and the environment. She argues that access to water is not a favour but a right. Mehta (2003) highlights the variability of the water cycle across space and time to argue that the idea of enduring drought and permanent water scarcity is without basis. She contends that scarcity is essentially transient but modernity made it permanent. She argues that water scarcity is always interspersed with overabundance and that water availability is regularly irregular. She adds that vested powerful interests promote an alarmist narrative of water scarcity to obfuscate asymmetries in water access. In a granulated analysis, Metha draws attention to the distributional and relational aspects of scarcity to argue that scarcity is not felt universally by all. This for example is when powerful agricultural and industrial interests and rich elites consume huge quantities of underground water resulting in depletion of poor people's wells. And large technical solutions such as dams and canals are designed to maximise allocation of scarce water to the powerful agro-industrial interests at the expense of the marginalised poor. In this way, argues Mehta (2003 and 2001), the rich are water secure but *cause* scarcity in poorer communities

Shiva (2006) highlights the Plachimada Declaration on water democracy as a victory of community movements against big private interests. The declaration asserts that because water is not a human invention and cannot be bound, it should not be sold as a commodity. Water cannot be substituted and all people and the environment have a right to sufficient water. The Plachimada Declaration is elevated to a symbol of struggle for water rights (Shiva, 2006).

3.2. Environmental Water Scarcity

On the other hand, abundance of water in human systems does not necessarily imply absence of water scarcity. Ecological systems have *environmental water requirements (EWR)* (Smakhtin et al. 2004; Rijsberman, 2006). The Falkenmark indicator (water stress index) is a combined metric for human and environmental water requirements (Falkenmark et al, 1989). When available renewable water per capita per annum is less than 1700m3, the country is defined as experiencing water stress. Water scarcity occurs at less than 1000m3 renewable water per capita. Absolute water scarcity occurs at below 500m3 renewable water per capita per annum. There is also a variety of other measures of water scarcity (Rijsberman, 2006). And, according to the United Nations (2015), 1.7 billion people are currently living in river basins where water use exceeds recharge. Depleting lakes and aquifers and rivers drying up before they reach the sea are obvious signs of unsustainable abstraction and environmental water scarcity. The Colorado River in the United States and the Yellow River in North China, are frequently completely or partially depleted before they reach the sea every year . The Aral Sea and Lake Chad are examples of water bodies disappearing because of reduced river inflows (see Mekonnen and Hoekstra, 2016). A key research imperative therefore is *to measure anthropogenic and environmental water scarcity* using the Falkenmark Index or another suitable indicator. Smakhtin proposes that environmental water requirements (ERW) be determined by classifying ecosystems into four classes: 1. Natural (pristine and unmodified); 2. Good (slightly modified); 3. Fair (moderately disturbed); 4. Poor (critically modified and degraded). Smakhtin recommends environmental water allocation for each ecosystem whereby the more undisturbed the system, the more water environmental water should be allocated to it to keep it in that condition (Smakhtin et al. 2004). A key research imperative is therefore *setting environmental management and water allocation objectives by classifying ecosystems*.

Environmental water is essential for ecosystem health and protection of freshwater ecosystem services. Freshwater ecosystems provide a range of valuable goods and services such as flood protection, fisheries, recreation opportunities and wildlife sanctuaries (Revenga et al, 2000; Acreman, 2001, Vié et al, 2009). It is estimated that these services are worth trillions of US dollars annually (Posteland Carperter, 1997). It is argued that freshwater ecosystem degradation has resulted in loss of services valued at 20 trillion dollars annually (Costanza et al, 2014). It is therefore in society's interests that aquatic ecosystem water requirements are met. This means that in regional planning, *ensuring sufficient environmental water availability* for watersheds is imperative.

Most urban areas are fully built up or paved and would hence fall under what Smakhtin (2004) describes as “modified beyond rehabilitation to anything approaching a natural condition”. Many cities do not have healthy freshwater ecosystems – meaning that they forfeit the immense value of related natural goods and services. However, at the intersection between nature and the urban built environment is ecological infrastructure, which is commonly encompassed under Water Sensitive Design (WSD) (Donofrio et al, 2009). Water sensitive approaches to urban design and planning can be used to introduce, safeguard and enhance freshwater ecosystems in the city. This is through linking new and existing water bodies and greenery into networks of blue-green natural infrastructure (Wong and Eadie, 2000; Carden et al, 2018; O'Farrell et al, 2019). Natural infrastructure offers active recreation opportunities such as walking, jogging, cycling, canoeing and fishing. Blue-green infrastructure in cities is also known to mitigate the urban heat island effect (Brears, 2018). Reduced temperatures, opportunities for active recreation and the pollution-cleansing effects of nature result in overall health benefits for city residents (Coutts et al, 2013). Research into *WSD for protection and enhancement of urban freshwater ecosystems is imperative*.

