The importance of the ‘urban’ in agricultural-to-urban water transfers

Insights from comparative research in India and China

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Abstract

The task of reconciling competing water demands is made more complex by the urban transition occurring in many of the world's river basins. As rising populations and economic development lead to the overexploitation of available water supplies, the largest water-using sector, agriculture, becomes the source of water for growing towns and cities. Yet, urbanisation is accompanied, not only by the movement of water from the agricultural sector, but also by the migration of people from rural areas, the conversion of agricultural land, and wider socioeconomic change. In this context, this thesis argues agricultural-to-urban water transfers are only partially explained by the institutional mechanisms of water policy and the politics of allocation, and that the movement of water from agriculture is also subject to the influence of 'the urban' – processes of urbanisation and the different attributes of urban areas that characterise towns and cities.

To examine the role of 'the urban' in shaping water agricultural-to-urban water transfers, the thesis applies two methodologies. The first is systematic mapping, which evaluates the water transfer literature to understand the scope and content of the evidence-base. The second is an empirical comparative case study of water transfers to three growing cities: Hyderabad in the Krishna River Basin; Coimbatore in the Cauvery River Basin (both in India); and Kaifeng City in the Yellow River Basin (China).

The thesis explores three research areas. The first is the influence of urban attributes – groundwater availability, urban planning, urbanisation rates and urban water governance – on the ways that growing cities obtain additional water resources. The second, is the problem of water transfer impact estimation in the context of rapidly urbanising river basins. The third is the relationship between urban wastewater irrigation and the mitigation of agricultural-to-urban water transfer impacts.

The thesis concludes that to understand how a growing city gains water share from the agricultural sector, and releases it again as wastewater, it is imperative to understand the nature of the city and its growth, in tandem with more conventional analysis of institutional mechanisms of water allocation and the political contexts in which these mechanisms operate.

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Acronyms

CAD	Command Area Development
CEE	Collaboration for Environmental Evidence
CMC	Coimbatore Municipal Corporation
CSE	Centre for Science and Environment
EV	External Validity
GHMC	Greater Hyderabad Municipal Corporation
GO	Government Order
GOI	Government of India
HIB	Hydrographic Information Bureau (Kaifeng)
HMDA	Hyderabad Municipal Development Authority
HMWSSB	Hyderabad Metropolitan Water Supply & Sewerage Board
IRAP	Institute for Resource Analysis and Policy
IV	Internal Validity
IWMI	International Water Management Institute
JnNURM	Jawaharlal Nehru National Urban Renewal Mission
MCM	Million Cubic Metres
MGD	Million Gallons per Day
MLD	Million Litres per Day
NREGS	National Rural Employment Guarantee Scheme
NWP	National Water Policy
PWD	Public Works Department (Coimbatore)
RI	Residual Imputation
TMC	Thousand Million Cubic feet
TNAU	Tamil Nadu Agricultural University
TWAD	Tamil Nadu Water and Drainage Board
ULB	Urban Local Body
UPA	Urban and Peri-urban Agriculture
WALMTARI	Water and Land Management Training and Research Institute
WRB	Water Resources Bureau (Kaifeng)
YRCC	Yellow River Conservancy Commission

1 Introduction

1.1 Research Problem

Reconciling competing demands for water in the context of population growth, economic development and urbanisation, is a looming global challenge. In river basins where rising water demand has reached the limits of supply, decision-makers seek to balance competing claims by developing robust allocation policies that maximise benefit, reduce conflict, and address issues of equity. One obstacle to the formulation of such policies is that 'the world does not revolve around water' (Hellegers and Leflaive, 2015, p.275). Not only are there the multiple and divergent objectives of productive, water-using sectors – agriculture, energy, and industry for example – but many overexploited river basins are experiencing additional changes that have profound effects on water resources. Urbanisation in developing and transition economies is one such example of a profound process of change, because it not only affects water use directly, by drawing it away from the largest water-using sector, agriculture, but also indirectly through its influence over the agricultural labour force, land-use, and wider socio-economic change. In the dynamic and rapidly evolving environments in which these changes are unfolding, this thesis argues that the mainstream institutional mechanisms of water policy, can only partially explain how sectors gain and lose their share of water resources.

