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Searching for Comparative International Water Research: Urban and Rural Water Conservation Research in India and the United States

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ABSTRACT: Comparison is common in water management research: every table, map, and graph invites comparisons of different places and variables. Detailed international comparisons, however, seem infrequent in water resources research. To assess this perceived gap, this paper searched for examples of comparative research between two water sub-sectors in two countries using systematic bibliographic mapping procedures. It focused on rural and urban water conservation research in India and the United States. Search methods built upon procedures initially developed for the FAO Investment Centre and more advanced systematic review methods. The search generally confirmed that there have been few detailed comparative international studies on the subject of this review. Not surprisingly, there are a greater number of comparative studies between rural and urban water conservation within each country. The search also identified different conservation emphases in the two countries, e.g., rainwater harvesting in India compared with stormwater quality management in the United States. It identified unanticipated publications and lines of comparative water conservation (e.g. comparative physiology). Some transnational research goes beyond comparison to address the diffusion of innovations, i.e. research linkages as well as comparisons, although these studies are also few. The more prevalent pattern involves parallel literatures, which indicate substantial opportunities for future comparative and transnational research. This review also identified diffusion of international knowledge paths that are not the product of formal comparative research. The final section focuses on the prospects and priorities for future international and inter-sectoral research, e.g. paired multi-objective river basin research, linkages between climate change adaptation and disaster risk reduction, diffusion of water conservation innovations, and synthesis of research on urban and rural rainwater harvesting in different countries.

KEYWORDS: comparative research, water conservation, bibliographic mapping, India, United States

A PERSPECTIVE ON COMPARATIVE INTERNATIONAL WATER RESEARCH

Comparative water inquiry is a fascinating if elusive topic (Wescoat, 2009a). Informal comparisons occur every day. They pervade water experience from perceptions of humidity to distinctions between hot, cold, pure, and impure waters while drinking, bathing, and watering. They call attention to water problems (e.g. leaks, spills, drops in pressure), compared with unproblematic conditions. They identify places that face similar problems, and precedents for addressing those problems, weighing their performance, and seeking ways to adapt them to new situations.

Comparisons also appear to be common in water research. Every map, table, and graph juxtaposes data about different places, topics, and variables (e.g. Gleick 2011, data tables). Some aspects of these graphic displays are discussed in the text while others invite further reflection by the reader. Some texts discuss multiple cases in rigorously comparative ways, qualitative and/or quantitative, (Mollinga and Gondhalekar, this issue; Ragin, 1989), while many simply note commonalities in passing. Edited volumes often contain country case studies with brief comparisons in introductory and concluding

chapters. Such chapters offer juxtapositions that readers may wish to compare, although there is rarely enough common research design or methodological detail to proceed very far. Other volumes purposely curate a diversity of cases and approaches in what may be called the 'varieties of' tradition of comparative research (Wescoat, 1994). Such compilations expand awareness of different types of inquiry but do not support comparative analysis of them.

There are exceptions to these general patterns of comparative research. Some historical-geographic comparisons have enduring scholarly value, such as Jean Brunhes' *L'irrigation: ses Conditions Géographiques, ses Modes et son Organisation dans la Péninsule Ibérique et l'Afrique du Nord* (1902) or Clifford Geertz's *The Wet and the Dry: Traditional Irrigation in Bali and Morocco* (1972). These are held in regard for the history of water thought but are only occasionally salient for water management and policy research (e.g. Maass and Anderson, 1986).

A comparative historical study that indirectly influenced water policy research was Wittfogel's (1957) *Oriental Despotism: A Comparative Study of Total Power*. This treatise was a macro-comparative project that had flaws similar to other grand cross-cultural studies by modern western scholars (Mahoney and Rueschemeyer, 2003). The literature refuting Wittfogel's hydraulic hypothesis is now much larger than that which supports it. However, those debates have had continuing influence on research about the relationships among social, environmental, and historical water processes (e.g. Coward, 1980; Maass and Anderson, 1986; Freeman, 1989; Steward, 1955; Wescoat, 2000a; Worster, 1992).

Water conservation seems a good topic for exploring the record and current situation of comparative research as it has a long history in agricultural soil and water management, an interim period of multi-purpose storage projects, and expanding prospects in urban design. As we shall see, the denotations and connotations of 'conservation' have varied widely over space and time. Many conservation techniques have deep historical roots in practice and policy. Increasing emphasis is placed on documentation and adaptation of traditional water conservation technologies in modern rural and urban areas (Agarwal and Narain, 1997).

At the same time, conservation has acquired disparate connotations in different social groups. Some analysts stress physical water use efficiency while others argue for economic efficiency, productivity, or protection. Environmentalists have proposed water use reduction to protect minimum in-stream flows. River basin authorities have stressed the conservation logic of multi-purpose storage. Farmers and ranchers have asserted that they are the true conservationists, managing water resources for food and fibre production. Water conservation research has thus changed considerably over the past century. It gave early emphasis to controlling run-off and soil erosion, and has progressively added demand management, water quality standards, and ecological design (Singh, 1990; Helms, 1992). In the U.S.; however, national research funding for water conservation research has declined over the past quarter century (NRC 2004: 9, 103, 114). State and local funding tends to increase during droughts and decrease afterwards. It would be interesting to compare these findings with research funding trends in other large countries that have a federal system of government (e.g. Brazil, India, Pakistan). During the same period, non-governmental organisations (NGOs) have mobilised to support adoption of conservation technologies through research as well as social movements (e.g. Centre for Science and Environment in India; and the Pacific Institute in the U.S.). Efforts to adapt traditional water conservation practices have increased (e.g. Agarwal and Narain, 1997; U.S. Environmental Protection Agency, 2011), as has private investment in conservation technologies (e.g. decision support software, filters, leak detection, management services, micro-irrigation, pumps, sensors, treatment technologies, etc). Each conservation method has its practitioners, trade organisations, and clientele in many, if not most, regions of the world – and all of their work depends to some measure on comparative knowledge.