3.3. Temporal Variations in the Water Cycle

Water scarcity is complicated by the spatial and temporal variations in water availability due to the dynamic nature of the hydrological cycle. The same place can experience scarcity and flooding in the same year. Global warming is increasing the intensity, frequency and duration of extreme weather events (Cisneros et al, 2014 and Arnell, 1999). The dynamic nature of the water cycle may explain why some authors argue that, unlike biospherical integrity and land systems, freshwater availability is not a critical contemporary limit (Rockström et al, 2009). Yet, Mekonnen and Hoestra (2016), in a fine scale spatial and temporal resolution, estimated that 66 percent of the global population lives under conditions of severe water scarcity for at least one month of the year. Moreover, 40 percent of the world’s population will be living in seriously water-stressed areas by 2035 (Guppy and Anderson, 2017 and Addams et al, 2009). In absolute terms, there has been a 55 percent drop globally in available freshwater per capita (Guppy and Anderson, 2017) while by 2030, global demand for water is expected to grow by 50 percent (United Nations Educational Scientific and Cultural Organisation [UNESCO], 2012). The World Economic Forum (WEF) warns that water scarcity is amongst the top ten global risks in terms of likelihood and impact (WEF, 2019). The relatively affluent are apparently oblivious to this critical problem given that they waste up to 80 percent of potable water on uses for which non-potable water would suffice (Sisolak and Spataro, 2011). Globally, 30 percent of global water abstraction is wasted through leakage (Liemberger and Wyatt, 2019). The reality of water-stress was emphasised, to rich and poor alike, when Cape Town almost ran out of water in 2017 and 2018 in what was known in global popular press parlance as Day Zero (Taing et al, 2019; Wolski, 2018). Thus, for significant portions of global population, water stress is a new normal. This means that it is imperative for research to be focussed on *adaption and building resilience* in the face of episodic and enduring water challenges. Adaptation and resilience building include: diversifying supply; reducing leakage; mainstreaming fit-for-purpose water use to avoid wastage of potable water; developing efficient technologies to reduce water consumption and wastage; nudging consumer mindsets from water wasteful to water mindful; and increasing water productivity. Furthermore, civilisations have been known to flourish in historically water stressed geographies because they developed adequate institutions (Rijsberman, 2006). Mehta (2003) also demonstrates that local people have evolved flexible livelihoods in order to intermittent availability of water. Hence, building resilience requires *developing appropriate institutions for water governance*.

But it is not just water scarcity that is at issue. Due to the dynamic nature of the water cycle, extreme weather events can cause sudden water overabundance which can result in flooding and landslides. Water plays a major role in all disasters. 90 percent of all disasters in 2017 were water related (Centre for Research on the Epidemiology of Disasters [CRED] 2017). Floods and landslides alone accounted for more 75 percent of the disaster-related deaths (ibid).

Climate change has been foregrounded as a cause of water scarcity. Due to climate change, the occurrence and severity of extreme weather events is projected to increase (WEF, 2019). Hence, *adaptation to and mitigation of flooding* is another important research imperative. Mehta (2006) claims that the attribution of long droughts to climate change is not supported by local data and instead, more attention should be focused on human-induced scarcity due to deforestation and unsustainable irrigation, for example. Edwards (2013) argues that, in Australia, the narrative of an imminent water crisis induced by climate change is accompanied by neoliberalization of water governance.

Bringing water to one area leaves a deficit elsewhere (Shiva, 2001). Dams upstream create scarcity downstream (Hussien, 2017a). Dams to provide water and power flood nature, displace communities and cause massive loss of flora and fauna.

Water can be a political matter. According to Yorke (2016), in water scarce countries such as Jordan, water is an instrument of patronage and power. And powerful elites consistently ignore or frustrate water demand management aimed at securing sustainable yields. Therefore, water demand and supply is not just one of demand and supply but it is also a wider structural problem of national governance. For this reason, Hussien (2018) argues, engineering and geological perspectives on water scarcity must be complemented by insights from the political and social sciences.

