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DE-STRESSING WATER-STRESSED INDIA: LESSONS FROM ANCIENT SCRIPTURES TO CONTEMPORARY MANAGEMENT PRACTICES

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Abstract: *Over the years, various scientific approaches have evolved in the domain of water resources management. The urge behind such evolution ensues from an impending concern before the society, where supply of the natural resource is grossly overwhelmed by its demand. Water scarcity, which is looming large in Indian context too, is not a single-dimensional phenomenon; it is a multi-layered "complex" system instead. Moreover, while designing the management policies for water resources, today's art of science tends to preclude ancient India's value-based principles. This review article attempts to explore two broad aspects as how to: (a) connect the contemporary scientific management regime with ancient India's spiritual interpretations, and (b) envisage various scarcity dimensions as a single-canvas representation. Thus, the present discourse signifies that while crafting policy-designs for sustainable water resources management, it is now imperative to recognize ancient India's value-based practices and consider all its scarcity-dimensions simultaneously. As a derivative of this contemplation, the article also paves the way for further research to investigate the appropriateness of bottom-up modeling frameworks, incorporating "local" values juxtaposed with various hydrological phenomena with in a spatial unit.*

Keywords: *Water Resources Management, Water Scarcity, Water Resources of India,Water in Ancient India*

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INTRODUCTION

The growing quantum of research on freshwater resources globally is a substantial indicator of emergence of an indisputable crisis in reality. India is no exception. In recent past, pronouncement of the Government of India (GOI) corroborates the impending concern before our society (NITI Aayog, 2018). It is, therefore, imperative and academically intriguing to delve deep into the fundamental issue of water scarcity in a meticulous manner. In Indian perspective, the soul of water is deep-rooted in her ancient epistemology, where the motivation to preserve the natural resource lies in recognizing the need for striking balance between ecology

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and mankind (Krishnamurthy, 1996). This ancient envision is primarily based on the tenet of conserving water through the notion of sacrality associated with it (Joshi and Fawcett, 2001). The contemporary management philosophies, however, often fail to recognize the relationship that exists between nature and her resources on the one hand and the people with their organically evolved value systems on the other, the relevance of which is colossal while configuring policy designs to protect natural resources and all its users (Verschuuren, 2007).

The phenomenon of water scarcity is multi-dimensional, comprising the entire biophysical and socio-economic processes. The broad dimensions include hydrological and institutional scarcities, quality-induced water scarcity, scarcity arising out of inter sectoral competition and inter-dependence. Various approaches to manage water resources are established in literatures, viz. integrated water management, adaptive water management and management from water-integrated perspective (Hoekstra et al., 2018). Broadly speaking, these philosophies are instituted on the fundamental notions of welfare, equity, sustainability and risk; each being a reference to and corroboration of an impending concern (Hoekstra et al., 2018). The present review aims to investigate various dimensions of water scarcity within a single canvas, without precluding India's ancient values.

The paper commences with recounting the essence of water resources of ancient India, and attempts to explore the epistemology of science embedded in the ancient philosophy. Next, various dimensions of today's water scarcity are critically discussed along with pertinent statistics and a variety of academic analyses. Various theories on water resources management are discussed subsequently with special emphasis on how the contemporary management tenets may be reconciled with the ancient Indian doctrine. The last section talks about a possible single-canvas representation of a complex system, portraying interactions between various elements in the water resource system at local level. This review article creates scope for further research to explore suitability of bottom-up modeling frameworks, powerful enough to capture local value-based social explanations in conjunction with hydrological phenomena.

MANAGING WATER RESOURCES IN INDIA: AN ANCIENT PERSPECTIVE

The contemporary scientific knowledge on water resources management primarily hovers around its geophysical existence with respect to human civilization, trillions of organisms and other fundamental resources of this planet. In contrast to this denomination of science, ancient Hinduism conceives water much beyond its mere physical form. Hinduism, as a way of life, portrays water as one of the five elemental spiritual emblems (*panchabhoota*), connecting the resource to the eternal universe. In one of their conference papers, Joshi and Fawcett (2001) illustrate the following mythological facets of water as derived from ancient Hinduism:

(a) *Apah*, the Vedic Sanskrit term for water, is considered to be *pratishtha*, the fundamental basis of this universe (*Shatapatha Brahmana*).

(b) Vedic philosophy confers a sanctified disposition on water, which is essentially conceived as spiritual, rather than physical. In quest of attaining eternity, the process of using water in daily life as well as in ritualistic ceremonies is connoted as a spiritual forfeit *(Atharva Veda)*.

(c) Early Vedic texts recognize water as *Sakti*, a feminine manifestation, where from *Purusa*, the primordial cosmic man is born (*Rig Veda*).

(d) In a social mechanism involving caste system, which is majorly a post-Vedic artifact and which crafts a socially stratified system based on caste-based occupations and gender, water is observed to play an instrumental role in purifying all forms of perceived impurities (*Rig Veda*).

As per Hindu belief, the river Ganges (or *Ganga*) is an imperative force for life on this earth. In Indian context, water of the *Ganga* (or *Gangeya*, as mentioned in early literatures) is portrayed as "liquid spirit of sustainability" (*Rig Veda*), or "universal form of supreme Lord Vishnu" (*Padma Purana*). This all-pervading manifestation of the river *Ganga*, bestowing her mythical power upon the life of Indians, is termed as "*Gangaisation*" (Singh, 1987). Over the years, religious practices and daily activities following these mythological beliefs are deciphered into traditions, establishing a "common chain of interrelationship between the river and human society", and thereby, conserving the "intrinsic value of sustainability" (Singh, 2017).

