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Rural water for thirsty cities: a systematic review of water reallocation from rural to urban regions

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Supplementary material for this article is available [online](#)

Abstract

Background: Competition for freshwater between cities and agriculture is projected to grow due to rapid urbanization, particularly in the Global South. Water reallocation from rural to urban regions has become a common strategy to meet freshwater needs in growing cities. Conceptual issues and associated measurement problems have impeded efforts to compare and learn from global experiences. This review examines the status and trends of water reallocation from rural to urban regions based on academic literature and policy documents.

Methods: We conduct a systematic literature review to establish the global reallocation database (GRaD). This process yielded 97 published studies (academic and policy) on rural-to-urban reallocation. We introduce the concept of reallocation 'dyads' as the unit of analysis to describe the pair of a *recipient* (urban) and *donor* (rural) region. A coding framework was developed iteratively to classify the drivers, processes and outcomes of water reallocation from a political economy perspective.

Results: The systematic review identified 69 urban agglomerations receiving water through 103 reallocation projects (dyads). Together these reallocation dyads involve approximately 16 billion m³ of water per year moving almost 13 000 kilometres to urban recipient regions with an estimated 2015 population of 383 million. Documented water reallocation dyads are concentrated in North America and Asia with the latter constituting the majority of dyads implemented since 2000.

Synthesis: The analysis illustrates how supply and demand interact to drive water reallocation projects, which can take many forms, although collective negotiation and administrative decisions are most prevalent. Yet it also reveals potential biases and gaps in coverage for parts of the Global South (particularly in South America and Africa), where reallocation (a) can involve informal processes that are difficult to track and (b) receives limited coverage by the English-language literature covered by the review. Data regarding the impacts on the donor region and compensation are also limited, constraining evidence to assess whether a water reallocation project is truly effective, equitable and sustainable. We identify frameworks and metrics for assessing reallocation projects and navigating the associated trade-offs by drawing on the concept of benefit sharing.

1. Introduction

Urban water demand is projected to increase by 50–80% by 2050, often in regions also experiencing irrigation development (Florke *et al* 2018, World Bank 2018). These trends are spurring competition between cities and agriculture for water (Bhatia *et al* 1995, Molle and Berkoff 2009, Florke *et al* 2018). The conflict between the city of Los Angeles and the Owens Valley in the early 20th century illustrates that this is not a new challenge (Libecap 2009), but a four-fold increase in urban populations since 1960 has created new flashpoints for rural-urban water conflicts globally (Molden 2007, Celio *et al* 2010, Scott and Pablos 2011, Punjabi and Johnson 2018). The water supply of approximately one-third of the world's surface-water dependent cities is already vulnerable due to competition with agricultural users, and this figure is expected to increase through 2040 as urban and agricultural demands continue to grow (Padowski and Gorelick 2014). Despite these trends, research on conflict and cooperation over water between urban and rural regions has been limited. Although research has intensified over the past 15 years, it is hindered by conceptual issues and associated measurement problems.

Water reallocation from rural to urban regions is one prominent response to meet growing demands for freshwater in cities, and address the impacts of climate change and water quality problems. Reallocation exists alongside the development of new water supplies and demand management, and is often pursued in conjunction with them (Molle 2003). Cities often view adjacent agricultural and rural regions as prime sources of urban water supply after local and lower-cost sources have been exhausted (Richter *et al* 2013). The relatively large volumes, the often low water-use efficiency and low marginal economic productivity of water in agriculture have prompted growing interest in water resource reallocation from rural to urban regions, despite important differences in the nature of water use and water stress in urban areas. In cities, only a small proportion of water withdrawals are consumed, which creates opportunities for wastewater treatment and reuse (Molle and Berkoff 2009).

Water reallocation refers to a change in historical patterns of water use when 'the existing allocation is physically impossible, economically inefficient or socially unacceptable' (Marston and Cai 2016: 658). Reallocation therefore implies an 'initial' allocation, such as a past decision by a community or government determining access, withdrawal and consumption of water (Schlager and Ostrom 1992). Informal (or unrecognized) claims and environmental water needs mean there is rarely a blank slate, and even an initial allocation typically involves reallocation from informal users or the environment (Molle and Berkoff 2009).

Reallocation from rural to urban regions involves distinct challenges and characteristics, influenced by patterns of urbanization and associated infrastructure and governance arrangements (Hooper 2015). Recent studies illustrate the diverse types of infrastructure and institutions used to redistribute water from rural to urban uses (figure 1; table 1). Inter-basin transfers move water from distant rural regions to growing cities, a phenomenon described as 'hydraulic reach' (Scott and Pablos 2011). Urban water infrastructure imports an estimated 500 billion litres per day travelling nearly 27 000 km with at least 12% of large cities reliant on inter-basin transfers (McDonald *et al* 2014).

Water reallocation can also occur more gradually and inconspicuously through land use change, exemplified by the conversion of prime cropland to urban areas, particularly in irrigated areas. A 3.2% reduction in cropland is projected to occur due to urbanization by 2030, with local extremes as high as 30% or higher (D'Amour *et al* 2017). Urban food production systems are also embedding agricultural water use within the city and its supply systems, creating novel allocation and management challenges (*ibid*). Finally, the failure of local utilities to deliver safe drinking water has prompted informal water vendors to fill the gap by pumping water from surrounding agricultural tube wells to urban dwellers, growing slums and peri-urban areas (Venkatachalam and Balooni 2018).

This review takes stock of global experience and evidence on the reallocation of water from agricultural (and other rural uses) to urban uses, providing the first systematic review on the topic. We address three objectives. First, we identify the status and trends of water reallocation from rural to urban regions based on documented cases in the literature. We examine the geographic coverage of the current literature, and the physical characteristics of water reallocation, including the sources, volume and distance of water reallocation. This analysis illustrates the diversity of contexts and types of water reallocation, as well as the spatial and temporal trends. Second, we seek to clarify the different types of infrastructure and institutional mechanisms governing water reallocation by examining the decision-making processes, actors and attributes of reallocation agreements. Finally, we identify important gaps in the data and knowledge regarding rural-urban reallocation, including on compensation and on the impacts on donor and recipient regions. This review exposes the reliance on myths and perceptions of water reallocation, in the absence of rigorous data and analytical frameworks to support policy decisions.