3.4. Water Quality and Pollution

Most water consumed and used by humans becomes part of the environment and the water cycle again. This opens numerous pathways for pollution. Two billion people worldwide contaminate water with faecal matter (WHO, 2015). Globally, 80 percent wastewater is dumped untreated (UN Environment). In developing countries, 70 percent industrial waste is untreated. 15 – 18 billion m3 of freshwater resources are polluted by fossil fuel production annually (UNESCO, 2020).

Eutrophication - from wastewater and agricultural run-off - has, according to recent estimates, reduced biodiversity in rivers, lakes and wetlands by about one-third globally. Ironically, eutrophication and biochemical oxygen demand (BOD) are caused by depletion of valuable nutrients and organics from society (Sisolak and Spataro, 2011). Hence, harvesting nutrients and organics from wastewater before releasing it to the environment simultaneously protects the environment and reclaims resources for agricultural systems. Two imperatives emerge here (1) *to research pollution of freshwater systems* (2) *research circular economy systems for wastewater treatment and resource reclamation*.

3.5. The Vertical Dimension

The above literature review reveals water related discourse from different perspectives. To find a common thread in the different perspectives, the literature-derived research imperatives are systemised into three distinct but interrelated categories:

- Problem description
- Problem drivers
- Mitigation measures

The first category is analysing and describing existing problems in reference to human and environmental systems. This category addresses the scale and scope of problems around water quantity and quality. One of the problems is water scarcity as measured against human and environmental water requirements. Another problem is the episodic occurrence of overwhelming amounts of water characterised as flooding. It is also here that the increasingly chronic nature of global water stress and the uncertainties unleashed by climate change are covered. A final problem is around water pollution and its effects. Therefore, research focus here is to ***describe the problem*** in terms of water quantity (scarcity, flooding and climate change) and water quality (pollution) over a range of spatial and temporal scales [descriptive research].

In the second category, the drivers of each of the problems above are analysed. The focus is to ***analyse the drivers*** of these problems [analytical research].

A final category is related to mitigation measures focused on addressing each problem. This includes setting ***performance targets*** (normative guidelines) using expert-led and/or participatory processes. It also focuses on ***generating*** new solutions or ***applying*** existing ones in a different context. This category also covers ***evaluating past*** solutions for positive and negative lessons [normative, creative, applied and evaluative research].

The problems, their drivers and associated mitigation measures form a broad spectrum of agendas for water research and constitute the vertical dimension in this paper's high-level outline.

3.6. Water Discourse

Apart from the literature about water, its availability and distribution, there is specific literature that focuses on discourse analysis of water-related research. The same reality can generate different, even opposed, discourses (Hussien, 2017a). In the extreme, some others claim that the environment is socially constructed (Escobar, 1996: 46). For Hussein (2017b), discourses do not just help us to make meaningful stories but constitute a substantial reality imbued with actual agency. Discourses define what matters and they foreground some issues and solutions at the expense of others. Dominant discourses are deployed across generations through textbooks at the interfaces of formal, practical and popular geopolitics (Ide, 2016). For Pieterse (1992) participation brings integration, rather than emancipation. Participation is problematised as being asymmetrical and manipulative (Mehta, 2006).

Power converges through coalitions of actors sharing the same discourse but not necessarily the same motives. Discourses connect local and international arenas to generate huge networks of actors from academic and non-academic spheres. Big infrastructure projects engender conflicting discourse alliances as described by Hussien (2017a) for example. Discourses and the coalitions they create are alive and mutable. Actors, discourses, plans and motives evolve with changes in broader contextual factors. Because of the contested context, Hussien (2017b) suggests that water discourses ought to be extended from the watersheds to the “problemsheds” beyond.

4. Worldviews

This section uses worldviews to reflect, at higher level, on the above normative and operational literature. Groat and Wang (2002) identify three worldviews. The positivist worldview underpins rational science and its quantitative approaches. It aims for value-free research as an ideal. The naturalist paradigm embraces multiple, socially constructed realities and the importance of values in research. In the emancipatory paradigm, there are multiplicity of realities and knowledge that are socially and historically situated. Knowledge is seen to be mediated by class, power, gender, economic, ethnic-cultural values. O’riordan (1981) distinguishes between technocentric and ecocentric perspectives. Technocentricism is the result of the positivist worldview and science while ecocentrism is associated with the naturalist and emancipatory worldviews.