Embedded in this spiritual interpretation of water is the art of science. Ancient and medieval Sanskrit literatures carry substantial evidences to support the fact that ancient Indians classify water into various categories; their physical and chemical properties, and hence, various qualities are explored extensively; and last but not least, the scientific knowledge of treatment of polluted water before various usages is not hard to come by (Krishnamurthy, 1996). It is quite intriguing to come across remarkable hydrologic references in Indian mythology; most of them are well documented and provide knowledge about the early development of water sciences in India (Mujumdar and Jain, 2018). These references support the fact that hydrological knowledge generated by Indians has a vintage of more than 5000 years. For example, the science of hydrologic cycle is appropriately captured in one of the verses of the *RigVeda*. Scientific measurements of natural phenomena like precipitation, groundwater, stream-flow and evapotranspiration find explicit mentions in an anthology of mythological literature (NIH, 1990). The archeological evidence found in the ruins of Mohen-jo-daro, the Indus valley metropolis dating back about 2500 BC, is possibly the oldest historical footprint indicating the existence of scientific approach towards water resources management, viz. provisions of water supply for domestic and irrigational purposes, drainage systems, places for public bath and walls for protecting the city from floods. Around 300 BC, Kautilya's *Arthashastra* (the science of politics) refers to rainfall measurements in a scientific way and suggests using such data to provide relief to the rural farmers. Of course, *Krishi-Parashara*, the ancient text between 6th century AD and 11th century AD, deals with meteorological influence on agriculture and measurements of precipitation in much greater detail. *Meghadūta*, the epic by Kalidasa around the 7th century, vividly describes monsoon. Archaeologists confirm that dams are constructed as early as 5th century AD (Sutcliffe et al., 2011). It is quite an established fact that scientific knowledge of water harvesting systems is testimony to the prevalence of a highly specialized surface and groundwater management regime prevalent in ancient India (Krishnamurthy, 1996). Such primordial instances of advanced hydrologic science are numerous and too wide to be captured in a single document.

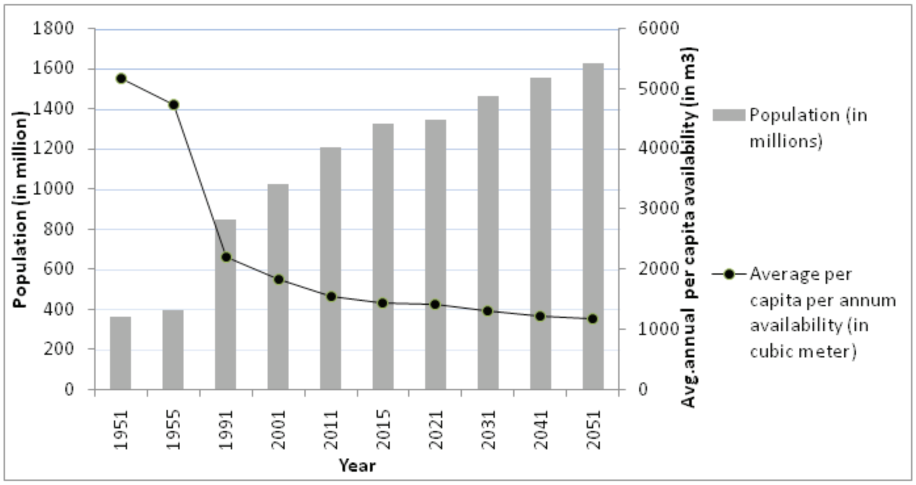
HYDROLOGICAL SCARCITY

Measuring Availability by Malthusian Logic

While the ancient envision is primarily founded on the tenet of conservation of water resources through the associated notion of sacrality, the essence of the contemporary literatures on the subject lies in the acknowledgement of the need for such conservation and revival in the face of an exponentially growing population and dwindling water availability. The primary concept of water scarcity, often having a precursor measurement, called "water-stress", may be conceived as a situation when the supply of renewable freshwater resources falls short of demand by all its users under an institutional set-up. According to the Falkenmark Water Stress Index (WSI) thresholds based on population-water equation, an annual per-capita availability lower than 1700 cubic meters is designated as "water-stress" situation, while the same measure below 1000 cubic meters indicates "water-scarce" condition (Damkjaer and Taylor, 2017).

According to the 2011 Census, India with a staggering 1.2 billon population, which approximately constitutes sixteen percent of the global population, possesses a meager four percent of freshwater resources of the earth (Prakash et al., 2013). An estimated projection indicates that the country's average annual per-capita availability of water is dwindling drastically, obviating the fact that the country is proceeding towards a water-scarce condition (Figure 1).