2. Methods

We conducted a systematic review to identify and screen for relevant cases of rural to urban water

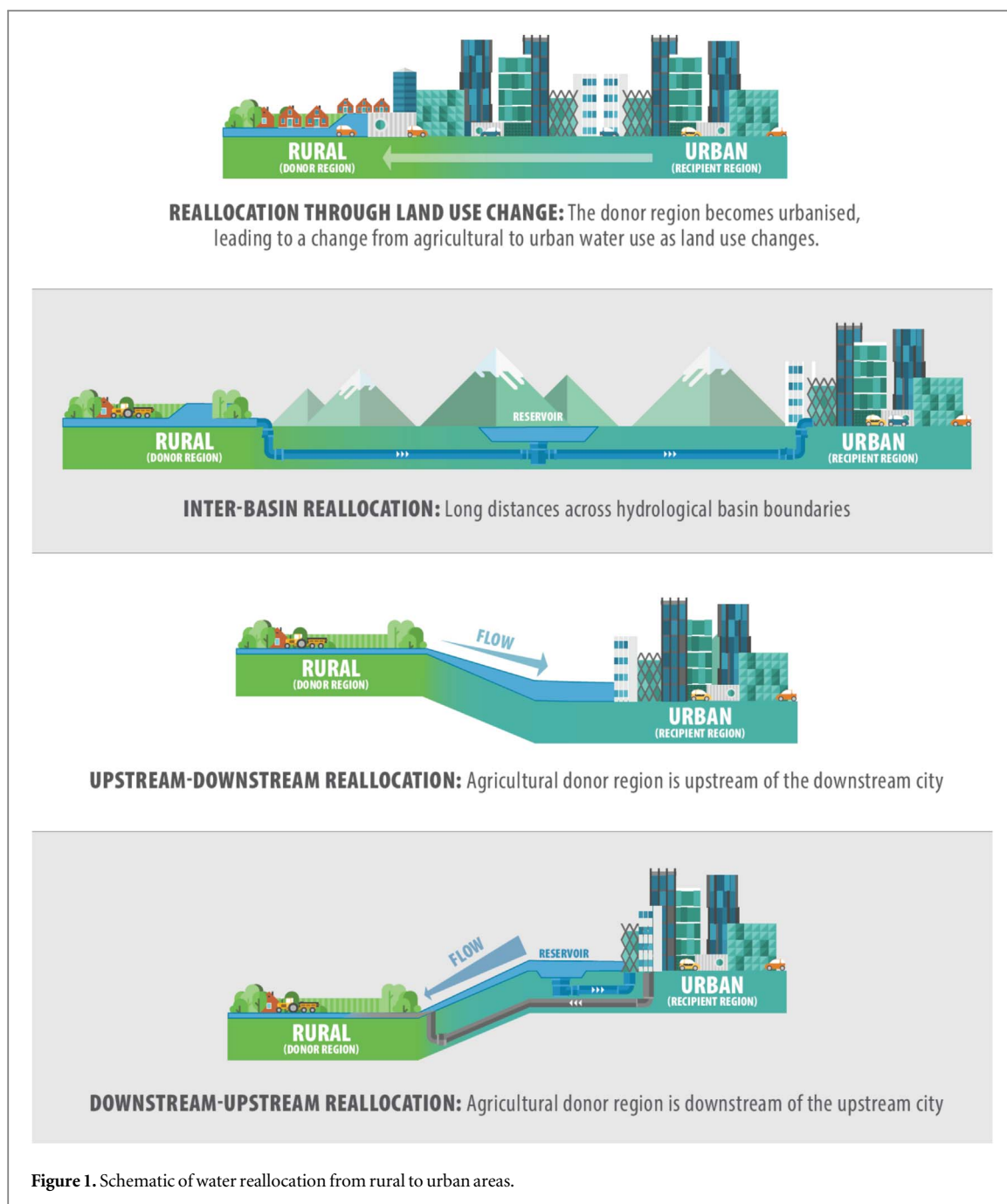


Figure 1. Schematic of water reallocation from rural to urban areas.

reallocation from the academic journal articles and policy reports, and to extract and validate relevant data (figure 2). This process was guided by the checklist of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher *et al* 2009). Initially developed in the health sciences, such reporting standards are being adapted and extended to address social science or interdisciplinary topics such as water reallocation, which require inclusion of contextual features and sample characteristics (Maki *et al* 2018).

First, we reviewed the literature by conducting a systematic database search and through citation tracing. Several academic literature databases were used to ensure coverage of relevant sources, including the Thomson Reuters Web of Science Core Collection and the Elsevier Scopus database. To obtain grey literature

results, we searched OpenGrey and OALster databases, as well as online databases of the focal policy and development organizations (table 2 in SI 1 is available online at stacks.iop.org/ERL/14/043003/mmedia). The search terms included ‘water reallocation’ and associated variants and cognates, including ‘transfer’, ‘transaction’, ‘markets’ and ‘grabbing’ (see full list in SI 1). Citation tracing supplemented the database search, involving both forward and backward tracing to capture literature addressed by seminal papers and prior literature reviews on the theme (Molle and Berkoff 2009) (for a full list of indicative literature ($n = 61$) see SI4).

As a second step, we screened the results of the literature review based on inclusion criteria, ensuring that the cases identified in the literature represented:

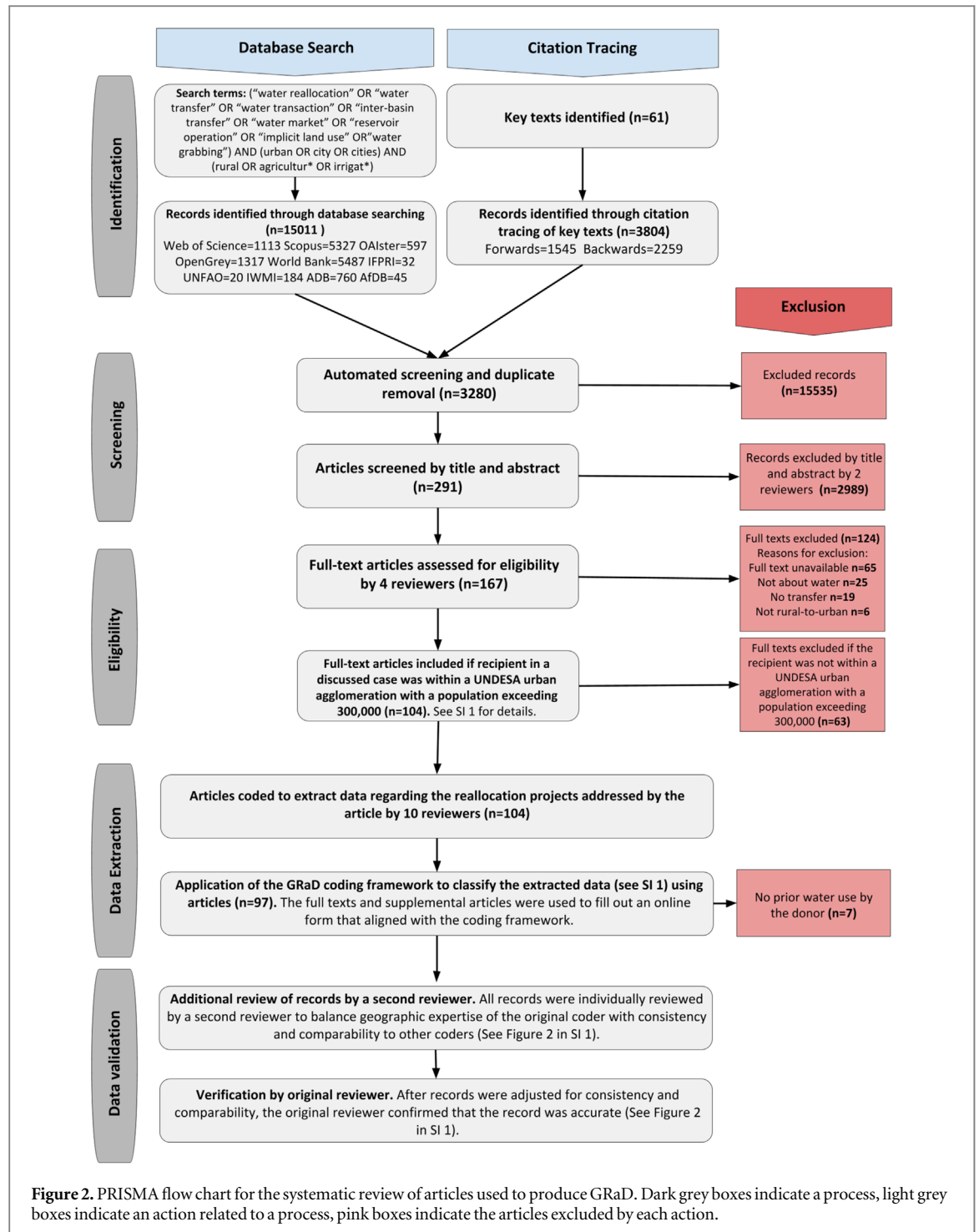
Table 1. Key terms.