Technocentricists who promote limitless growth are described as cornucopians by O’riordan (1981) while Dryzek (2013) calls them prometheans. However both authors extend technocentricism to sustainability in the forms of environmental managerialism, ecological modernisation and sustainable development. Environmental managerialism and ecological modernisation focus on predominantly addressing ecological issues through continuous innovation. But sustainable development embraces ecology as well as intra and intergenerational equity. In their variety, the above technocentric discourses span approaches ranging from expert-lead, through participatory democracy, to unbridled free-market mechanisms for development. Underpinned by scientific rationalism, technocentric approaches are politically and economically dominant (Dryzek, 2013). Technocentric actors include governments, bureaucrats and technocrats. They operate at local and global levels. Local governments work with international bodies such as WHO, the UN and other multilateral national corporations. They may also include compliant NGOs that act as intermediaries with various communities. The normative and operational discourse by international bodies discussed above can therefore be said to be technocentric. Similarly, the more quantitative approaches to normative and operational level water research are technocentric (including authors like Falkenmark, Mekonnen, Hoekstra, Smakhtin, Rijsberma, Kuylenstierna, Conforti, Contanza, Guppy, others and others). Here would also fall those who drive the agenda of climate change.

Ecocentric approaches on the other hand question the dominance of scientific rationality and question the desirability of perpetual economic growth. Framed by naturalists and emancipatory worldviews, they reveal and critically engage the values that underpin normative practice and discourse and challenge man to fundamentally change consciousness (Arne Naess (1973 and 1990). For Dryzek (2013), ecocentrism is synonymous with green radicalism because it agitates for a rupture from the dominant technocentricism. Ecocentricism covers fields like deep ecology, critical history, ecofeminism, ecotheology, environmental humanities and posthumanism. From the above normative and operational level analysis therefore, the authors who exemplify ecocentricism include Shiva, Mehta, Edwards and Hussien amongst others.

5. Academic fields

Compiling the work of several authors, the website *enacademic.com* (see enacademic, 2020) identifies five main academic groups: humanities, social sciences, natural sciences, formal sciences, professions and applied sciences. Each academic group holds several sub-groups. In turn, each sub-group holds many academic fields each of which the authors describe in some detail. This paper referenced the groups, sub-groups and descriptions by *enacademic.com* to classify the main academic fields under the worldviews discussed above. This classification will form the horizontal dimension of the schema.

Natural and applied sciences fall in the positivist paradigm and technocentrism. They use scientific rationality, technocrats, bureaucrats and experts. Some social sciences (those that emphasise use of quantitative methods such as controlled experiments and statistics) are also included here. Together, these fields are responsible for engineering water infrastructure: designing, constructing, maintaining, managing it. They also include applied sciences such as health sciences and agricultural sciences. Multilateral organisations such as the World Bank and a range of United Nations subsidiaries use methods of the natural and social sciences..

Humanities arguably fall in the naturalist and emancipatory worldview. Together with the critical fields in social sciences, humanities problematise water discourse through historical and socio-cultural lenses and structures of class and power. Together with civil society, they engage in politics through building societal movements and grassroots democracy. Particular types of fine arts and literature viscerally reveal underlying social and environmental injustices.

Spatial design fields such landscape design, architecture, urban design and planning straddle both scientific rationalism and the humanities. As creative fields, they offer visions of sustainable bioregions, water sensitive cities and liveable neighbourhoods.

Locating the academic fields under their respective worldviews defines the horizontal dimension of the research outline.

6. Outline Schema for Water Research

The above vertical dimension (see section 3.6) and academic fields in the horizontal dimension are brought together to yield a high-level outline for water research.

See Figure 1 below.

A single cell in the in the schema below is a well-focused water research area that relates to a specific field of study or practice. Any vertical column in the outlined schema defines a range of possible areas for disciplinary research. Any horizontal row in the schema draws focus to a single water issue around which an IDTD team can be mobilised by drawing competencies from relevant academic and societal partners along that row. Finally, choosing several cells from the schema without being constrained by cell adjacency or vertical and horizontal alignment enables formation of purposive IDTD networked research spanning a diversity of knowledge areas deemed relevant to address a unique wicked water problem.