Figure 1 Average Annual per capita Water Availability Trend in India



Source:MoSPI, GOI, 2018

The "utilizable water resources" is also estimated as 1122 billion cubic meters (BCM), implying an availability of 48.8 percent of India's available water resources (Gupta and Deshpande, 2004). Narasimhan (2008), as cited by Prakash et al.(2013), estimates the utilizable water resources in India as low as 654 BCM, and explains the discrepancy by attributing it to a higher evapotranspiration rate of 65 percent instead of the lower denomination of 40 percent as used in the official estimate, implying a much more alarming condition of water availability for human consumption. It is only in the recent past that GOI, while introducing Composite Water Management Index (CWMI), underlines the bare fact that India is facing "the worst water crisis in its history" (NITI Aayog, 2018).

Temporal and Spatial Variations

It is often argued that the above measurements are national representations at the aggregate level leading to both over- and under-estimations, as variations in the water-resource distribution in the country are too divergent both on temporal and spatial scales. Such macro measurement, therefore, fails to serve as an employable indicator for policy formulations at local level. Average annual potential of water resources in the country is estimated at 1869 BCM, of which 690 BCM constitute the surface water, supplied from rivers and other inland water resources (Table1).

Table 1 Water Resources Potential in India across River-basins

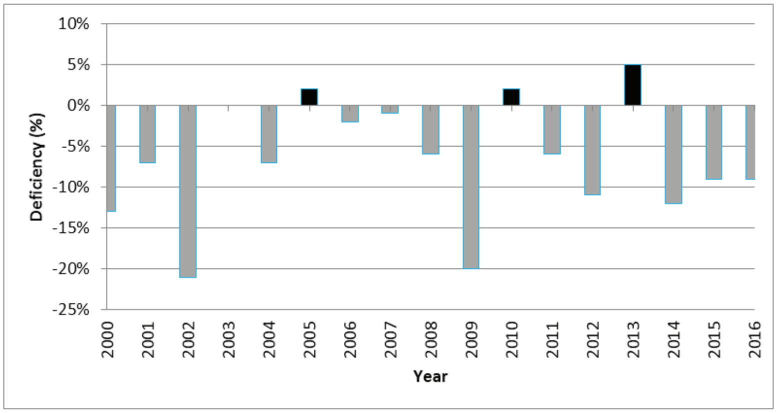
Basin	Catchment area (sq. km.)	Water resource potential (BCM)	Utilizable surface water resources (BCM)
Indus	321,289.0	73.3	46.0
Ganga-Brahmaputra-Meghna	1,097,588.0	1,110.6	274.0
Godavari	312,812.0	110.5	76.3
Krishna	258,948.0	78.1	58.0
Cauvery	81,155.0	21.4	19.0
Subernarekha	29,196.0	12.4	6.8
Brahmani-Baitarani	51,822.0	28.5	18.3
Mahanadi	141,589.0	66.9	50.0
Pennar	55,213.0	6.3	6.9
Mahi	34,842.0	11.0	3.1
Sabarmati	21,674.0	3.8	1.9
Narmada	98,796.0	45.6	34.5
Tapi	65,145.0	14.9	14.5
Others	796,869.0	286.0	80.8
Total	3,366,938.0	1,869.4	690.1

Source: MoSPI, GOI, 2018

It is quite intriguing to observe that 59 percent of India's water resources potential lie in a single river basin, viz. Ganga-Brahmaputra-Meghna, comprising only 33 percent of the total catchment areas. In the early seventies, this spatial skewness remains the point of departure for enunciation of the debate over forming a national water-grid through inter-basin water connections (Prakash et al., 2013).

Monsoon rain is the principal supply source for groundwater recharge. But, India witnesses nearly 70-90 percent of annual precipitation caused by southwest Monsoon, confined primarily during the months of June to September (Lacombe and McCartney, 2014). Along with that, there exists a sharp contrast on spatial scale too, which is substantiated by the volume of rainfall received by the north-eastern states vis-à-vis the desert-bound north-western part of the country. This phenomenon of spatio-temporal variations is further exacerbated by the critical fact that there is a continually deficient monsoon from the normal level observed since the year 2000, except for the years 2005, 2010 and 2013 (Figure 2).

Figure 2 Year-wise Percentage Deviations from Normal Rainfall in India



Source: MoSPI, GOI, 2018

Groundwater Dynamics

The proportion of groundwater recharge to draft on an annual scale, termed as stage of groundwater development (SOD), is a critical indicator of stress on the groundwater resources, and is estimated around 63 percent for the country as a whole (CGWB, 2019). However, the SOD itself is subject to spatio-temporal variations because of different aquifer potentials across the country, their different recharge capabilities and varying degree of groundwater exploitations (Saha et al., 2017). According to the 2010-11 Agriculture Census, India's agricultural practices come out as the largest exploiter of groundwater resources in the world, and approximately 63.63 percent (45.17 percent through tube-wells and 18.46 percent through wells) of country's net irrigated area is dependent on groundwater (MoSPI, 2018). This unsustainable extraction of groundwater (Table 2) not only adds to its scarcity by lowering the groundwater table, but also allows intrusion of saline water in many areas of the country (Prakash et al., 2013).