Category	Key term	Definition
Mechanisms	Water allocation ^a	A decision-making process where the amount of water available to users and user groups is determined based on a set of guiding principles, typically related to efficiency, equity and sustainability criteria. Often synonymous with 'apportionment'.
	Water reallocation ^b	Transfer of water between users who are committed formally or informally to a certain amount of water when the existing allocation is physically impossible, economically inefficient, or socially unacceptable.
	Transfer ^{b,c}	A transfer refers to the physical movement of water. It differs from 'reallocation' in that the water is not necessarily formally allocated and used.
Participants	Destination (Recipient) Region ^d	Geographical area that received water from a reallocation project. In the context of rural-to-urban reallocation, the destination region is within an urban agglomeration, which will determine access to the water.
	Source (Donor) Region ^e	Geographical area that provides water to the recipient region through changes to the volume, timing and/or quality of water delivered to itself.
Drivers	Dyad ^f	A unique pairing of a single recipient and a single donor.
	Drivers ^f	A direct or indirect factor leading to a reallocation project. Drivers can affect the supply and/or the demand side and can occur over different time scales, including rapid, slow and prolonged onset processes or events.
	Supply drivers ^b	Drivers related to limitations on water supplies. This includes physical limits (climate change, hydrological, meteorological), policy or socioeconomic limits (law or policy change, economic feasibility), infrastructure limits, and degradation of water quality, among others.
	Demand drivers ^b	Drivers related to evolving water demands. This includes recognition of previously neglected rights, recognition of environmental uses, and factors related to urban growth and industrial development.
Decision Types	Administrative decision ^{b,c}	Reallocations made by a national, provincial/state or basin entity depending on the functions assigned to each under the constitution or in law. This action may be taken unilaterally or through negotiation with the donor region.
	Collective negotiation ^{a,b}	A voluntary negotiation process that provides mutually agreeable terms for the transfer of water, often involving some form of compensation.
	Court decree ^b	A unilateral decision by the court that results in non-voluntary transfer of water.
Compensation	Market transaction ^{a,c,g}	Voluntary sales of transferable water rights in a formal market (with associated trade rules) between willing buyers (urban recipient region) and willing sellers (rural donor region). These may be permanent sales, temporary leases, dry-year contracts, or similar.
	Compensation ^c	A mechanism for offsetting the negative impacts associated with the reduction of water availability in the donor region.
	Types of compensation ^d	There are three main types of compensation: 1) Financial compensation where money is paid to actors to offset the reduction of water availability 2) Material compensation where material improvements to infrastructure are made to offset the reduction of water availability and 3) Alternative water supply source to substitute for the prior water source.
	Compensation source ^d	The party that provides compensation. This may be the government, the municipal water utility, etc. This party is not necessarily the direct beneficiary of the water reallocation.
	Compensation recipient ^d	The party that receives compensation. Recipients of compensation include those affected by the negative impacts associated with the reduction of water availability, which can include historic water users and third parties impacted indirectly by the reallocation (i.e. regional economic activities and industries linked to water user groups).

^a Dinar *et al* (1997), Hooper (2015).^b Marston and Cai (2016).^c Molle and Berkoff (2006).^d Dai *et al* (2017).^e Garrick *et al* (2019).^f Wolf *et al* (2003).^g Saliba and Bush (1987).

(1) reallocation from rural to urban regions, (2) projects that have already been fully or partially implemented, (3) donor regions that historically used the water based on a formal allocation and, (4) recipient

regions securing water for drinking water supplies with a population of over 300 000 inhabitants (exceeding the UN threshold of an urban agglomeration), and (5) cases analyzed using empirical research methods



(case studies or comparative research rather than review or synthesis papers). Papers were excluded first based on a review of the title and abstract (eligibility phase). Exclusion at this stage occurred due to a focus on (1) simulation of potential reallocation, rather than implementation of actual projects, (2) planned reallocation projects that were never implemented and/or (3) analysis of hydrological or ecological processes and relationships unrelated to water reallocation.

Third, this systematic review led to the development of the global reallocation database (GRaD), and a coding framework to characterise: the drivers, processes and

outcomes of reallocation; the quality and confidence in the data extracted, including supplemental data sources for priority questions; and the disciplinary framework, methodological approach and scope of the studies. The codebook was developed and tested iteratively by a coordinating team ($n = 4$) and then applied by regional scholars who were allocated literature and reallocation projects based on their geographic location and expertise. The coordinating team verified the coding results by consulting the itemized sources and page numbers used to substantiate coding (figure 2; additional detail of this verification procedure is included in SI 1).