	Naturalist and Emancipatory Worldviews Ecocentrism						Positivist Worldviews Science Rationality Technocentrism					
	Informal sector	Poor households	Civil society	Humanities	Law		Social Sciences	Governments, Multilaterals etc	Private sector & societal elites	Engineering	Applied Sciences	Pure sciences
Problem: Water Scarcity assessment (a metric e.g. Falkenmark Index)												
Assess/ classify overall water scarcity												
≥1700 m3 per capita per annum: water secure												
≤ 1700m3 ppa: water stressed												
≤ 1000m: physical water scarcity												
≤ 500m3 Absolute water scarcity												
Assess and describe seasonal availability [episodic water scarcity]												
Flooding (overabundance)												
Drought												
Assess and describe economic water scarcity												
Households and firms												
Industry												
Agriculture												
Drivers of water scarcity												
Natural drivers												
Seasonal variation												
Climate change												
Other												
Anthropogenic drivers												
Supply constraints												
Infrastructure and technology												
Governance and Institutional capacity												
Capital (finance)												
Poverty (supply constraint)												
Demand pressures												
Population growth												
Increasing standards of living												
Water wasteful habits												
Mitigation												
Set performance targets												
Human water requirements												
Households and commercial												
Industry and energy sector												
Agriculture												
Environmental water requirements												
Pristine												
Moderate												
Poor												
Irredeemable												
Preserve, enhance, connect nature in the city												
Solutions and innovations												
Tech and infrastructure												
Governance and Institution												
Capital (finance solutions)												
Economic measures (e.g. Subsidy for poor (social justice)												
Subsidies												
Tariffs												
Environmental protection and enhancement												
Freshwater ecosystems												
Sustain drainage systems												
Catchment health												
Circular economy (for water recycling)												
Domestic (municipal = hh and firms)												
Industrial												
Agricultural												
Build resilience (vs episodic shocks & enduring pressures)												
Tap multiple water sources												
Enhance disaster prepared												
Behaviour change												
etc												
Adaptation of infrastion												
Disaster preparedness												
Problem: Water pollution (prevalence and effects)												
In freshwater ecosystems												
In society												
Drivers of water pollution												
Poor sanitation in households and firms												
Untreated effluent from industry												
Organics and nutrients from agriculture												
Mitigate pollution												
Set performance targets												
Improve Sanitation												
Treat industrial waste												
Solutions for agricultural pollution												
	Spatial design fields (e.g. architecture, urban design and planning)											

Figure 1: Outline Schema for Water Research

7. Discussion and Conclusion

Water supply is a contemporary global challenge with multiple options for disciplinary, interdisciplinary and transdisciplinary research. But there is no generic outline schema for articulating the specificities and overlaps between the different research directions. Through a rigorous review of existing water-related scholarship, this paper outlines a schema that hinges on societal and environmental water scarcity to delineate a range of research options that cover such aspects as drivers of water problems, solutions and innovations to mitigate scarcity and build resilience. The schema allows positioning of disciplinary, interdisciplinary and transdisciplinary research. This allows an individual or a team of researchers to locate their work vis-à-vis other studies and to identify complementary efforts and synergies. This therefore allows quick scoping, positioning and prioritization of research endeavors while also allowing researchers to avoid unnecessary duplication. This can facilitate collaboration and is hence valuable for accretional bottom-up coalescing of scattered study endeavors into a networked interdisciplinary research program. Moreover, the schema can be used to reflect on the current state of the art – for example as an aid in articulating knowledge gaps for future research. At a broader level, the outlined schema can allow an interdisciplinary institute to be critically reflexive about its work and assess whether it is comprehensive in scope and appropriate in focus. It can be used to map existing areas of interest within a diverse interdisciplinary institute. Such a map would make explicit the convergences and divergences of the interests of various people involved and thus be a useful aid to the framing of new IDTD research endeavors. Such an exercise can also illuminate the sorts of knowledge streams that are missing and needed to strengthen interdisciplinary research. At a national level, this can be useful in mapping the state-of-art in water research to identify what is being over-researched and where critical gaps exist, and to come up with measures to address any such asymmetries. This enables research managers to critically assess the field of water research nationally to identify and focus resources where they are most needed. Moreover, the outlined schema can be a useful tool in the setting up of a national center of excellence in water research that bring together existing relevant expertise from several universities to undertake highly relevant IDTD water-related research that cannot be executed within the confines of a single institution.

Water research is pulled by the enduring tension between the environment and development. This tension is mirrored in positivist scientific rationalism on one hand and naturalist and emancipatory worldviews on the other. The schema outlined here locates different academic fields within these worldviews. A significant value of the outlined schema is that it readily highlights that, although various strands of discourse may be underpinned by different assumptions and languages, they all essentially focus on the same issues highlighted in the vertical dimension. Whereas the dominant scientific approaches can be charged with the ills of modernism, their version of sustainability begins to define interfaces with naturalist and emancipatory paradigms. These interfaces may be manipulated to neutralize criticism and sustain the status quo. But they may also well be used to bridge across the paradigmatic differences. It is by engaging in these interfaces that critical scholars and practitioners can work with scientists to see past the watershed to the problem-shed beyond.