There is a small but significant body of comparative synchronic water research, often among adjacent countries in a region, such as the *Drawers of Water* studies in East Africa (Thompson et al., 2001; White et al., 1972). Water resources databases also support synchronic international comparison of modern water systems. Widely used international water databases include CRED-EMDAT's natural disaster epidemiology database, FAO's Aquastat and Legislative Series, ICSU's World Data Centre partners, IWMI's water and agricultural data, Oregon State University's Transboundary Freshwater Dispute Database, UN-Water's Indicator Portal, and the WHO/UNICEF Joint Monitoring Programme for Water and Sanitation. The quality and comparability of data in these resources are important considerations (Gleick 2011, data table notes; Satterthwaite 2003).

Notwithstanding these expanding resources and diverse exceptions, there appears to be no organised body of comparative water research. As a contribution to these efforts, this paper conducts a systematic bibliographic search to identify the frequency and types of comparative water research that have been conducted. As a case study I focus on rural and urban water conservation in India and the United States. Water conservation was selected because it is an established field of practice in these countries. Presumably advances have occurred in part through comparison and diffusion. At the same time, countries vary in their traditional and modern conservation practices, programmes, trends, and innovative frontiers. India and the United States were selected to assess such variations through long-distance comparison (*vis-à-vis* comparison within regions such as North America or South Asia). There is also a history of comparative inquiry and exchange between the two countries (Wescoat, 2000a, 2013). Finally, I have previous research experience in both places that enabled critical assessment of strengths, weaknesses, patterns, and omissions in the bibliographic search results.

Patterns of comparative research on rural and urban water conservation in India and the United States can be visualised in Table 1. The working hypothesis is that there are small but significant bodies of research that compare rural and urban conservation within each country (A: C and B: D). Fewer studies are anticipated that compare water conservation activities between India and the United States (A: B and C: D). The least likely comparisons expected are those that cut across subfields *and* countries (A: D and B: C), although there is no reason in principle why innovative water harvesting or drip irrigation technologies should not be compared across sectors and regions.

Table 1. Matrix of subfields and countries.

Subfields/Countries	India	United States
Rural Water Conservation (RWC)	A	B
Urban Water Conservation (UWC)	C	D

In the early-21st century era of globalisation, urbanisation, water research, and information technology, a systematic bibliographic search should be able to falsify these perceived deficiencies in comparative international research.

BIBLIOGRAPHIC SEARCH AND MAPPING METHODS

This section describes the search methods and scope of the review. It builds upon previous approaches to research review, which assess the patterns, trends, and gaps in a field (Cooper, 2009). Bibliographic search contributes to traditional literature reviews as well as quantitative synthesis of previous research results. Research synthesis methods go far beyond those of traditional literature reviews (Cooper, 2009; Gough et al., 2012). Quantitative research synthesis is applicable when there is a substantial body of scientific research on a focused question, e.g. to what extent does rainwater harvesting reduce household water demand under different policy incentives and constraints, different climatic

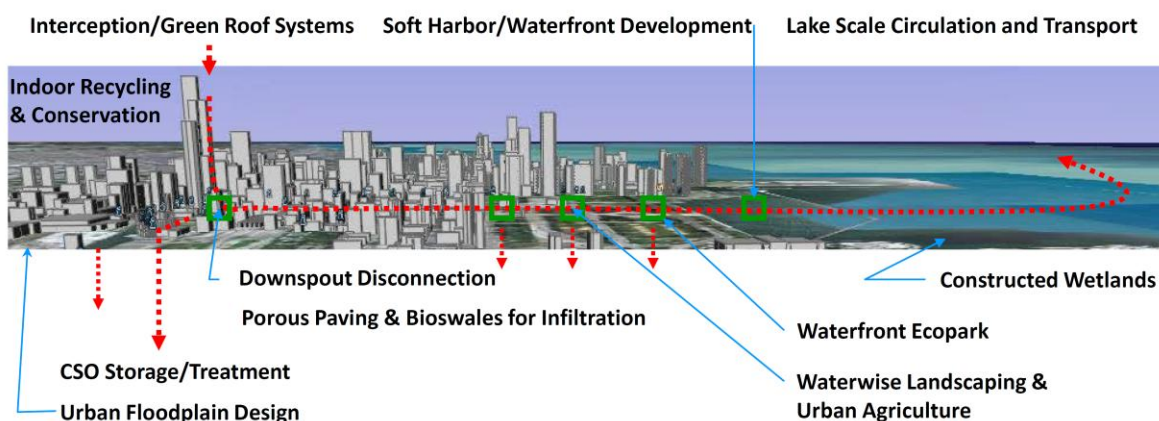
conditions, or different patterns of human settlement? Quantitative synthesis is less applicable for surveying broad fields, such as water conservation with the aim of identifying major research patterns, exceptions, and gaps.

For that purpose, the initial phase of research synthesis, known as systematic bibliographic search and mapping is useful (Collaboration for Environmental Evidence [CEE], 2013, section 2.4.3; Gough et al., 2012, ch. 7; Randall, 2008; Randall and James, 2012). The bibliographic search methods employed here build upon traditional literature review methods (Harris, 1976). They were extended to searches on water and environmental research using online libraries for the UN Food and Agriculture Organization (FAO) Investment Centre (Wescoat, 1997); the profession of landscape architecture (Wescoat, 2003); and the Aga Khan Development Network's Disaster Risk Management Initiative (e.g. Williamson, 2013). This study of comparative water research links these project-oriented searches with broader bibliographic mapping methods that survey the major patterns of research in a field (CEE, 2013). The first steps are to introduce the search keywords, online libraries, and screening procedures.