Table 2 Availability and Utilization of Groundwater Resources (BCM)

Year	2004	2009	2013
Annual replenishable groundwater resource	433	431	446.9
Natural discharge during non-monsoon season	33.77	35.03	35.56
Net annual groundwater availability	399.25	396.00	411.3
Annual groundwater draft: irrigation	212.50	221.4	228.30
Annual groundwater draft: domestic & industrial uses	18.10	21.89	24.76
Total annual groundwater draft	230.60	243.31	253.06
Stage of Groundwater Development (%)	58%	61%	62%

Source: Ground Water Year Book, India; 2009-2010; 2011-12; 2016-17

INSTITUTIONAL SCARCITY

Necessary Accessibility and Sufficient Service Delivery

The notion of "hydrological scarcity" is primarily built on and driven by the lack of or rapid depletion of physical availability of water resources in the midst of exponentially growing population. Based on such Malthusian logic, administering advancements in terms of water infrastructures does not necessarily translate into a favorable and impactful result on the state of institutional phenomena like differentiated access conditions based on social, economic and political marginalities (Shah and Narain, 2019). According to the WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply, Sanitation and Hygiene (WASH) (UNICEF and WHO, 2019), basic drinking water coverage is reported to have expanded from 82 to 92 percent at the global level over the period 2000-2017.

Table 3 depicts the percentage composition of population with accessibility to various sources of drinking water with respect to the dwelling premise both for rural and urban India. It is quite evident that over the years, while disparities in water supply between urban and rural India have reduced significantly, the advancement in piped water-supply infrastructures reveals a downward slip, arguably because of slower pace of infrastructural expansion in the face of exponentially growing population.

Table 3 Percentage Composition of Population with Drinking Water Accessibility in India

	Rural		Urban	
	2000	2017	2000	2017
Available within premises	20	56	68	77
Available on time	63	79	88	87
Piped supply	33	32	74	68
Non-piped supply	47	60	21	28

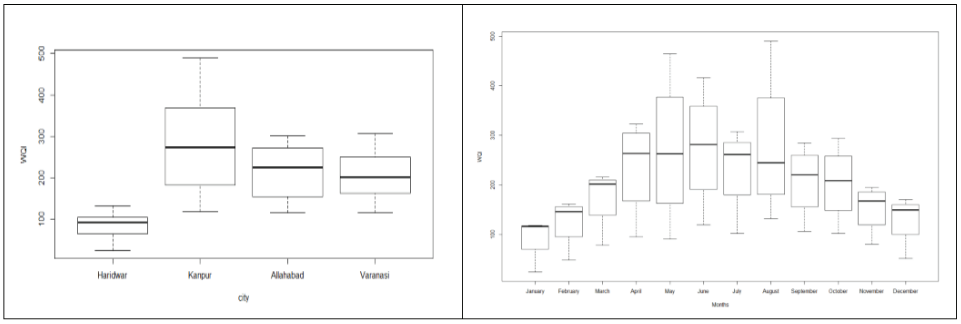
Source: UNICEF and WHO, 2019

QUALITY-INDUCED WATER SCARCITY

Polluted water, arising out of natural as well as anthropogenic factors, adds to water scarcity with varying degree of intensity both on spatial and temporal scales. Defined by multiple parametric assessments, a water quality index (WQI) is used as a measure to evaluate overall water quality. Ayub and Agarwal (2012) emphasize that the pollution generating from the untreated discharge of wastewater from domestic, industrial and municipal bodies, coupled with insufficient availability of rainwater for dilution of the pollutants, lead to increased level of biochemical oxygen demand (BOD) both on spatial and temporal scales, particularly in urban areas of the country. In India, the urban wastewater treatment capacity stands at a meager 31 percent as per the report published by Central Pollution Control Board (CPCB) in 2008 (Murty and Kumar, 2011). The authors also point out that approximately 70 percent of surface water and a substantial portion of groundwater are polluted in India.

Kumar et al. (2015) demonstrate multivariate statistical techniques to capture intra-annual variations in the average WQI of the river Ganges at different locations along its course for the year 2013-14. The study finds that as the river flows down from the upper course at Hardwar towards Varanasi, degradation of water quality near the industrial city of Kanpur can be attributed to inefficiently treated effluents discharged from the industrial units, tanneries particularly, situated on the bank of the Ganges. Also, on temporal scale, pollution levels can be seen as low during winter as compared to the summer season (Figure 3).

Figure 3 Spatial and Temporal Variations in Average WQI of the Ganges



Source: Kumar et al., 2015

Source-wise spatial variations in groundwater quality across Indian states in terms of intensity of pollution are captured in Romani's work cited by Garduño et al. (2011). Based on their report, anthropogenic and geogenic contaminations are predominant in India, and are present approximately over all the four regions of the country.

INTERSECTORAL COMPETITION AND INTERDEPENDENCE

Competition versus Nexus

Demand is originated for the scarce fundamental resource from different competing claimants. India, as a growing and diversified economy, also witnesses demands for freshwater from various sectors (Table 4).With agricultural sector accounting for the biggest water withdrawals, mounting pressures from other sectors over the years denote the severity in intersectoral competition impelled by the growing economic activities. Again, incremental losses due to evaporation are indicative of changes in the climatic condition on temporal scale.