References

Abell, R., Vigerstol, K., Higgins, J., Kang, S., Karres, N., Lehner, B., ... & Chapin, E. (2019). Freshwater biodiversity conservation through source water protection: Quantifying the potential and addressing the challenges. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *29*(7), 1022-1038.

Addams, L., Boccaletti, G., Kerlin, M., & Stuchtey, M. (2009). Charting our water future: economic frameworks to inform decision-making. *McKinsey & Company, New York*.

Akhmouch, A., & Clavreul, D. (2016). Stakeholder engagement for inclusive water governance:"Practicing what we preach" with the OECD water governance initiative. *Water*, *8*(5), 204.

De Amorim, W. S., Valduga, I. B., Ribeiro, J. M. P., Williamson, V. G., Krauser, G. E., Magtoto, M. K., & de Andrade, J. B. S. O. (2018). The nexus between water, energy, and food in the context of the global risks: An analysis of the interactions between food, water, and energy security. *Environmental Impact Assessment Review*, *72*, 1-11.

Arnell, N. W. (1999). Climate change and global water resources. *Global environmental change*, *9*, S31-S49.

Becker, E. (2006). Problem transformations in transdisciplinary research. Unity of knowledge in transdisciplinary research for sustainability. Encyclopedia of Life Support Systems (EOLSS) Publishers, Oxford, UK. Available online at: http://www. eolss. net/Sample-Chapters C, 4.

Brears, R. C. (2018). Blue-Green Infrastructure in Managing Urban Water Resources. In *Blue and Green Cities* (pp. 43-61). Springer.

Carden, K., Armitage, N., Fisher-Jeffes, L., Winter, K., Mauck, B., Sanya, T., et al. (2018). Challenges and opportunities for implementing Water Sensitive Design in South Africa.

Centers for Disease Control and Prevention. (2015). Diarrhea: Common illness, global killer. *USA: Department of Health and Human Services*.

Centre for Research on the Epidemiology of Disasters [CRED] (2017) Disaster Data: A balanced perspective: Floods: Issue No. 48 "Disaster Data: A Balanced Perspective" September 2017.

Chapagain, A.K. and Hoekstra, A.Y., (2004). Water footprints of nations.

Cisneros, J., BE, T.O., Arnell, N.W., Benito, G., Cogley, J.G., Döll, P., Jiang, T., Mwakalila, S.S., Fischer, T., Gerten, D. and Hock, R. (2014). Freshwater resources.

Conforti, P. (2011). *Looking ahead in world food and agriculture: perspectives to 2050*. Food and Agriculture Organization of the United Nations (FAO).

Connor, R., Renata, A., Ortigara, C., Koncagül, E., Uhlenbrook, S., Lamizana-Diallo, B. M., ... & Hendry, S. (2017). The United Nations world water development report 2017. Wastewater: The untapped resource. *The United Nations World Water Development Report*.

Costanza, R., De Groot, R., Sutton, P., Van der Ploeg, S., Anderson, S. J., Kubiszewski, I., ... & Turner, R. K. (2014). Changes in the global value of ecosystem services. *Global environmental change*, *26*, 152-158.

Coutts, A. M., Tapper, N. J., Beringer, J., Loughnan, M., & Demuzere, M. (2013). Watering our cities: The capacity for Water Sensitive Urban Design to support urban cooling and improve human thermal comfort in the Australian context. *Progress in Physical Geography*, *37*(1), 2-28.

Donofrio, J., Kuhn, Y., McWalter, K., & Winsor, M. (2009). Water-sensitive urban design: An emerging model in sustainable design and comprehensive water-cycle management. *Environmental Practice*, *11*(3), 179-189.

Dryzek, J. S. (2013). The politics of the earth: Environmental discourses. Oxford university press.

Edwards, G. A. (2013). Shifting constructions of scarcity and the neoliberalization of Australian water governance. *Environment and Planning A*, *45*(8), 1873-1890.

enacademic : List of academic disciplines. https://enacademic.com/dic.nsf/enwiki/152269 [Accessed Dec 2020]

Escobar, A. (1996) Constructing Nature. Elements for a Poststructural Political Ecology. In R. Peet and M. Watts (eds) *Liberation Ecologies. Environment, Development* (p. 46-68),

Falkenmark, M., Lundqvist, J., & Widstrand, C. (1989, November). Macro-scale water scarcity requires micro-scale approaches: Aspects of vulnerability in semi-arid development. In *Natural resources forum* (Vol. 13, No. 4, pp. 258-267). Oxford, UK: Blackwell Publishing Ltd.