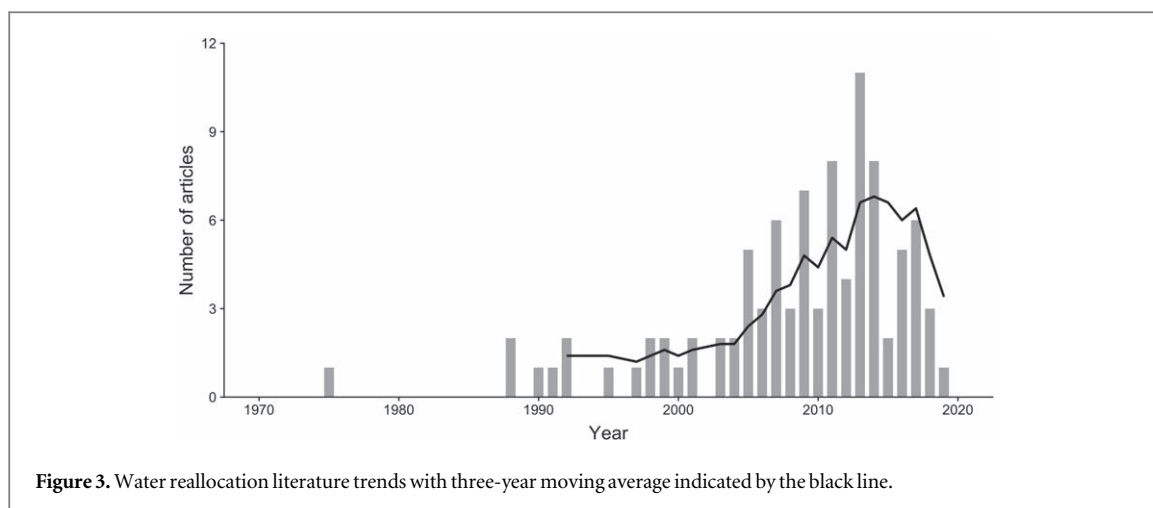


Figure 3. Water reallocation literature trends with three-year moving average indicated by the black line.

The database includes two units of analysis, which are linked. First, the database stored the screened literature, and characterized attributes of the studies. Each article addressed one or more case of water reallocation from a rural ‘donor’ region to an urban ‘recipient’ region. Second, the database established unique records for each reallocation project, some of which have been the subject of multiple studies. We employ the concept of a ‘dyad’ involving a unique pairing of donor (rural) and recipient (urban) region, adapting this term from studies on transboundary river basins in which dyads, or pairs of riparian countries, share a watercourse. The geographic territory combining the donor and recipient region forms the problem-shed (Kneese 1968) associated with changing patterns of water use and associated externalities. The dyad allows for discrete treatment of each water reallocation project serving a city, allowing for the possibility of multiple reallocation projects that serve a given recipient region (e.g. Amman has four different projects with distinct donor regions, therefore involving four dyads). In case of re-development of existing water infrastructure, the project would not be coded as a new dyad, but rather as an evolution of an existing one (provided that the donor and recipient remain the same). Thus, the dyad forms the basis for examining the dynamics of water reallocation, tracing the patterns of interaction and distribution of impacts between rural and urban regions over time. It also allows us to examine changes in the characteristics of the donor and recipient region, such as the urbanization of the donor region, which may trigger efforts to renegotiate reallocation agreements.

The coding process explored the political economy and governance of water reallocation by examining four categories of data for each dyad: (1) contextual features, (2) drivers and characteristics of donor and recipient regions, (3) reallocation processes and institutional mechanisms, and (4) impacts and outcomes. Confidence ratings were included for each priority question to determine the existence and quality of the evidence and to guide supplemental data searches for

information that was either excluded or unsubstantiated in the academic literature. Data synthesis relied on frequency and content analysis using ArcGIS and R studio. Unless otherwise stated, the results of frequency analysis refer to dyads as the unit of analysis.

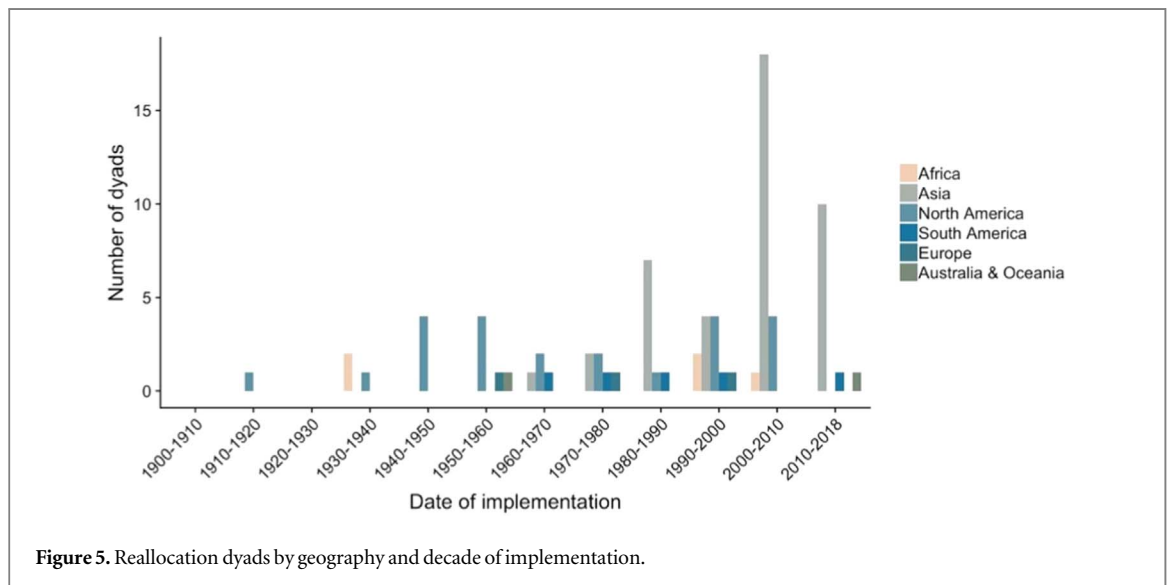
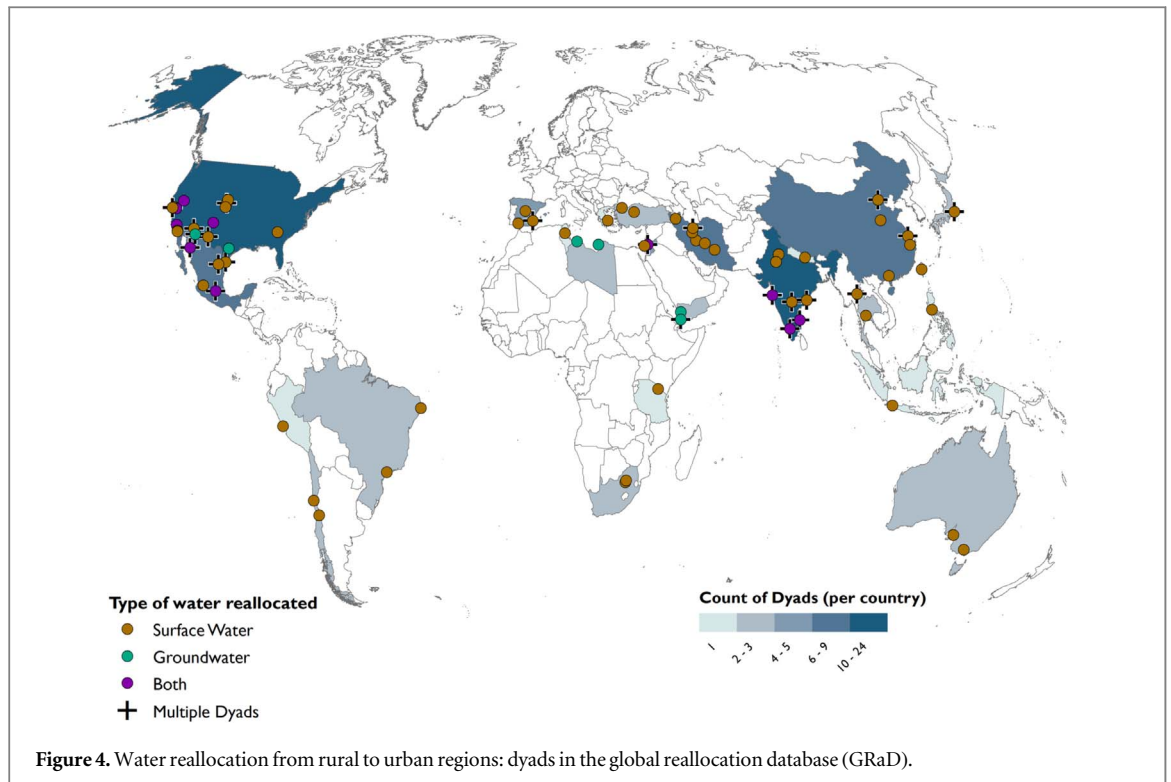
3. Results