Despite the wider implications of urbanisation, and other processes of change in river basins, on sectoral water share and intersectoral water flows, the academic and policy literatures continue to focus predominantly on the design and performance of water allocating institutional mechanisms. Although this policy-centric, technical perspective has been tempered in recent years by the increased attention now given to the political aspects of allocation and transfer (Allan, 2003, Hellegers and Leflaive, 2015, Chakrabarti, 2013, Feldman, 2009, Wester, 2008), the literature rarely addresses the wider question of how material factors and contexts shape the movement of water between sectors. Hence, the framework used to conceptualise water allocation, transfer[1] and its impacts, is arguably incomplete. This thesis addresses this gap using the example of agricultural-to-urban water transfers. Its premise is that processes of urbanisation and urban attributes, a range of biophysical and institutional indicators that characterise towns and cities (see Chapter 5), influence water transfer processes

[1] The distinction between water allocation and water transfer is described in section 1.4.1.

and their impacts at local and river basin levels. Thus, this thesis highlights the importance of considering 'the urban' in the analysis of agricultural-to-urban water transfers.

1.1.1 Research Context

Driven by rising water demand and increased urbanisation, agricultural-to-urban transfers are becoming increasingly prevalent (Molle and Berkoff, 2009, Brewer et al., 2008, Falkenmark and Molden, 2008). The underlying cause of rising water demand is population growth; the world's current population of nearly 7½ billion is growing at a rate of 1% per annum (The World Bank, 2014). At the same time, economic development and urbanisation, particularly in large countries like India and China, are changing societal preferences for water use. Rising wealth, for example, brings with it changes to lifestyles which lead to increased per-capita water consumption (Gerten et al., 2011). In light of these growing pressures on water resources, transfers from agriculture – the largest water using sector – are inevitable (Gohari et al., 2013). However, transferring water from agriculture is controversial for two important reasons. The first is that transferring water from agriculture can constrain agricultural output[2]. This creates additional food security pressures and exacerbates the challenge of feeding growing populations (Godfray et al., 2010). The second reason relates to potential impacts on farmer livelihoods. These are likely to be felt disproportionately by poor farmers (Meinzen-Dick and Ringler, 2008).

1.1.2 Overview of Research Design

The thesis applies an exploratory inductive research design, to understand how urbanisation and urban attributes shape agricultural-to-urban water transfer processes and their impacts. It draws on two methodologies. The first is a systematic map, which evaluates the evidence supporting current understandings of agricultural-to-urban water transfer theory. The map aims to summarise the state of knowledge in this field and highlight research gaps. The second methodology is a stepwise comparative case study approach[3] (Levi-Faur, 2006, Levi-Faur, 2004), based on three empirical cases developed using interdisciplinary, mixed research methods. Two of the cases are located in India. These are water transfers to the large city of Hyderabad in the Krishna River Basin and transfers to the smaller city of Coimbatore in the Cauvery River Basin.

[2] See Loeve et al. (2007) for an example where agricultural production is maintained despite water transfers to higher value urban uses.

[3] See Eisenhardt and Graebner (2007) on the links between inductive research, theory-building and comparative case study methods.

The third case examines transfers to Kaifeng City in northern China's Yellow River Basin. Cases span different size cities, with different rates and styles of urbanisation, different types of urban water governance, and different institutional arrangements for water transfers. This allows water transfer processes and their potential impacts to be understood in different contexts.

Growing cities in India and China provide a propitious setting for the study of agricultural-to-urban water transfers for two reasons. Firstly, both countries are experiencing significant and well-documented water challenges related to the overexploitation of surface and groundwater resources (Vaidyanathan, 2013, Rodell et al., 2009, Narain, 2000, Zheng et al., 2010). Secondly, they are the world's most populous countries and are expected to contribute, in absolute terms, the most to urbanisation between now and 2050 (United Nations Department of Economic and Social Affairs, 2014). As they shift from being primarily agricultural economies towards increasing levels of industrialisation and urbanisation, their national water use priorities are changing. In water-stressed river basins, this is resulting in transfers of water away from agriculture. For example, Indian urban water demand is expected to rise by over 2½ times its current level by 2050 (Mukherjee et al., 2010) and China's national industrial water consumption (normally situated in urban areas) has increased by 4% in 10 years (Wang et al., 2015). These water transfers bring with them controversy and conflict (Joy et al., 2008, Wang et al., 2015) because of both the importance of agriculture for food security and livelihoods, and also the opaque ways in which cities and the industries[4] they host, effect change in the share of water used by agriculture.