Keywords

The core search terms used were "compar*", "agricultural conserv*", "rural conserv*", "urban conserv*", "India", and "United States". As conservation denotes a wide range of practices, discussed above, additional conservation terms were identified for screening (i.e. selecting the most relevant) search results. On the rural side, the FAO AGROVOC thesaurus (<http://aims.fao.org/standards/agrovoc>); Soil and Water Conservation Society (SWCS) *Environmental Management Glossary* (Happe, 2006); and *Manual of Soil and Water Conservation Practices in India* (G. Singh, 1990) were used to recognise water conservation terms in titles and abstracts. For example, the *Manual of Soil and Water Conservation Practices in India* includes sections on "bunds, terraces, diversion drains, land levelling, grassed waterways, embankments, farm ponds, gully control, ravine reclamation, wind erosion, landslides, streambank protection and watershed management" (G. Singh 1990, abstract). Analogous practices occur in urban areas, so screening terms were also compiled from handbooks on urban water conservation (Vickers, 2001). Urban water conservation is an expanding field that is diagrammatically represented in Figure 1. As with rural conservation practice, it shares an emphasis on water saving, water reuse, and water use efficiency. As depicted in Figure 1, however, it also includes some distinctive methods and terms, such as green roofs, living walls, downspout disconnection, rain gardens, bioswales, porous paving, urban soil design, water-wise irrigation, constructed wetlands, grey water reuse, and stormwater best management practices, which were used for screening urban search results.

Figure 1. Idealised section of urban water conservation measures.



Source: Author on Google Earth base, 2013.

At the same time, rural and urban water conservation practices are increasingly applied across wider metropolitan regions. Some conservation methods have applications across rural and urban areas, as well as intermediate suburban and peri-urban areas (e.g. floodplain management, micro-irrigation, non-point source pollution control, stream restoration, water harvesting, and watershed planning to name a few). These considerations led to the use of "water conserv*" as an initial search term, adding 'rural' and 'urban' as qualifiers in searches that returned large numbers of hits, and in the individual country searches.

Online libraries searched

It is important to stress that this search is limited to research catalogued in online international scientific libraries. These sources include a wealth of research, but it is important to understand their limitations. For example, although they include increasing bodies of research produced in and about India, relatively few Indian water and environmental journals are currently indexed. This bias can be slightly offset by using major bibliographic studies when available, such as Kapur's (2009) *On Disasters in India* which is a systematic mapping of 4004 natural hazards publications largely from Indian libraries and journals. It includes flood and drought hazard research and associated conservation studies. However, the present study did not undertake extensive citation analysis or snowball sampling of bibliographies produced in India.

On the positive side, the use of online indexes enabled a common set of methods to be used to assess the status of comparative international research. The down side is that many interesting comparative studies conducted by NGOs, consulting firms, professional organisations, and government agencies are not indexed by online libraries. Different methods are required to search grey literatures. Large water firms (e.g. in consulting, irrigation, beverage, and utilities sectors) prepare technical reports that include comparative analyses. Technical tours involve informal comparative exchange (cf. Wescoat et al., 1992). These additional sources of comparative international inquiry warrant follow-up study. Here we concentrate on comparative research in scholarly libraries. The following on-line libraries were searched:

- WorldCat for books
- Water Resources Abstracts for studies and reports
- Web of Knowledge for scientific journal articles
- Compendex for engineering journal articles
- SCOPUS for interdisciplinary journal articles
- Avery Index for environmental design periodicals
- ProQuest for dissertations and theses

Each library has a different search interface. Search terms were entered as "keywords", "topics", "title, abstract, and keywords" or "All but full text", depending upon the library. In the initial search, the terms used were: "compar*", "water conserv*", "India", and "United States" (Table 2). As results were limited, as hypothesised, a second set of searches for parallel literatures focused on rural and urban water conservation research in either India or the United States.

Screening procedures

An interesting challenge in any bibliographic search is to assess the relevance of publications from their titles and abstracts. Some bibliographic mapping studies review full text when available; however this search yielded an overwhelming proportion of low- relevance publications. Instead, our research team used common keywords, and then jointly reviewed a sample of search results to calibrate hits deemed 'highly relevant', 'moderately or possibly relevant', and 'likely irrelevant'. The total numbers of hits are

reported in Table 2, with some of the most relevant works discussed in the text. When a search exceeded 100 hits, the "compar*" keyword term was changed into a "title" term to focus on comparative studies.

SEARCH RESULTS

This section presents results by the online library source and search terms used, after which they are discussed thematically.

Books

WorldCat includes an expanding range of resources, but it is currently the largest online library catalogue for books. It is sobering that when one searches for books with the full set of search terms – "compar*", "water conserv*", "India" AND "United States" – only six e-books of conference proceedings were identified. They include some comparative articles but not as an emphasis of the volumes as a whole.

Conversely, when one includes just the core terms "compar*" and "water conserve*" as keywords, there are 387 hits, most of them with very low relevance. Changing "compar*" to a title term yields a more promising but still wide-ranging set of 87 books. Using keyword searches for each country had the most relevant results. Some observations are that:

- U.S. technical missions focused on water conservation in India from the late-1950s at least through the 1970s. Further research in the U.S. Department of Agriculture, U.S. Agency for International Development, Office of Arid Lands Studies, and similar library collections and archives would likely prove fruitful.
- At least from the 1970s, international development organisations such as FAO have also produced comparative international water conservation studies on India, suggesting a similar follow-up with their organisation libraries.
- During the most recent decade, several dozen interesting comparative books have been produced on the U.S. or India with other countries (Table 2, column 2). Some of these studies concentrate on North American or South Asian countries. Other studies were funded by international programmes such as an Indo-Dutch sponsored edited volume on *Managing Water Scarcity* (Vaidyanathan and Oudshoorn, 2004). *Making Water Everybody's Business: Practice and Policy of Water Harvesting* by Agarwal et al. (2001), compiled rural, urban, Indian, and international cases, though not on the U.S.
- The WorldCat search missed multi-country studies that did not refer to comparison or conservation in their keywords or title (e.g. Moench, et al., 1999; Mollinga et al., 2006).