3.1. Status and trends

Our systematic review identified 103 reallocation projects (hereafter ‘dyads’) serving 69 urban agglomerations with a population of 300 000 or higher. Twenty one cities have two or more dyads, with several having three or more (e.g. Amman, Hermosillo, and Chennai). Research investment in water reallocation from rural to urban regions is growing, with 77 of the 97 articles published since 2005 (figure 3). Two notable forerunners are a seminal 2006 report addressing over 30 case studies (Molle and Berkoff 2009, Molle and Berkoff 2006) and a special issue of Paddy and Water Environment journal in 2007 (Molden 2007).

Asia and North America account for the vast majority of reallocation dyads documented by the current literature. Of the 103 dyads (covered by 97 articles), 49 are in Asia (covered by 39 articles), while 33 dyads (covered by 52 articles) are in North America (figure 4). Asia accounts for most of the new dyads since 2000, including 23 of 41 dyads implemented since the start of this millennium (figure 5). The five countries with the most documented dyads include the USA (24 dyads, 41 articles), India (18, 17), China (7, 10), Mexico (9, 16) and Iran (7, 5). Conversely, Europe (8 dyads, 5 articles), South America (5, 9), Africa (6, 8), and Oceania (2, 2) had a limited number of reallocation cases described in the studies reviewed.

The geographic distribution of dyads documented by the literature may not fully represent actual reallocation patterns due to several potential biases (see Discussion), as well as the potential for water reallocation to occur through gradual and informal processes that are frequently undocumented due to the lack



of infrastructure and formal decision-making (Venkatachalam and Balooni 2018). We also follow previously developed typologies by distinguishing between reallocation and transfers, where reallocation forms a subset of the broader category of transfers (Marston and Cai 2016); reallocation involves changes to existing or historic patterns of water use, while transfers involve the development of new supplies often considered ‘excess flows’ or undeveloped water in the donor region (Molle and Berkoff 2009). In addition to the 103 reallocation dyads included in our analysis, a further 28 dyads involved transfers of water that had not been historically allocated and used for

human purposes in the donor region (described as ‘excess flows’ by Molle and Berkoff 2009, see SI 2(a)).

Water reallocation from rural to urban regions is driven by a set of factors associated with water supply, demand or, often, the combination of the two (Marston and Cai 2016). We expect that reallocation will be driven by increases in urban water demand associated with population growth in regions with limited, unreliable or polluted supply options. Applying the typology of supply and demand factors identified by Marston and Cai (2016), we confirm these expectations: 80 dyads cited ‘population growth’ and/or ‘growing or emerging water demand’ as a

demand-side driver of reallocation (and all dyads cited at least one demand driver). Common supply-side drivers included water supply limitations ($n = 75$), low water reliability ($n = 36$) or water quality problems ($n = 14$). All dyads with data on drivers ($n = 92$) refer to both supply and demand factors, reflecting that reallocation responds to the interaction of multiple factors rather than just one acting alone (the remaining dyads lacked data regarding drivers).

Investment in irrigation efficiency and wastewater reuse in agriculture are key emerging drivers of reallocation and can also be a part of the donor region's response or adaptation strategy, reducing the amount of water required to sustain agricultural productivity or relying on alternative water supplies. For example, Florke *et al* (2018) estimate that a 10% increase in irrigation water-use efficiency could reduce urban surface-water deficits by 2.7 billion m^3 by 2050, affecting almost 240 million urban dwellers. The GRaD illustrates the emergence of this trend, as increased irrigation efficiency has been cited as a driver in eight dyads. Whether irrigation efficiency investments are a cause or response to reallocation is less clear. In Melbourne, irrigation efficiency in the donor region, and the associated capital financing requirements, constituted an important driver that motivated the project (Cruse *et al* 2014), while in Monterrey, downstream agricultural regions invested in efficiency improvements in response to declining water availability (Aguilar-Barajas 1999, Scott *et al* 2007).

Although multiple factors lead to water reallocation, a single event (e.g. drought, political crisis) was ascribed as the 'trigger' for 27 dyads (26%). For example, drought may play multiple roles, with potential to act both as a stimulus of reallocation and source of tension during implementation. The other 76 dyads involved more gradual (i.e. slow onset) drivers, often spanning many years and, in some examples, several decades from conception of the project (i.e. in planning efforts) to implementation. Experiences in Kathmandu and Northeast Brazil illustrate these decadal timespans and the importance of understanding the political economy and governance dimensions of rural-urban reallocation (Roman 2017, Rest 2018). Several regions experienced extended delays due to political resistance from the donor region and associated demands for compensation (Wester *et al* 2008).

3.2. Sources, structures and processes

Reallocation from rural to urban regions takes many forms. In this review, we identified the sources of water, infrastructure systems and decision-making processes associated with rural-urban reallocation, highlighting the diversity of global experiences. The dyads in the GRaD involve approximately 16 billion m^3 of water per year (median per dyad: $75 \text{ Mm}^3 \text{ yr}^{-1}$, Q10–Q90: $4.5\text{--}453 \text{ Mm}^3 \text{ yr}^{-1}$) travelling a total of approximately 13,000 km (median per dyad: 90 km,

Q10–Q90: 10–274 km) to urban agglomerations with a 2015 population totaling 383 million (median per urban agglomeration: 2.5 million, Q10–Q90: 518 000–18.4 million).¹² Longer-distance reallocation projects tend to involve relatively large volumes of water, while shorter-distance reallocation projects can involve a wide range of volumes (figure 6). There are no documented trends over time toward longer or shorter distances, or smaller or larger volumes. The vast majority ($n = 82$) of reallocation involves surface water, although groundwater is also an important source ($n = 20$). Seven dyads utilize both groundwater and surface water, and eight incorporate wastewater or desalination. Some urban agglomerations in India and North America have multiple dyads, and therefore multiple donor regions, and receive water from both groundwater and surface water sources through multiple transfers (figure 4).