Table 4 Composition and Trend of Intersectoral Demand for Water (in BCM)

Sector	2010	2025	2050
Irrigation	557	611	807
Industries	43	62	111
Domestic	37	67	81
Power	19	33	70
Inland Navigation	7	10	15
Environment	5	10	20
Evaporation Losses	42	50	76
Total Demand	710	843	1180

Source: MoSPI, GOI, 2018

The third version of National Water Policy (NWP) documented in 2012 (after NWP, 1987 and NWP, 2002) by the Ministry of Water Resources (MoWR) of GOI, includes "minimum" ecological needs, water for drinking and sanitation along with other non-potable domestic requirements, and food-security driven irrigation towards sustainable agriculture also remains "high priority" claimants for receiving water allocation. A judicious trade-off between these competing sources of water demand must be achieved based on "equity and social justice" (MoWR, 2012)to avoid the risk of deepening water scarcity. Narain (2014) suggests that peri-urban or urban water supply contexts must not be treated in isolation, but integrating the stakeholders from both the regions in planning and decision making processes is vital for equity and sustainability.

While water, as a fundamental resource, has many competing origins of demand, water resource system itself is connected to other global resource systems, viz. food and energy. This relatively freshly brewed view of the phenomenon has gained popularity in academia under the nomenclature of water-energy-food (WEF) nexus. Water is needed for agriculture, while energy is required to channelize required water from various sources to the destinations. Barik et al. (2017) observe that increased population pressure along with a declining trend in monsoon lead to an intensive irrigation regime primarily abstracting groundwater, resulting into more electricity consumption.

MANAGING SCARCE WATER RESOURCES: DIFFERENT PHILOSOPHIES

Contemporary Philosophies

The essence of managing water resources evolves through various philosophies over time. This section discusses the emergence of three such concepts, each being structurally overlapped with other to a great extent.

The first concept, introduced during the mid-eighties, is integrated water resources management (IWRM),which talks about focusing on the whole of water systems, from surface water to groundwater, both quantitatively and qualitatively. The philosophy, as conceived by Global Water Partnership (GWP), encompasses: (i) a synchronized progress of water, land and associated resources, (ii) maximization of welfare, both economic and social, (iii) equitability, and (iv) environmental sustainability (Ait-Kadi and Lincklaen Arriëns, 2000). The expression "IWRM package", as summarized by Shah and Koppen (2006), comprises: (i) drafting water policy at national level, (ii) defining framework to regulate water, (iii) recognizing river basin as the hydrological unit, (iv) treating water as an economic good, (v) establishing water rights, and (vi) institutionalizing participatory approach and inclusiveness in water resources management. Harsha (2012), while examining integrated river basin management (IRBM) as part of IWRM, remains critical about too many overlapping and contradicting policies from too many authorities simultaneously. The discourse of IWRM is severely criticized primarily because it appears too sophisticated to be appropriate for Indian context.

The second philosophy of adaptive water resources management is evolved purely out of the dire necessity to adapt to and adjusting with changing climatic needs continuously, while retaining flexibility to respond swiftly to such changing eco-system (Hoekstra et al., 2018). Jain (2012) emphasizes on the risk of climate change, calling for a focus on sustainability while managing water resources in India. The author stipulates that effective adaptive measures should include: (a) water pricing for all sectors, (b) demand management initiatives with emphasis on usage efficiency, (c) water conservations, reuse, desalination and waste-water treatment, (d) drought management measures at river-basin scale, (e) prohibition to illegal water use, and (f) public awareness.

Finally, the third philosophy of water-integrated approach entails the use of water as a resource in conjunction with food and energy, redefining a new narrative for water security (Hoekstra et al., 2018). The concept emerges in the 2011 Bonn Nexus Conference in the backdrop of rapidly changing climatic and socio-economic patterns. The nexus philosophy creates cooperation and synergies between multiple sectors and paves the way for adopting a multi-disciplinary approach (Allan, 2003). The recommendations given by Bhaduri et al. (2015)for adoption of nexus approach and its sustainability include: (a) responsible governance, (b) stakeholders' participation and collaboration, and (c) expansion of organizational, technological and financial base to develop the nexus phenomenon at various scales.

Development versus Risk Focus

Hoekstra et al. (2018) classifies the entire array of literature on water resources management into four premises, each being a reference to and corroboration of an impending concern. While the dimensions of welfare, equity and sustainability constitute the "development" focus of water security, the "risk" focus, in contrast, aims at insulating the society from vulnerabilities on account of climate change and water-related hazards.

According to the author, while the notion "economic welfare" can be defined quantifiably, the broader connotation of the term, encompassing all ecological and social values of welfare, is hard to comprehend.

The second premise speaks about the inclusion of social equity, the tenet that remains unanswered in an overall welfare metric. Equity facet answers how benefits are percolated down to all the users, including the poor in a society, usually deprived of the fundamental natural resources in the midst of a severe scarcity. According to Tyagi et al. (2018), equity does not necessarily imply equal distribution, but more importantly, it connotes an "equal opportunity paradigm".