While these results are interesting in their own terms, the working hypothesis that comparative research has produced limited sustained or detailed analysis still holds.

In light of these limited *comparative* results, a search for *parallel literatures* on rural and urban water conservation in India and the U.S. was undertaken (Table 3). The overall patterns are clear. Both countries have produced a much larger number of rural than urban water conservation books, especially India. Few books jointly emphasise rural and urban water conservation. Notwithstanding common conservation practices, there are different emphases in the U.S. (e.g. habitat and environmental protection, and hydropower) compared with India (e.g. soils and forestry). There is a proportionately larger number of urban water conservation books on the U.S. compared with India, but they address similar topics (e.g. water efficiency, environmental planning, and global change). These observations tend to support the working hypothesis that there has been limited explicit comparison of

rural and urban conservation, but substantial published resources are available to conduct such research.

Table 2. Summary of comparative search results.

Search terms/ Sources	WorldCat Books	WRA	Web of Knowledge	Compendex S/T/A#	Scopus T/A/K	Diss
"compar*" AND "water conserv*"	387 KW 86 TI	489 AB 19 TI	902 TOPIC 46 TI	[2 S/T/A] 557 TI#	2917 T/A/K 188 TI	211 ALL 8 TI
"water conserv*" AND "India" AND "United States"	24	0	1	12	6 T/A/K	4
"compar*" AND "water conserv*" AND "India"	10	9	35	10	79 T/A/K 5 TI	0
"compar*" AND "water conserv*" AND "United States"	68	12	31	32	293 T/A/K 20 TI	115 ALL 4 TI
"compar*" AND "water conserv*" AND India AND "United States"	6 ebooks	0	0	1	2 T/A/K	0

Table notes: KW – keyword; AB –abstract; TI – title (only for the word compar* if KW>100); S/T/A – subject, title, abstract; T/A/K – title, abstract, keyword; ALL – all but text; RUR – rural; URB – urban. # – water conserv* not in quotes.

Table 3. WorldCat search for books on water conservation in either India or the U.S.

Conservation term	Country term	Subfield term(s)	Raw hits	Selected topics
water conserv*	India	rural, urban	11	Rivers, climate change, rural development; international conference proceedings
water conserv*	India	rural	93	Agricultural conservation, forestry
water conserv*	India	urban	7	Environmental management, global environment
water conserv*	United States	rural, urban	18	Water sustainability, land protection, international conference proceedings
water conserv*	United States	rural	596	Headwater control, rural environmental planning, land use, habitat protection, water and power, soil and water
water conserv*	United States	urban	137	Water efficiency, climate change

Water Resources Abstracts

This index focuses on applied water research. It includes some government documents and technical reports as well as scientific literature. It yielded a small number of hits on comparative water research in India or the United States (Table 2, column 3 above). Still there were some highlights, such as a comparison of rural and urban lake water quality in Karnataka (Gaval et al., 2011). Other studies adapted USDA models for use in India (e.g. Bhadra et al., 2010).

In contrast to these few explicitly comparative studies, the parallel literatures on water conservation in India and United States are very large (hits of 232 and 753, respectively). Limited by rural and urban search terms these drop to a fraction of the total but indicate a more similar array of topics in each category than in the WorldCat book search.

Table 4. Water Resources Abstracts on water conservation in either India or the U.S.

Conservation term	Country	Sector	Raw Hits	Selected topics
water conserv*	United States	-	753	Drinking water protection, soil and water conservation, irrigation, climate change
water conserv*	India	-	232	Water security, dams, democracy, river basin planning, development
water conserv*	United States	agriculture	104	Drinking watersheds, energy and water resources, water quality, forecasting technologies, erosion, policy, wastewater, groundwater protection
water conserv*	United States	rural	59	Irrigation, water quality, policy, pollution
water conserv*	United States	urban	26	Urban water management, water use in the western us
water conserv*	India	agriculture	26	Integrated watershed management, conservation and management of rivers, agricultural water resources, geomorphology
water conserv*	India	rural	12	Water protection, vegetation, rural livelihoods
water conserv*	India	urban	12	Watershed management, groundwater quality

Web of Knowledge scientific journal articles

The Web of Knowledge databases are some of the best for natural sciences. They are good for social science and fair for humanities journals. Interestingly, they gave a similar number of hits for comparative water research in India and the United States (35 and 31, respectively; Table 2, column 4 above). However, many of these titles involved comparisons of crops, models, conservation techniques, and watersheds within a country. A significant number of scientific papers dealt with the intriguing though distant topic of comparative physiology of biological water conservation in different species.

Exceptional hits included comparison of irrigation water use efficiencies in India and the U.S. (Howell, 2000); and a historical survey of soil and water conservation policies in five countries between 1960 and 2010 (de Graaff et al., 2010).

The parallel scientific literatures on water conservation are impressive, with similar overall patterns as above (n=1639 for the U.S. and n= 643 for India). Rather than repeat the general conservation searches reported above, Table 5 below presents a selection of more detailed contrasts between the

U.S. and India results. Two points stand out: first, the much larger scientific literature on rainwater harvesting in India; and second, the proportionally larger literature on urban water conservation in the U.S. These represent key opportunities for drawing lessons from innovations in one country for adaptation in the other.