Water reallocation is often seen as an alternative to the construction of new water supply infrastructure. For example, the US National Water Commission concluded that an era of reallocation from low-value to high-value users, such as rural-urban reallocation, could 'make unnecessary the construction of new sources of supply' (Cody and Carter 2009: 59). This logic is also pervasive globally, giving rise to the perception that reallocation occurs because 'most of the easily exploited water resources had been tapped' or come with 'increasing financial and ecological costs' (Meinzen-Dick and Ringler 2008: 211). However, our analysis demonstrates that reallocation and new water infrastructure are not mutually exclusive. Instead, reallocation often requires new built infrastructure ($n = 63$ dyads, 61%), including new reservoirs, canals, pipelines or wellfields. Irrigation efficiency improvements illustrate how reallocation may also lead to the modification of existing infrastructure. Inadequate urban water supply infrastructure can also lead to reallocation through highly decentralized systems of informal water vending, relying on tanker trucks to fill the gap in piped water networks. Such forms of reallocation prove difficult to monitor and track systematically due to their dispersed and informal nature.

Reallocation occurs through multiple modes of governance, both formal and informal. Meinzen-Dick and Ringler (2008) identify three main types: administrative reallocation, market-based transfers, and negotiations with communities, each carrying different sets of impacts, compensation and perceptions. Molle and Berkoff (2006, 2009) distinguish between reallocation governed 'by water rights' ('free markets', 'regulated markets', or 'legal means') and 'by administrative decisions' (by 'formal decision' or 'transfer by stealth') (2006: 14), which highlights the contrast between voluntary versus involuntary mechanisms and the

¹² Data on volume and distance were available for 86 and 89 dyads (of 103), respectively.

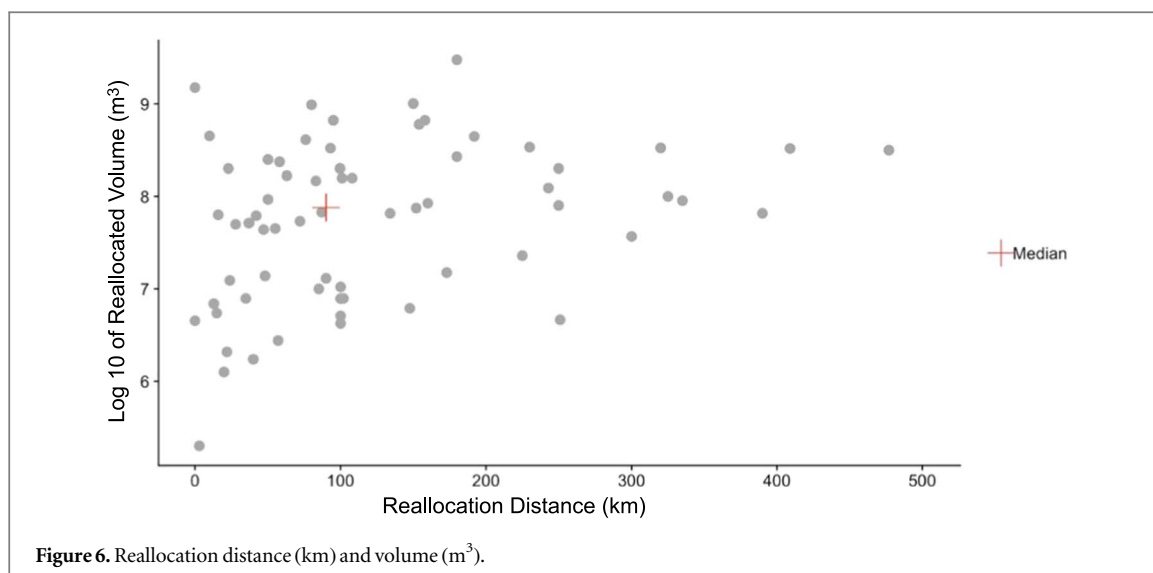


Figure 6. Reallocation distance (km) and volume (m³).