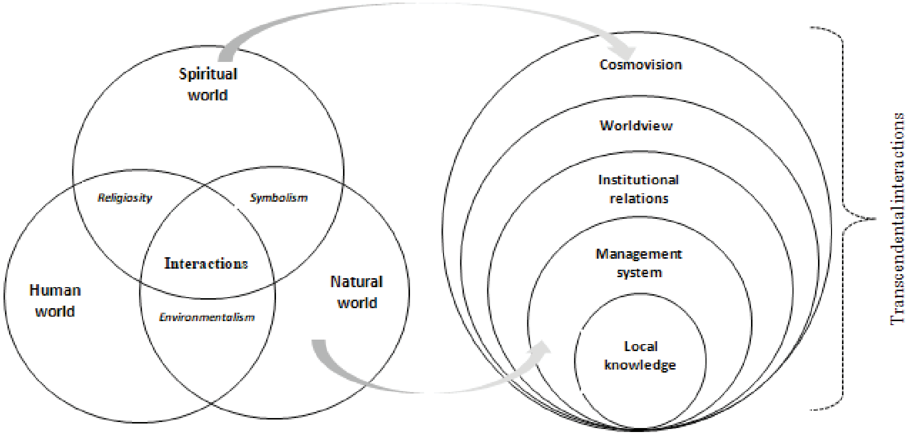
Achieving long-term sustainability is the third motif which refers to the measurement of water availability in terms of its welfare-theoretic contribution over time scale. Gained popularity during the nineties, the philosophy of sustainability is designed to ensure that the present requirements are fulfilled "without compromising the ability of future generations to meet their own needs" (WCED, 1987).

The fourth premise is the inclusion of risks in welfare metrics, which fundamentally remains challenging as risks generally tend to include huge uncertainties that are quite tricky to quantify. The risk focus is principally in sync with various operational dimensions of water resources management, and therefore, usually tends to ride on the subject expertise from engineering or economics (Hoekstra et al., 2018).

Reconciliation with India's Ancient Values

The epistemology pertaining to contemporary scientific (also called Cartesian) paradigm often faces trenchant criticisms for not being able to recognize the dotted line that connects the nature and her resources on the one hand and the people with their organically evolved value systems on the other. Perceiving nature and her resources is deeply influenced by "culturally defined value and belief systems that form an important, often inter generational, source of information" (Verschuuren, 2007). The present discourse coins these conceptual overlaps from the original works of Verschuuren (2007), as adopted by Singh (2017); the latter refers the spiritual linkages as "transcendental interactions" in the context of ecosystem management and conservation strategies (Figure 4).

Figure 4 Spiritual Linkages in Ecosystem Management and Conservation Strategies



Source: Verschuuren, 2007, as adopted by Singh, 2017

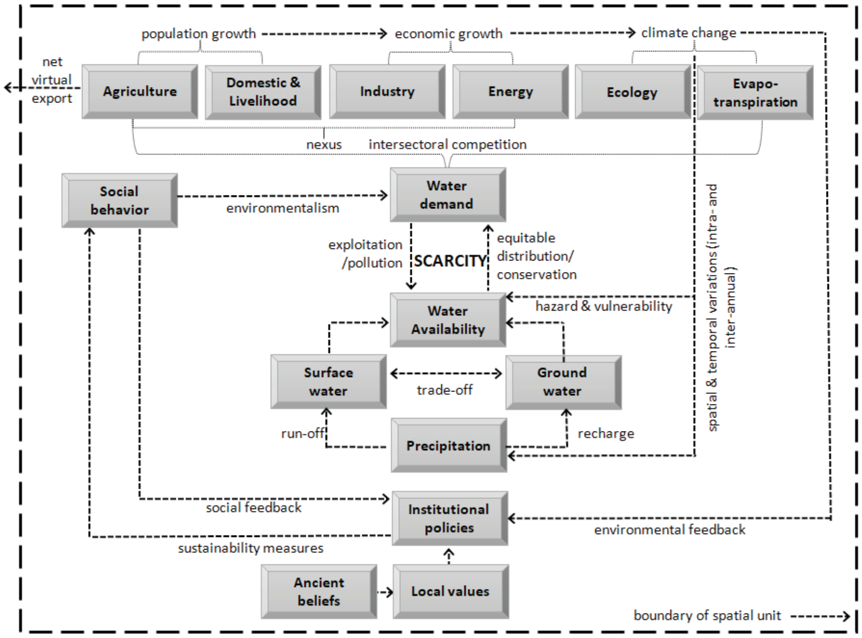
Any policy design to manage natural resources should recognize the "sense of place", a "world view" as an emblem of local ethos, and a connecting chord with the place called "genus loci", which is the origin of the word "sacred" (Shackley, 2001; Singh, 2017). India's biological, cultural and ecological diversities are attributed to her geographical vastness, coupled with the cultural vintage. It is, therefore, imperative to adopt a bottom-up approach while crafting the management principles for natural resources like water, i.e. starting from local levels where the societal values are deep-rooted, up to regional and national levels.

COMPLEX SYSTEM IN A SINGLE CANVAS

Critiques often argue that the phenomenon of water scarcity remains peevishly addressed if the whole gamut of water resources management is confined to comprehending the notion of scarcity only from the perspective of physical availability (Shah and Nara in, 2019). In fact, the notion of water scarcity is multi-layered, comprising all biophysical and socio-economic phenomena, and the fact that water is a scarce resource necessarily falls under the domain of what is known as "complex systems".

In a complex system, various elements at the local level interact with each other to give rise to a fairly deterministic "emergent" outcome at the global level (Wilensky and Rand, 2015). Water resources management is even more intriguing as challenge remains to embrace the complete range of water-human relationships, comprising aesthetic, perceptual, emotional and spiritual values (Burmil et al., 1999). The present discourse argues that water resources management can hardly be effective by addressing the causal components of scarcity individually; more importantly, it is critical to recognize how these causal elements interact with each other at any point of time to yield an emergent shape of scarcity on spatial and temporal scales (Figure 5).