Table 5. Selected water conservation searches in *Web of Knowledge* databases.

Conservation	Country	Hits	Selected topics
water conserv*	United States	1369	Groundwater management, climate change, soil, water and energy
water conserv*	India	643	Water harvesting, urban growth, climate change
rainwater harvesting	United States	12	Stormwater management, water demand, carbon footprint
rainwater harvesting	India	92	Groundwater recharge, drought, urban drainage
water conserv*	United States urban	137	Water conservation, climate change, water conservation
water conserv*	India urban	34	Water supply projects, water conservation, urban

Compendex engineering journal articles

The journal index *Compendex*, also known as *Engineering Village*, is the largest online search tool for engineering publications. It initially surprised us with only two (2) hits for the "compar*" AND "water conserv*" search. However, when water conserv* was entered without quotes, the gross hits exploded to over 9,000, underscoring the importance of understanding search interface variations in each online tool. Restricting compar* to a title term dropped that number to 570, of which only 10 had India as a keyword and only 32 had the United States as a keyword.

As with other databases most comparative research involved cases, technologies, and models within one country. In the parallel literatures, both countries had large numbers of hits for watershed conservation, albeit with greater emphasis on climate change, drought, and stormwater quality in the U.S. compared to land use, forestry, and socioeconomic issues in India. Soil erosion remains a shared concern but only occasionally a comparative research topic.

Rainwater harvesting research in Indian engineering journals again far outpaced that in the U.S. Other interesting comparative studies in India involved south-south comparisons (e.g. Araral and Wang [2013] on water demand management in India and Southeast Asia; Erenstein [2009] on rice-wheat water management in India and Pakistan; and van Rooijen et al., [2010] on urban water management in Hyderabad, India and Accra, Ghana).

Scopus scholarly articles

Scopus stands out as a major interdisciplinary journal index that includes peer-reviewed agricultural and natural resources as well as other journals. Of its 187 comparative water conservation studies, most were limited to comparisons within each country.

However, two explicitly comparative studies involving India and the U.S. stood out. One examined methods for estimating spatial variations in soil moisture, crop yield and water productivity in eight regions including sites in the U.S. and India (Zwart and Bastiaanssen, 2007). The other was a U.S. chapter on optimal water management in grain cultivation, published in a volume on water and agricultural sustainability in India (Westfall et al., 2010).

The parallel literatures on water conservation in India and the U.S. identified in Scopus are rich in substance and may be sufficient for more detailed comparative review.

Environmental design articles in the Avery Index

Publications on water in architecture, landscape architecture, and planning cite outstanding precedents around the world to inspire and guide design practice (Wescoat, 2009b). However, they rarely compare those examples rigorously. There are no comparative water conservation publications cited in the *Avery Index to Architectural Periodicals*. The words "rural" AND "urban" AND "water conservation" also yield zero hits.

However, single country research on water conservation planning and design in the United States is large and growing (n=82). Although Avery cited only six articles on "water conservation" in India, which underscores the limited indexing of Indian design journals, there is a much larger number devoted to "water". The Indian journal *LA! The Journal of Landscape Architecture* has had several special issues devoted to water in its ten years of publication, as has *Environmental Design: Journal of the Islamic Environmental Design Research Centre* (Archnet.org). As none of these are comparative *per se* they are not reviewed here.

Dissertations and theses

Graduate student theses and dissertations catalogued in the *Proquest* database include several hundred studies of water resources in India as well as orders of magnitude more in the United States, though only a small proportion focuses on water conservation, and none of the studies identified in this search were comparative. Not surprisingly, most are US-centric, compared with other databases. Recent U.S. theses and dissertations have more of an urban water conservation emphasis than those on India.

Similarly, while UK theses in the British Library EThOS database address water issues in India, only a few have a comparative international scope (<http://ethos.bl.uk/Home.do>) (e.g. Van Rooijen, 2011). While some Indian dissertations are catalogued in *Proquest* they are only a small fraction of the total. However, *Shodhganga* an online Indian repository of dissertations presents almost a thousand water studies, but none of them explicitly comparing water conservation practices in different countries (<http://shodhganga.inflibnet.ac.in>). A search in the expanding *Networked Digital Library of Theses and Dissertations* supports these overall observations (<http://thumper.vtls.com:6090/search/query?theme=NDLTD>). Once again, the parallel water conservation literatures in these thesis databases are enormous. Individual studies have sufficiently detailed methodological documentation to enable rigorous qualitative and perhaps quantitative research synthesis.

The one water topic that is generating comparative research is international water law, conflict, and policy. This is no accident as it is also the field most affiliated with an established subdiscipline, comparative international law, and dozens of scholarly journals in that field. Doctoral dissertations have compared the Indus, Ganges, Jordan, Amu Darya, Nile, Colorado, and other contested basins. This field provides a precedent for other international comparisons, e.g. on drought policy, water sector planning, hydro-climatic change, and so on. Although smaller scale water conservation practices and programmes are less obvious candidates for comparative international research, that is the subject of the next section discussing the results of this search.

DISCUSSION AND EXTENSIONS

This section discusses search findings and implications for future research. It examines overall patterns, exemplary works, search omissions, and parallel literatures that can help address research gaps on the following topics:

1. Comparative water conservation research in India and the United States
2. Rural and urban water conservation research in the United States
3. Rural and urban water conservation research in India

In light of the limited number of formal comparative studies, this discussion extends to research on other types of linkages that include transfers of knowledge between sectors and regions. There is a long and complex history of water resources linkages between India and the United States (Wescoat, 2000a, 2013).

Comparative water conservation research in India and the United States

The online library searches identified a significant number of comparative studies of water conservation *within* each country, including some that compared rural and urban conservation practices. Rural-urban comparisons were more frequent in the U.S. than in India, presumably because conservation began in agricultural areas and has subsequently followed the path of urbanisation. An interesting exception is the field of rural and urban rainwater harvesting where research in India has advanced further than in the U.S.