Food and Agriculture Organization of the United Nations [FAO] (2016). AQUASTAT Retrieved March 17, 2020 from http://www.fao.org/nr/water/aquastat/water_use/index.stm

Gleick, P. H. (2003). Global freshwater resources: soft-path solutions for the 21st century. *Science*, *302*(5650), 1524-1528.

Gough, S., Scott, W., & Stables, A. (2000). Beyond O'Riordan: balancing anthropocentrism and ecocentrism. *International Research in Geographical and Environmental Education*, *9*(1), 36-47.

Groat, L., & Wang, D. (2002). Systems of Inquiry and standards of research quality. *Architectural Research Methods*, 21-43.

Guppy, L., & Anderson, K. (2017). Global Water Crisis: The facts. Hamilton, UNU-INWEH.

Hoekstra, A. Y. (2003). Virtual water: An introduction. *Virtual water trade*, *13*.

Hou, J., Spencer, B., Way, T., & Yocom, K. (Eds.). (2014). *Now urbanism: The future city is here*. Routledge.

Howe, C., & Mitchell, C. (Eds.). (2011). *Water sensitive cities*. IWa Publishing.

Hussein, H. (2017). Politics of the Dead Sea Canal: A historical review of the evolving discourses, interests, and plans. *Water International*, *42*(5), 527-542.

Hussein, H. (2017b). Whose 'reality'? Discourses and hydropolitics along the Yarmouk River. Contemporary Levant, 2(2), 103-115.

Hussein, H. (2018). Lifting the veil: Unpacking the discourse of water scarcity in Jordan. *Environmental Science & Policy*, *89*, 385-392.

Hussein, H. (2018). Tomatoes, tribes, bananas, and businessmen: An analysis of the shadow state and of the politics of water in Jordan. *Environmental Science & Policy*, *84*, 170-176.

Ide, T. (2016). Critical geopolitics and school textbooks: The case of environment-conflict links in Germany. *Political Geography*, *55*, 60-71.

International Water Management Institute [IWMI]. IWMI Strategy 2019-2023: Innovative water solutions for sustainable development (Food, Climate, Growth). Colombo, Sri Lanka:.

Karr, J. R., & Dudley, D. R. (1981). Ecological perspective on water quality goals. *Environmental management*, *5*(1), 55-68.

Kuylenstierna, J., Najlis, P., & Björklund, G. (1998). The comprehensive assessment of the freshwater resources of the world-policy options for an integrated sustainable water future. *Water International*, *23*(1), 17-20.

Langhelle, O. (2000). Why ecological modernization and sustainable development should not be conflated. *Journal of environmental policy and planning*, *2*(4), 303-322.

Liemberger, R., & Wyatt, A. (2019). Quantifying the global non-revenue water problem. *Water Supply*, *19*(3), 831-837.

Mehta, L. (2001). The manufacture of popular perceptions of scarcity: Dams and water-related narratives in Gujarat, India. *World Development*, *29*(12), 2025-2041.

Mehta, L. (2003). Contexts and constructions of water scarcity. Economic and political weekly, 5066-5072. Stable URL: https://www.jstor.org/stable/4414344 Accessed: 17-12-2020

Mekonnen, M. M., & Hoekstra, A. Y. (2016). Four billion people facing severe water scarcity. *Science advances*, *2*(2), e1500323.

Naess, A. (1973). The shallow and the deep, long-range ecology movement. A summary. *Inquiry*, *16*(1-4), 95-100.

Naess, A. (1990). Ecology, community and lifestyle: outline of an ecosophy. Cambridge university press.

O'Farrell, P., Anderson, P., Culwick, C., Currie, P., Kavonic, J., McClure, A., ... & Audouin, M. (2019). Towards resilient African cities: Shared challenges and opportunities towards the retention and maintenance of ecological infrastructure. *Global Sustainability*, *2*.

O'Riordan, T. (1981). *Environmentalism* (Vol. 2). Taylor & Francis.

Pieterse, J. N. (1992). Empancipations, modern and postmodern. *Development and change*, *23*(3), 5-41.