Figure 5 Various Local Elements of a Complex Water Resource System Interacting in a Spatial Unit



CONCLUSION

The notion of water scarcity is multi-dimensional. India's ancient philosophy embeds the science of managing scarce water in the fold of its spiritual interpretation based on the belief of sacrality. The contemporary management philosophies, however, often ignore this ancient value system while configuring policy designs for the relationship that exists between the natural resource and all its users. The current review recognizes that the realm of water resource systems follows the dynamics of complex systems, wherein the local interactions between various elements pave the way for an overall emergent global pattern. This raises three significant queries as to how all the dimensions of scarcity can be integrated within a single canvas while designing policies. The first question is what modeling paradigm can be envisaged wherein all elemental levers are maneuvered simultaneously to arrive at some optimal scenarios as far as the scarce resource is concerned. Secondly, the modeling design should have the power to incarcerate local value-based social explanation along with the hydrological phenomena. The third important inquiry extends to the cognition of how these biophysical and socio-economic processes are integrated in the design of a bottom-up modeling framework. The present study, therefore, calls for a complete review of modeling frameworks in water resources management in order to de-stress our water-stressed country, and the world at large.

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SUPPLEMENTARY INFORMATION

I. Tables used in the article:

"DE-STRESSING WATER-STRESSED INDIA: LESSONS FROM ANCIENT SCRIPTURES TO CONTEMPORARY MANAGEMENT PRACTICES"

Table 1 Water Resources Potential in India across River-basins

Basin	Catchment area (sq. km.)	Water resource potential (BCM)	Utilizable surface water resources (BCM)
Indus	321,289.0	73.3	46.0
Ganga-Brahmaputra-Meghna	1,097,588.0	1,110.6	274.0
Godavari	312,812.0	110.5	76.3
Krishna	258,948.0	78.1	58.0
Cauvery	81,155.0	21.4	19.0
Subernarekha	29,196.0	12.4	6.8
Brahmani-Baitarani	51,822.0	28.5	18.3
Mahanadi	141,589.0	66.9	50.0
Pennar	55,213.0	6.3	6.9
Mahi	34,842.0	11.0	3.1
Sabarmati	21,674.0	3.8	1.9
Narmada	98,796.0	45.6	34.5
Tapi	65,145.0	14.9	14.5
Others	796,869.0	286.0	80.8
Total	3,366,938.0	1,869.4	690.1

Source: MoSPI, GOI, 2018

Table 2 Availability and Utilization of Groundwater Resources (BCM)

Year	2004	2009	2013
Annual replenishable groundwater resource	433	431	446.9
Natural discharge during non-monsoon season	33.77	35.03	35.56
Net annual groundwater availability	399.25	396.00	411.3
Annual groundwater draft: irrigation	212.50	221.4	228.30
Annual groundwater draft: domestic & industrial uses	18.10	21.89	24.76
Total annual groundwater draft	230.60	243.31	253.06
Stage of Groundwater Development (%)	58%	61%	62%

Source: Ground Water Year Book, India; 2009-2010; 2011-12; 2016-17

Table 3 Percentage Composition of Population with Drinking Water Accessibility in India

	Rural		Urban	
	2000	2017	2000	2017
Available within premises	20	56	68	77
Available on time	63	79	88	87
Piped supply	33	32	74	68
Non-piped supply	47	60	21	28

Source: UNICEF and WHO, 2019

Table 4 Composition and Trend of Intersectoral Demand for Water (in BCM)

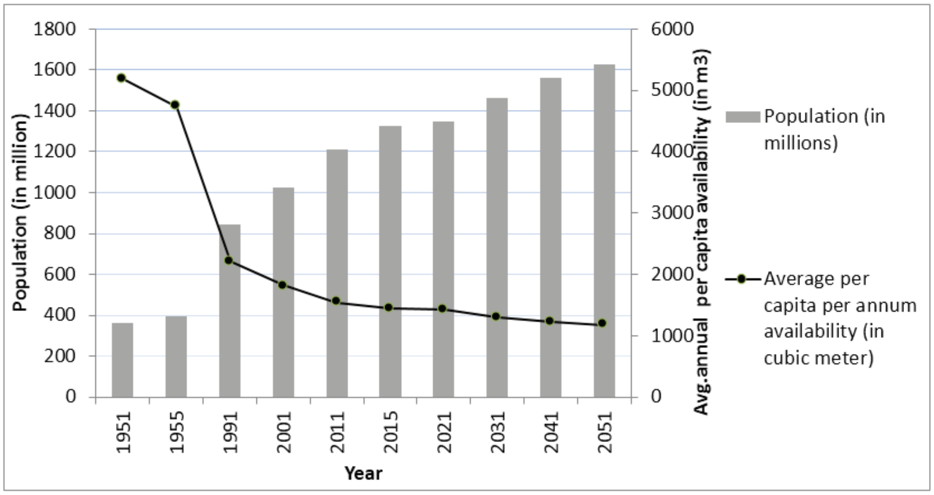
Sector	2010	2025	2050
Irrigation	557	611	807
Industries	43	62	111
Domestic	37	67	81
Power	19	33	70
Inland Navigation	7	10	15
Environment	5	10	20
Evaporation Losses	42	50	76
Total Demand	710	843	1180