The main issue that arose in this search of scholarly publications concerns the low frequency of comparative research between the two countries. The search identified large parallel literatures but found few comparisons of them. Exceptions and extensions are discussed for the following topics: irrigation and drainage, rainwater harvesting, water and wastewater reuse, groundwater management, floodplain management, and comparative water law. Follow-up searches on these topics would identify more comparative studies beyond those that focused on water conservation.

Irrigation and drainage. As noted early in the paper, an important line of comparative research arose in reaction to the infamous treatise on *Oriental Despotism: A Comparative Study of Total Power* by Karl Wittfogel (1957). This bibliographic search identified few comparative irrigation studies, in part because they are not framed as water conservation studies. The search results reported here deal more with technical and management issues than with transnational or socio-political issues. At the same time, journal indexes indicate that readers are exposed to a wide range of international irrigation and drainage practice. The U.S.-based *Journal of Soil and Water Conservation* includes 83 articles on India. India is well represented in irrigation journals such as *Agricultural Water Management, Irrigation and Drainage Systems*, and the American Society of Civil Engineers' *Irrigation and Drainage Engineering*. The International Water Management Institute (IWMI) links irrigation researchers in part through its international publications, as does the International Commission on Irrigation and Drainage (ICID), albeit with different emphases. The U.S.-based Irrigation Association bridges rural and urban irrigation sub-sectors and contains a small number of publications on India among its publications (www.irrigation.org; 11/16/2013). As noted in the WorldCat search of books, however, a much larger body of comparative research may be found in the grey literature of international development reports commissioned by the U.S. Agency for International Development and others.

Rainwater harvesting. Rainwater harvesting also known as water harvesting or rainwater catchment systems has advanced in both countries, particularly in India (Agarwal and Narain, 1997; Kinkade-Levario, 2004). Both countries have rainwater harvesting associations as do other nations such as Switzerland that promote practical exchange but not much comparative research. Important exceptions include a doctoral dissertation comparing rainwater harvesting in Rajasthan and Arizona, which is precisely the type of comparative research sought in this review (Nagrath, 2008). By way of contrast, Agarwal and Narain's (1997) *Dying Wisdom* has received limited scientific attention in the United States, as represented by citation indexes that report only seven citations in Web of Knowledge and one in the Lexis/Nexis Law Review index.

Groundwater conservation and creeping environmental hazards. Several comparative international water studies focus on groundwater depletion and degradation which, like drought and climate change,

have sometimes been referred to as "creeping environmental hazards" due to their relatively slow rate of onset compared to floods, cyclones, and other hazards (cf. Glantz, 1999; Moench et al., 2011). Tushaar Shah's *Taming the Anarchy: Groundwater Governance in South Asia* contrasts South Asia with other regions, concluding that management principles in the latter do not address the problems and needs in South Asia (Shah, 2009). Several climate change studies were also identified in this search, and it is likely that climate adaptation studies that encompass water conservation were not captured by the search procedures employed here. An interesting collaborative project between the University of Kansas and IWMI-South Asia on groundwater law and management was identified (Peck and Griggs, 2008). It presents case studies of issues, experiences, and approaches, but it does not analyse them or discuss what was learned from the exchange of case studies. As international conferences and projects are an important vehicle for comparison, their role in advancing comparative analysis should be explored.

Water and wastewater reuse. Recycling municipal wastewater for irrigation and agricultural water reuse are increasingly active fields of inquiry in both countries (Drechsel et al., 2010; NRC, 2011). International as well as domestic water quality and health standards are cited in most studies, e.g. those of the World Health Organization). A recent review of *Water Reuse* by the U.S. National Research Council's (NRC, 2011) Water Science and Technology Board took a more international approach than usual for that organisation. It reported that South Asian countries do not yet figure prominently in wastewater reuse compared with China and Latin American countries. This may be a reporting problem, or it may reflect the exclusion of irrigation with untreated wastewater. In any case, this rural-urban linkage will probably expand as reuse of treated wastewater increases worldwide.

Floodplain management. Another small but expanding field of water conservation research in India and the U.S. involves floodplain planning. Mathur and da Cunha (2001, 2009) have studied the floodplain landscapes of the Mississippi, Mahim and Ganga rivers. Indeed, Mumbai seems to be a laboratory for urban floodplain research by U.S. and Indian landscape planners (CSE, 1991; Gandy, 2008; Berger and Mehrotra, 2010). But again, these tend to be place-based rather than comparative studies. Comparative flood hazards and planning research in the Mississippi, Bengal and Mekong deltas have expanding prospects (e.g. Jacobs, 1999; NRC, 2013).

Comparative water law, treaties, and institutions. Comparative international water law and policy are long-standing disciplines, driven in part by concerns about international conflict (Zawahri, 2008). Although water conservation seems relevant, more emphasis has been given to water allocation and development. Few comparative water law publications were identified in this bibliographic search on conservation, but escalating debates about the respective rights of upstream and downstream users could lead to closer linkages between comparative water law and conservation (cf. Bruns and Meinzen-Dick, 2000; Burchi and Mechlem, 2005; Cullet, 2009; Cullet and Koonan, 2011).

Rural and urban water conservation research in South Asia

Most water conservation research in India continues to focus on rural practices, notwithstanding the rapid pace of urbanisation. We thus proceed from rural conservation practices to those connected with urban development.

Watershed conservation. Rural water conservation programmes are linked in part with forest and pastoral land management and associated fields of applied vegetation and soil science. Search results reflected the fact that watershed management has been a key topic in water conservation research for decades (Farrington and Turton, 2000). Although largely rural, its emphasis on governance could link it with analogous movements in urban and regional planning, as has occurred in the U.S.