Rijsberman, F. R. (2006). Water scarcity: fact or fiction?. *Agricultural water management*, *80*(1-3), 5-22. doi:10.1016/j.agwat.2005.07.001.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III, F. S., Lambin, E., ... & Nykvist, B. (2009). Planetary boundaries: exploring the safe operating space for humanity. *Ecology and society*, *14*(2).

Sharma, A., Gardner, T., & Begbie, D. (Eds.). (2018). Approaches to Water Sensitive Urban Design: Potential, Design, Ecological Health, Urban Greening, Economics, Policies, and Community Perceptions. Woodhead Publishing.

Shiklomanov, I. A. (1991). The world's water resources. In *International symposium to commemorate the* (Vol. 25, pp. 93-105).

Shiva, V. (2001) Water Wars. Privatisation, Pollution and Profit. Pluto Press, London.

Shiva, V. (2006, March). Resisting water privatisation, building water democracy. In *World Water Forum in Mexico*, http://www. globalternative. org/downloads/shiva-water. pdf (03.10. 2011).

Sisolak, J., & Spataro, K. (2011). Toward net zero water: best management practices for decentralized sourcing and treatment. Cascadia Green Building Council.

Smakhtin, V., Revenga, C., & Döll, P. (2004). A pilot global assessment of environmental water requirements and scarcity. *Water International*, *29*(3), 307-317.

Taing, L., Chang, C. C., Pan, S., & Armitage, N. P. (2019). Towards a water secure future: reflections on Cape Town's Day Zero crisis. *Urban Water Journal*, *16*(7), 530-536.

United Nations, Department of Economic and Social Affairs, Population Division (2019). *World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420)*. New York: United Nations.

United Nations (2015). Wastewater management-A UN-water analytical brief. New York.

United Nations (2017). *Sustainable Development Goals-17 goals to transform our world*. United Nations [Online]. Retrieved June 04, 2018 from https://www. un. org/sustainabledevelopment/energy/.

United Nations Educational Scientific and Cultural Organisation (UNESCO) (2020) *The United Nations World Water Development Report 2017: Wastewater the Untapped Resource*. United Nations Educational, Scientific and Cultural Organization (UNESCO), Paris. Retrieved from http://unesdoc.unesco.org/ images/0024/002471/247153e.pdf

United Nations International Children Fund [UNICEF] and World Health Organisation [WHO] (2015). *Progress on sanitation and drinking water: 2015 update and MDG assessment*: World Health Organization.

Vié, J. C., Hilton-Taylor, C., & Stuart, S. N. (Eds.). (2009). Wildlife in a changing world: an analysis of the 2008 IUCN Red List of threatened species. IUCN.

Vörösmarty, C. J., Green, P., Salisbury, J., & Lammers, R. B. (2000). Global water resources: vulnerability from climate change and population growth. *science*, *289*(5477), 284-288.

Vörösmarty, C. J., Osuna, V. R., Cak, A. D., Bhaduri, A., Bunn, S. E., Corsi, F., ... & Marcotullio, P. J. (2018). Ecosystem-based water security and the Sustainable Development Goals (SDGs). *Ecohydrology & Hydrobiology*, *18*(4), 317-333.

Webber, M. M., & Rittel, H. W. (1973). Dilemmas in a general theory of planning. *Policy sciences*, *4*(2), 155-169.

Weitz, N., Nilsson, M., & Davis, M. (2014). A nexus approach to the post-2015 agenda: Formulating integrated water, energy, and food SDGs. *SAIS Review of International Affairs*, *34*(2), 37-50.

Wolski, P. (2018). How severe is Cape Town's "Day Zero" drought?. *Significance*, *15*(2), 24-27.

Wong, T. H., & Brown, R. R. (2009). The water sensitive city: principles for practice. *Water science and technology*, *60*(3), 673-682.

Wong, T. H., & Eadie, M. L. (2000). Water sensitive urban design: a paradigm shift in urban design. In *10th World Water Congress: Water, the Worlds Most Important Resource* (p. 1281). International Water Resources Association.

World Economic Forum [WEF]. (2019). *The Global Risks Report 2019* (14th Edition). [Insight Report].

World Health Organisation [WHO] (2019a). *Factsheets*. Retrieved from https://www.who.int/news-room/fact-sheets/detail/drinking-water

World Health Organisation [WHO] (2019b). *Factsheets*. Retrieved from https://www.who.int/en/news-room/fact-sheets/detail/sanitation

Yorke, V. (2016). Jordan's shadow state and water management: prospects for water security will depend on politics and regional cooperation. In *Society-Water-Technology* (pp. 227-251). Springer, Cham.