Source: MoSPI, GOI, 2018

II. Figuresused in the article:

"DE-STRESSING WATER-STRESSED INDIA: LESSONS FROM ANCIENT SCRIPTURES TO CONTEMPORARY MANAGEMENT PRACTICES"

Figure 1 Average Annual per capita Water Availability Trend in India



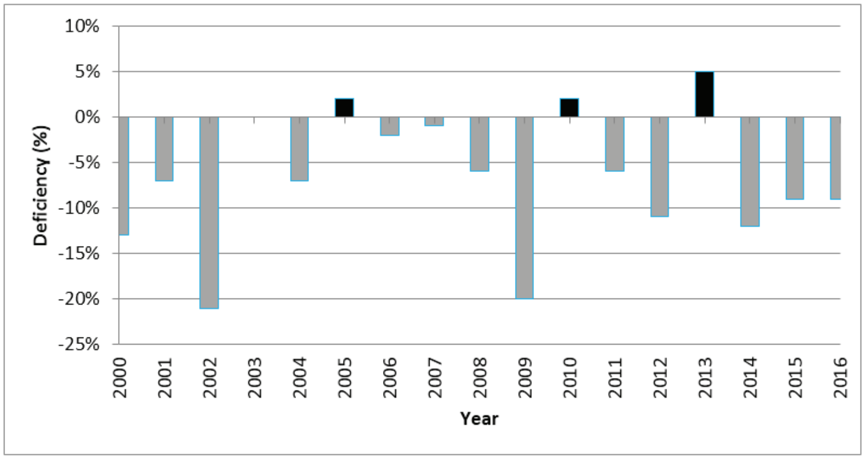
Source: MoSPI, GOI, 2018

Database Used to Generate Figure 1

Year	Population (in millions)	Average annual per capita water availability (in cubic meter)
1951	361	5178
1955	395	4732
1991	846	2210
2001	1027	1820
2011	1211	1544
2015	1326	1441
2021	1345	1421
2031	1463	1306
2041	1560	1225
2051	1628	1174

Source: MoSPI, GOI, 2018

Figure 2 Year-wise Percentage Deviations from Normal Rainfall in India



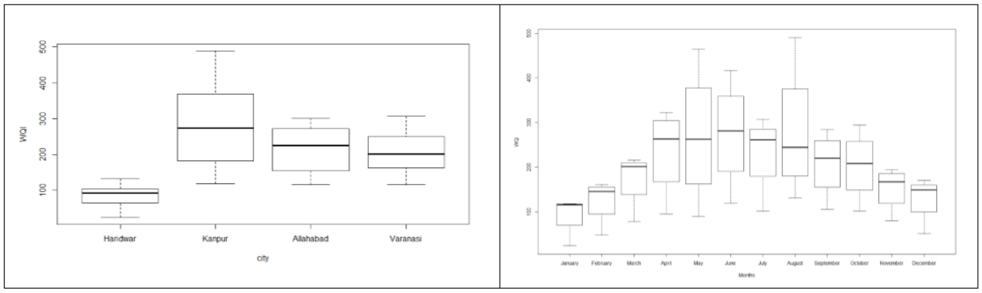
Source: MoSPI, GOI, 2018

Database Used to Generate Figure 2

Year	**Deficiency %**
2000	-0.13
2001	-0.07
2002	-0.21
2003	0
2004	-0.07
2005	0.02
2006	-0.02
2007	-0.01
2008	-0.06
2009	-0.2
2010	0.02
2011	-0.06
2012	-0.11
2013	0.05
2014	-0.12
2015	-0.09
2016	-0.09

Source: MoSPI, GOI, 2018

Figure 3 Spatial and Temporal Variations in Average WQI of the Ganges



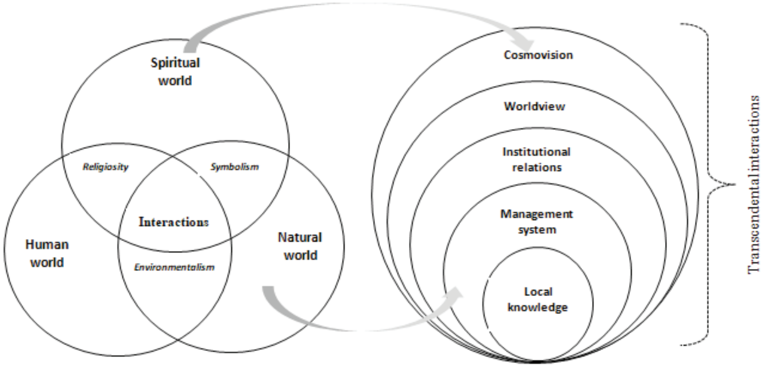
Source: Kumar et al., 2015

Database Used to Generate Figure 3

	Haridwar	Kanpur	Allahabad	Varanasi
January	24	118	115	116
February	48	161	150	141
March	78	215	204	199
April	95	322	287	240
May	90	464	290	235
June	119	416	301	262
July	102	264	258	307
August	132	490	229	260
September	106	284	235	205
October	102	294	221	195
November	80	194	158	177
December	51	170	149	149

Source: Kumar et al., 2015

Figure 4 Spiritual Linkages in Ecosystem Management and Conservation Strategies



Source: Verschuuren, 2007, as adopted by Singh, 2017

Figure 5 Various Local Elements of a Complex Water Resource System Interacting in a Spatial Unit