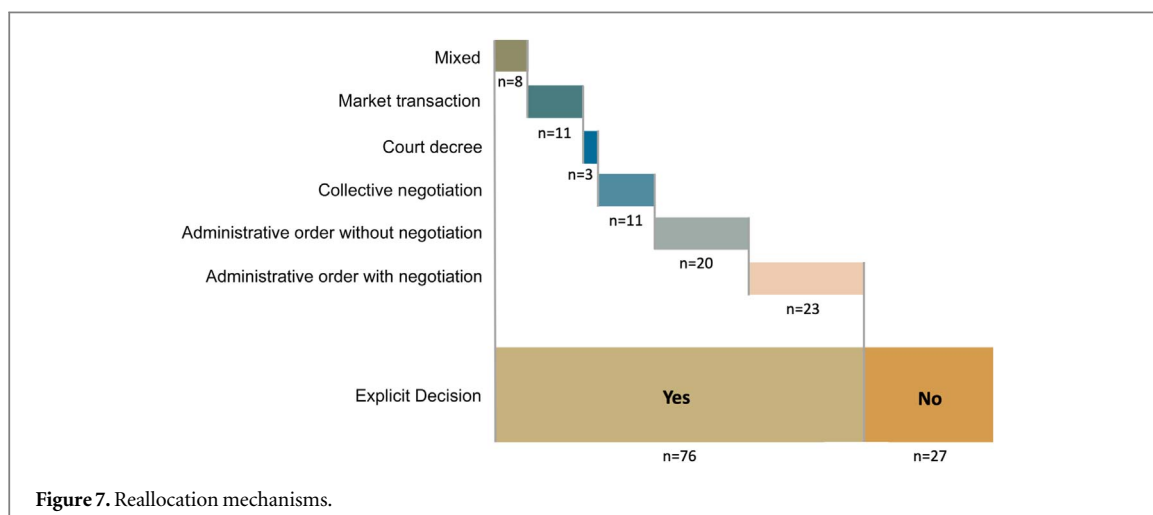


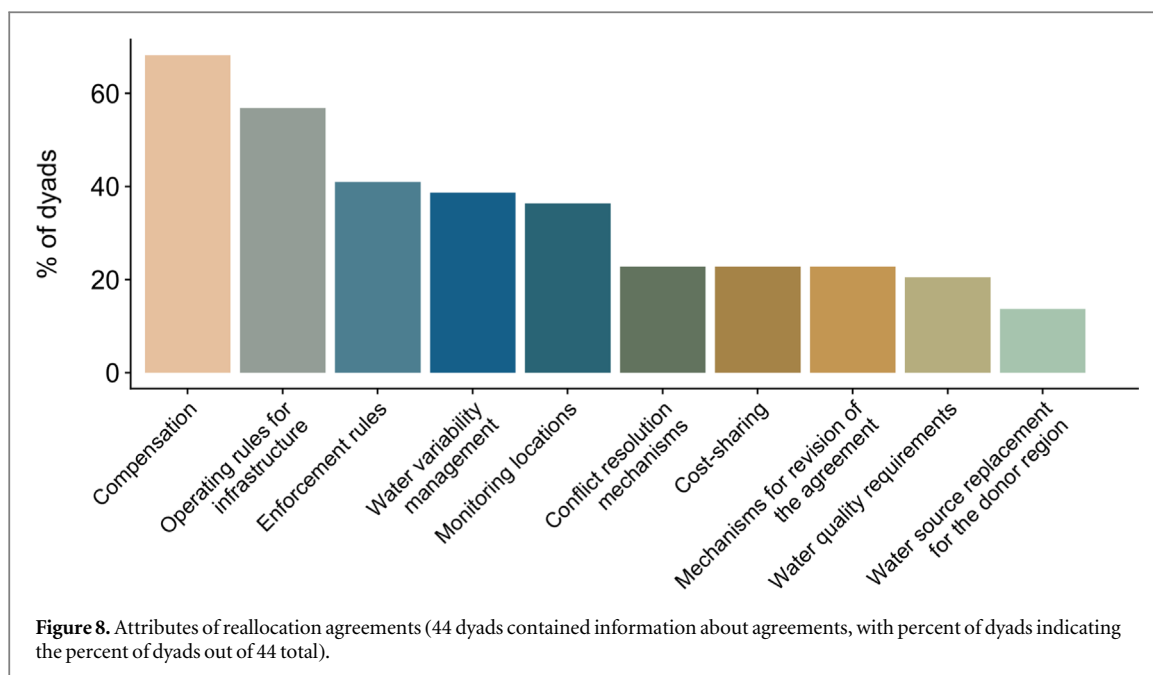
Figure 7. Reallocation mechanisms.

level and type of compensation (ibid; Marston and Cai 2016, Dai *et al* 2017). However, the GRaD shows that few dyads fit neatly into any single ‘pure’ type, often involving a blend or sequence of reallocation mechanisms (e.g. formal administrative decision followed by negotiation with the community, or vice versa).

We examine the existence and type of formal decision-making processes governing reallocation for each dyad. The majority of dyads ($n = 76$, figure 7) involved explicit decision-making processes, which we classified across five, mutually exclusive, options: water transactions governed by a formal water market and associated trading rules ($n = 11$), collective negotiation between the donor and recipient region ($n = 11$), court decree by judicial processes ($n = 3$), administrative order without negotiation ($n = 20$), administrative order with negotiation ($n = 23$), or a mixture of multiple types ($n = 8$). The other 27 lack data (see Discussion).

These results highlight that water reallocation frequently involves horizontal coordination between

rural and urban regions, relying on administrative processes or collective negotiation for over two-thirds of the projects ($n = 54$ of the 76 with an explicit decision). Formal agreements determine the distribution of risks and benefits from the project, including the compensation, broadly analogous to the role of treaties for a watercourse shared by two sovereign territories. Such agreements become an important instrument for governing reallocation, and can be scrutinized in terms of their design attributes (figure 8). We identify 10 design attributes for the agreements discussed by the literature (information was available for 44 dyads). Provisions regarding compensation ($n = 30$) and infrastructure operating rules ($n = 25$) are the most common among those documented in the literature, indicating that over two-thirds of the reallocation projects with information about the agreement include provisions for compensating the donor region. The design and implementation of the agreements involves multiple governance roles and responsibilities. Fifty-one dyads include information regarding the government agency



responsible for administering the agreement, with most relying on national governments ($n = 14$), state or provincial governments ($n = 13$), mixed ($n = 8$), and/or basin authorities ($n = 7$).¹³ Rural to urban water reallocation by its very nature requires coordination across multiple regions, while simultaneously depending on smaller-scale governance bodies for the implementation of individual projects. The dyads reflect *nested governance* arrangements within diverse legal and constitutional settings (Garrick and De Stefano 2016).

3.3. Impacts and outcomes

Reallocation changes both the *magnitude* and *distribution* of costs and benefits among the donor region, recipient region, and the environment as water moves from rural uses to meet the needs of growing cities. Early experiences such as the Owens Valley transfer to Southern California led to the perception of a zero-sum outcome (Libecap 2009): that increasing water security for cities comes at the expense of the donor region, which suffers from the lost water, jobs and productivity. This perception has fueled resistance and renegotiation, underscoring the role of compensation and benefit-sharing arrangements. Despite these trends, rigorous measurement and accounting of costs and benefits is surprisingly rare. Explicit information regarding the impacts of reallocation is available for only 32 of the dyads (31%), which constrains efforts to assess the performance and political economy of reallocation. None of the dyads include fine-grained longitudinal data regarding changing water availability

¹³ Information about the design of the agreements is available for 44 dyads. Information about the administration of the agreements is available for 51 dyads because some agreements have information about the implementing body, but not the design.

and associated changes in the magnitude and distribution of costs and benefits.

Compensation and benefit-sharing arrangements attempt to offset the negative impacts of reallocation on the donor region. Compensation can take many forms, including financial payments, new infrastructure and alternative water supplies. It also varies in terms of the magnitude, recipients and financing source. Literature for 41% ($n = 42$) of the dyads explicitly indicates that compensation was provided to the donor region, and only 14% ($n = 15$) explicitly note that no form of compensation was offered (the remaining 46 dyads, or 45%, lacked any mention or information regarding compensation). Lack of comparable data regarding the type, magnitude, recipients and financing of compensation emerged as a major data gap.

4. Discussion

4.1. Gaps and biases

This review has identified some clear trends, as well as exposing some unsupported expectations about the drivers and outcomes of water reallocation. However, what has emerged most clearly are the gaps in our collective understanding of water reallocation projects.

4.2. Does the literature represent global experience with water reallocation?

Water reallocation projects appear to be focused in the regions with high levels of urbanization (North America) and rapidly urbanizing population centres (Asia) (United Nations Population Division 2014). However, the geographic distribution of projects documented by the literature reviewed in this study

may not fully represent reallocation patterns due to several potential biases: (1) dependence on English-language sources, (2) the tendency to focus on large cities, (3) the predominance of academic research teams led by the Global North, (4) difficulties conceptualizing and measuring more informal processes of water reallocation (including the role of land use change, groundwater depletion and unrecognized or informal water claims and uses), (5) extended lags between the implementation of the projects and their coverage by the literature and (6) the inherent difficulty with data on politically-sensitive mega projects. It also reflects the tendency for water reallocation procedures to ignore customary water rights systems and unlicensed water use, which are still prevalent across the world and particularly in the Global South, as illustrated by the rural-urban water conflicts of Eastern Africa (Komakech *et al* 2012). For example, Molle and Berkoff (2009: 12) refer to several forms of 'surreptitious' reallocation, highlighting the impacts of unlicensed groundwater depletion by a city or its peri-urban dwellers and gradual changes in water use as urbanization leads to unplanned conversion of existing irrigated land (see also figure 1). They point to Lima, Peru and Cairo, Egypt as examples. Gradual changes in reservoir operations could also fit in this category as irrigation dams are slowly re-prioritised to meet the needs of cities, as exemplified by Chao Phraya, Thailand and Hermosillo, Mexico in our database.