Irrigation and drainage have been primarily associated with agricultural water conservation in South Asia. The Indian committee of the International Commission on Irrigation and Drainage (ICID) cites few urban projects in their website and publications. Even progressive irrigation initiatives, e.g.

participatory irrigation management, are conceived as rural development programmes. Major reviews such as *Asian Irrigation in Transition: Responding to Challenges* (Shivakoti et al., 2005) acknowledge but do not fully engage the opportunities and challenges posed by urbanisation. An important exception to this rural emphasis involves the drip irrigation sector, led by organisations such as the Irrigation Association of India and multinational irrigation companies. At the same time, India has been the locus of innovative social research on irrigation systems in recent decades under the auspices of organisations such as the International Water Management Institute (IWMI), which has researched the links between irrigation research and reuse of treated municipal wastewater (e.g. Celio et al., 2009).

Rainwater harvesting. One of the major breakthroughs in rural and urban water conservation has involved rainwater harvesting led by the Centre for Science and Environment, Tarun Baghat Sangh, and other organisations (Agarwal and Narain, 1997; Dua, 2001; Mukherjee et al., 2002). Connections between rural and urban water harvesting systems were curated in the Centre for Science and Environment's *Dying Wisdom: The Rise, Fall and Potential of India's Traditional Water Harvesting Systems*. A follow-up volume on *Making Water Everybody's Business* was explicitly structured into urban and rural case studies (it also includes some international examples though not formal comparisons across case studies, or North American cases). These movements have had policy adoption at the urban (e.g. Chennai) and state levels (e.g. Maharashtra and Andhra Pradesh). Productive scientific debates have focused on the performance and potential of water harvesting at different scales of water planning.

Water and landscape heritage conservation. This bibliographic search did not identify studies of India's rich heritage of ancient, mediaeval, and early modern water conservation systems (Bhatnagar, 2005; Cosgrove and Petts, 1992; Hegewald, 2002). Physical systems range from sewers of Harappan cities to step-wells, tanks, and cisterns. The cultural as well as archaeological significance of these water-conserving systems has been thoughtfully studied (e.g. R.P.B. Singh, 1994, 2004). However, water heritage conservation has had limited connection with water resources conservation to date (Wescoat, 2009c). The magnitude of this challenge is exemplified by the degraded conditions of sacred rivers such as the Ganga and Yamuna which have manifold rural, peri-urban, and urban sources of pollution (Alley, 2002; Haberman, 2006; World Bank, 2011).

Urban water conservation and sanitation. The escalating pace of urbanisation has outstripped urban water supply and wastewater disposal systems in India (CSE, 2011, *Excreta Matters*, 2 vols.). Basic water needs of informal settlements are not met, and even many upper class areas experience water supply disruptions (e.g. Birkenholtz, 2010; R.B. Singh, 2001, 2004). In this context, one would expect an emphasis on urban water conservation research focused on control of water loss, wastewater reuse, and low water use sanitation methods. Instead large literatures document the intense debates about conventional reservoir storage projects and trans-basin diversions, along with privatisation and pricing policies for water and wastewater utilities (Asthana, 2008; Briscoe, 2006; Briscoe and Qamar, 2006; Iyer, 2007). This search did not identify urban water conservation research commensurate with these challenges, which represents an important gap. The search methods also failed to identify links between urban water conservation and peri-urban water management, perhaps due in part to keyword selection and indexing.

Flood, drought, and hazards mitigation are growing issues in South Asia, as evidenced by increasing damages incurred in every region of the countries (CSE, 1991; National Research Council, 2012). Kapur's (2009) intensive bibliographic search yielded 4,004 research articles on natural hazards in India, which revealed that while both rural and urban flood and drought hazards have been studied, their linkages with water conservation have received little attention to date. This is unfortunate, as floodplains pass through and thus connect rural, peri-urban, and urban landscapes, and as droughts precipitate rural-urban migration as well as regional reallocation of scarce water supplies.

Integrated water resources management advanced by the Global Water Partnership internationally and in India should, in principle, draw together the many threads of rural and urban water conservation discussed above (Mollinga et al., 2006). However, the bibliographic search conducted here did not find an association between IWRM and rural or urban water conservation.

Rural and urban water conservation research in the United States

Water conservation in the United States also varies by region and settlement type. Water erosion control arose in agricultural areas, while sanitary engineering arose in urban areas (Duffy, 1992; Helms, 1992; Lee, 1980; Steiner, 1990). One important association developed through water budget analysis was originally created for agricultural purposes but then diffused into urban water planning (Wescoat, 2014). Rural and urban conservation also intersect in fields of irrigation, drainage and stormwater management, particularly in suburban landscapes (Scott et al., 2013).

Irrigation and drainage. The U.S. Bureau of Reclamation engaged in rural settlement planning and water conservation, as well as irrigation development, from its early years, as did the Tennessee Valley Authority. Over time, many irrigation districts have faced urbanisation pressures. A search on the U.S. Bureau of Reclamation website for the term "urban" yielded 2083 hits (though only 30 of them for "urban irrigation" and none comparative). A search for the term "urban" in the American Society of Civil Engineers' *Journal of Irrigation and Drainage Engineering* yielded 4191 hits (including 443 for India) though again not comparative. Agricultural drainage techniques have also been adapted for new town and suburban land development, including stormwater drainage which has become one of the most active frontiers in urban water management.

Erosion, sedimentation, and water quality. Other rural soil water and vegetation management programmes have shifted from rural to urbanising landscapes. The U.S. Natural Resource Conservation Service (1992-present) had its origins in soil erosion and sediment control, but has increasingly engaged in urban, or more broadly metropolitan environmental management. One key challenge has been to calibrate rural models for urban land cover, infiltration, and run-off applications. Water quality conservation has involved a reverse flow from urban to rural contexts. Gross contamination of urban streams in the late-19th and early 20th centuries led to ambient, point source, and ultimately non-point source control programmes that are slowly diffusing into rural environments, albeit without much support from explicitly comparative research.

The suburban interface. The term urban is sometimes used loosely to denote non-rural landscapes. This is particularly evident in research on urban stormwater management, where best management practices (BMPs) stress infiltration strategies that apply more to suburban landscapes than to dense urban centres that lack permeable area. Many urban water conservation innovations originated in suburban areas, and diffused into more densely settled places through miniaturisation, regulation, and urban finance. Interestingly, some urban conservation innovations have had positive feedback loops for rural programmes that aim at high-efficiency, high-value, horticultural landscapes (Gober et al., 2011; Smith et al., 2010).

Stream restoration, riparian buffers, and floodplain management. Stream restoration is advancing rapidly in the U.S. Streams pass through rural, suburban, and urban landscapes, thereby connecting them with one another (Newson et al., 2002; Rhoads et al., 2008). Key differences between rural and urban channels include their edge conditions, bed conditions, and uses, in which hyper-urban areas are more associated with waterfront redevelopment while suburban areas undertake riparian channel restoration, and rural areas attempt broader modes of floodplain management. Ecological floodplain management remains a frontier for all contexts of conservation design.

Watershed hydrology and management arose at the intersection of forestry, water supply, and erosion control. It had early importance in urban flood control after devastating events in Pittsburgh and cities of the Ohio River Basin in the early 20th century (Wescoat, 2000b; Wolman and Schick, 1967).

Even basic research on the geomorphology of drainage networks employed urban field sites, as in Schumm's (1956) research on "badlands" of urban landfill in Perth Amboy, New Jersey. Many watershed organisations strive to strengthen the linkages between upstream and downstream land and water management (e.g. the Center for Watershed Protection, Association of Watershed and Stormwater Professionals, and US EPA's Surf Your Watershed), though only a small portion of this research is indexed in online libraries.

Metropolitan water conservation. The current leading *Handbook of Water Conservation* in the U.S. begins with urban demand management and proceeds toward agricultural extensions of those water measurement, analysis, technologies, and planning methods (Vickers, 2001). From its historical origins in rural areas water conservation now embraces metropolitan regions as spatial frameworks for integrating rural, suburban, and urban water management. Metropolitan regions are extensive laboratories from the urban core to its rural hinterlands. New York City has successfully developed a networked, functional region, with its headwater catchment communities agreeing to practice land and water management to offset New York's future treatment costs in return for financing from the city. These are several examples of emerging practices in metropolitan water management (Novotny et al., 2010).

Each of these major themes had several significant hits in the systematic bibliographic search and mapping study undertaken in this paper. However, the largest number of hits in this search reflected the historically well-established topics of erosion control, stream quality, and water use efficiency.

CONCLUSION

This search identified an interesting albeit small body of explicitly comparative studies. By also compiling the extensive parallel literatures in India and the U.S., it did more to identify the prospects for future comparison than the findings of previous comparative studies. In this final section we reflect upon the prospects for comparative international water research.

The discussion above underscored the highly promising but as yet under-realised role of comparison even across water sub-fields within a country. Rural and urban conservation practices are not simply comparable, they are interlinked with one another in a gradient of conditions from wildlands to dense urban cores, and in historical processes of innovation and adaptation. Different search terms, perhaps ones that are method-specific could shed light on these similarities, differences and interactions. But the discussion also observed that much of the inquiry in these fields is not well-documented or analysed in scholarly publications. Instead, the field may develop more through projects and practice, which are more commonly reported in the grey literature.

It would be worth assessing to what extent and in what ways grey literature searches and publications complement indexed scholarly research. Methods of grey literature search are less well-developed than those for indexed research. They tend to be catalogued by organisations, which increasingly post their newsletters, reports and sometimes archives online. As they are uploaded, they become available for formal comparative research.

In an era of purported globalisation, the limited body of comparative international research on water conservation comes as a surprise. U.S. water specialists are actively engaged in water research and development in India, and leading Indian water researchers regularly study in the U.S. But these modes of exchange have yielded few explicitly comparative research publications.

It seems likely that even grey literature may not be sufficient to shed light on comparative international water knowledge. There are many other modes of international knowledge exchange, but few formal comparative research publications about them. Thus, in addition to comparative research on modes of practice, far more understanding is needed about informal processes of comparative inquiry.

The full range of international water inquiry has a long history mentioned in the introduction but not adequately reflected in bibliographic search results. Using historical search terms in stronger online social and historical research databases may help. Systematic searches for organisation grey literatures will also be useful. For deeper explanation, archival research in those organisations including engineering firms will likely be necessary. But it seems even more likely that most comparative inquiry and knowledge is unrecorded. It arises through international travel, education (now including online programmes), professional practice, project funding, and other mechanisms – all of which are highly structured but little understood in terms of the effects they have had on water conservation programmes, policy, and practice (Klingensmith, 2007; Wescoat et al., 1992). The positions of the persons involved and the direction of inquiry, either as an export or import and adaptation of international precedents, affect their use and performance. Some international water initiatives have helped mitigate the dearth of comparative historical and international research documented here. They include comparisons of climate change adaptation and natural hazards mitigation, comparisons of river basin management, and comparisons of specific water conservation practices.

Nineteenth-century water planners in India and the U.S. looked around the world for promising models that could be adapted for local use. In the 20th century they exported many of these approaches to water management to other countries. The 21st century may witness more rigorous comparative analysis of exchanges of water knowledge and practices across sub-fields and regions around the world.

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