Approaches developed in recent studies of climate change adaptation (Berrang-Ford *et al* 2011, Araos *et al* 2016) can be applied to rural-urban water reallocation to improve the representativeness of the literature. A global-scale analysis can identify whether reallocation is occurring, where and in what ways, starting with representative sampling of urban agglomerations. A systematic process would rely on a multi-lingual research network capable of mining data from both literature and primary sources, including interviews for largely undocumented projects. A focus on the past is not sufficient, however, as rapid urbanization is likely to produce pressures and opportunities for reallocation, and research drawing on hot-spot analysis and fine-grained vulnerability assessments will be needed (Busby and Krishnan 2014).

4.3. Bridging conceptual divides to generate comparative insights

Conceptual issues related to the definition, processes and outcomes of reallocation have impeded past efforts to compare and learn from reallocation experiences across diverse contexts. These challenges stem in part from the predominance of individual case study approaches in the literature ($n = 53$ of 97 articles with a single case, and $n = 73$ articles with 2 or less), rather than comparative analyses, often produced without an

explicit analytical framework. Progress will hinge on the development of a common conceptual language and compatible analytical frameworks to guide case selection, identification of key variables and their measurement and evaluation.

Frameworks for studying human-environment interactions have proliferated, however, suggesting that future research can adapt and apply existing frameworks rather than starting from scratch (Cox *et al* 2016). For example, water reallocation involves collective action problems and distributional conflicts studied extensively by scholars of common pool resources, political ecology and environmental justice, who have increasingly addressed larger, complex systems relevant for the analysis of urban-rural systems (Mancilla García *et al* 2019). Qualitative and historical analysis can expose rural-urban struggles over water involving informal or unrecognized claims and uses by drawing on ethnographic approaches, legal pluralism and mixed methods. Improvements in water accounting, agricultural water management and urban hydrology can underpin more integrated assessment of the hydrology and political economy of water reallocation, accounting for changes to the water balance for donor and recipient regions, and the associated changes in the flow of costs and benefits within and across these regions. Virtual water trade (e.g. the water embedded in agricultural trade) can also offer a different way of framing the concept of reallocation that accounts for emerging concerns regarding 'water-grabbing' associated with large-scale land acquisition leading to the export of water-intensive agricultural commodities from rural donor countries to often urban consumers in more advanced economies (Dell Angelo *et al* 2018).

The field of urban science is also developing rapidly, presenting opportunities to integrate research on water reallocation into comparative and global studies of sustainable urbanization (Acuto *et al* 2018). Concepts and analytical approaches from studies of urban metabolism and urban-rural linkages can enrich research on resource allocation and conflict between cities and their hinterlands, particularly in the Global South where patterns of urbanization diverge from historical models (Nagendra *et al* 2018). Realising this potential will require a shared data architecture and coding framework to facilitate cross-case learning and understand changes over time. It can also better harness advances in data science to link earth observation data regarding changing water-use patterns with field observations, large-scale surveys and institutional analysis.

4.4. Is reallocation effective and equitable?

Reallocation can produce a range of outcomes including win-win, win-lose and lose-lose outcomes for donor and recipient regions. Outcomes also evolve

over the course of the project and its implementation, and can involve negative impacts concentrated on vulnerable sectors of the donor region, particularly early in the transition process. Yet data on the impacts of reallocation, both positive and negative, are sparse, and evidence about the performance of water reallocation is constrained. Perceptions and myths regarding reallocation have become entrenched (Libecap 2009), fueling resistance within the donor region and debates about the ownership of water, water use efficiency and the fairness of compensation approaches.

Concern regarding the negative impacts on the donor region has prompted experimentation with different approaches to compensation (Dai *et al* 2017). Insight regarding the type, magnitude, recipient and financing of compensation is a critical area for future research and practice. Given the cross-border externalities linking rural and urban regions, the concept of 'benefit sharing' may offer a constructive analytical and practical path forward, and can learn from the term's application to transboundary water negotiations (Sadoff and Grey 2002). Evidence from existing historical case studies suggests some potential 'win-win' situations where the donor region adjusts to less or different sources of water and thrives due to the ancillary benefits (e.g. flood control, irrigation efficiency) and compensation packages (e.g. new infrastructure, alternative water supplies, community development). Such assessments would require applying a systems approach and a long-term perspective in order to capture and document unexpected consequences of reallocation and distributional implications, including the impacts on ecosystems and third parties.

Progress on comparative studies needs to go hand in hand with in-depth, longitudinal studies regarding costs, benefits, unintended consequences, and compensation. If combined with rigorous analysis of institutional design and governance processes, such research can uncover patterns and regularities associated with different outcomes and identify principles and pathways for more effective and equitable water reallocation.

4.5. Connecting research, policy and practice

This review highlights three critical contributions that research into water reallocation projects can make for policymakers and practitioners. Firstly, new research can inform whether and under which conditions a 'win-win' outcome is feasible, as well as how to achieve this outcome. Second, there is a broader question related to conflict management, and how to establish effective institutions to coordinate water flows across the urban-rural interface. Finally, reallocation experiences cannot be separated from social, environmental and economic contexts, illustrating the need to balance general lessons with context-specific insights

linked to local geographic, political and economic conditions.

Further development of the GRaD and additional comparative studies, coupled with a growing network of researchers and practitioners with local expertise, can offer a resource for planning and policy. First, the GRaD provides a repository of case studies, options and lessons that can be filtered based on context and drivers to facilitate policy transfer. Second, policymakers can identify and understand the common myths and perceptions of reallocation to guide engagement, communication and compensation approaches. Third, a systems perspective that links reallocation with wider discussions regarding development, infrastructure investment and institutional strengthening can offer entry points and opportunities to build flexibility into water resource allocation at a regional level, enabling adjustments in rapidly urbanizing regions. Finally, emerging trends related to irrigation efficiency and wastewater reuse can benefit from the progress and challenges encountered by early adopters.

5. Conclusion

Water reallocation from rural to urban areas will remain a key policy response to the trends of increasing urbanization, changing water supply reliability under climate change, and growing populations. This review demonstrates that we lack the evidence to assess whether a water reallocation project is truly effective, equitable, and sustainable. Policy dialogue on water reallocation is often dominated by relatively unsubstantiated myths, which are frequently tailored to suit the local political context. Any transfer of water from rural to urban areas is often opposed to as a net loss to rural communities; while in other cases, policymakers depend on the alternative myth that increasing irrigation efficiency will always deliver win-win outcomes for both donor and recipient regions.

Water reallocation projects are often expensive, time-consuming, and can have significant consequences for donors and recipients, as well as the environment. These decisions are ultimately political, and deserve to be underpinned by rigorous evidence to negotiate the trade-offs for all involved.

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