1.1.3 Chapter Structure

The remainder of this introductory chapter proceeds as follows. Sections 1.2, 1.3, and 1.4 develop the main contention of the thesis related to the influence of urbanisation and urban attributes on processes of water transfers and their local and river basin scale impacts. The argument begins with section 1.2, which compares two different concepts regarding the causes of water transfer and how they influences the theorisation of agricultural-to-urban water transfers. Section 1.3 defines urbanisation and explains why it has profound effects on river basins and water transfer processes. Section 1.4

[4] Because the political economy of water allocation and transfer to municipal/urban uses and industries are different, researchers argue that these sectors should be treated separately in water transfer analysis (Molle and Berkoff, 2009). However, industrial and urban water uses are often difficult to isolate, particularly where industries are supplied by centralised urban water distribution networks or where informal water use in urban areas is high. Therefore, this thesis includes both urban and industrial water use in its framing of agricultural-to-urban water transfers.

examines the water allocation and transfer literature and summarises its main features. Section 1.5 sets out the thesis objectives and expands upon the central contentions. Section 1.6 presents the thesis structure, which guides the reader through the remaining chapters. Finally, section 1.7 summarises the findings of the thesis and its original contributions.

1.2 Drivers of Intersectoral Water Transfer

This section considers the drivers of water transfer and changing sectoral water share, which are typically understood in terms of water scarcity and economic development. It argues that there is an emphasis given to water scarcity rather than economic development, which shapes the conceptualisation of transfers. Here, water scarcity is defined in the sense of sufficiency, where water supply is no longer sufficient to meet rising demand. While scarcity is unequivocally an important driver of transfers, the scarcity framing of water allocation and transfer research tends to exclude theoretical reflection on how *shifts in water demand*, caused by economic development and urbanisation, also change the share of water between sectors. The shifts caused by changes to water demand relate to both changing water production preferences in developing and industrialising economies (Anand, 2007) and but also to how changing market signals influence agricultural inputs and outputs (Meinzen-Dick and Ringler, 2008). Hence, sectoral water use, whether urban or agricultural, is shaped by the wider economy in addition to the limits imposed by scarcity.

1.2.1 Water Scarcity and Transfers

Water scarcity, the trigger for many transfers, is often depicted as an inevitable outcome of river basin development. As river basins develop and the level of water utilisation increases, basins move through common stages of a development trajectory (Molle et al., 2007). The final stage of the trajectory, where water demand meets the limit of supply and river basins close, triggers the reallocation of water from the agricultural sector to higher value uses. Basin trajectories of this sort have been presented by a variety of researchers and applied to many river basins around the world. See for example, Molden et al. (2000) whose trajectory model distinguishes between three phases of water use: development, utilisation, and allocation. An example of the application of this model is to the Lerma-Chapala Basin in Mexico, where it shows how water use and policies changes over time (Wester, 2009).

River basin closure is a basin condition against which many water transfers are set. It is defined as the overexploitation of river basins that prevents downstream commitments from being met (Molle et al., 2007, Seckler, 1996, Molden, 1997). Closure is either hydrological, for example when discharge to the ocean is reduced. Or, it can be understood in administrative terms whereby a river basin is over-allocated and no further permits nor licences can be granted (Lannerstad, 2008). The significance of river basin closure for water transfer theory is that closure increases the hydrological 'interconnectivity' between water users and between surface and groundwater systems (Molle et al., 2010). In this scenario, rising demand in one sector causes a reduction in water use elsewhere, often described as a zero-sum game[5] (see for example, Bhatia et al. (2006)). In the context of the zero-sum game environment, institutional mechanisms for water allocation are applied to move water from agriculture to other sectors.

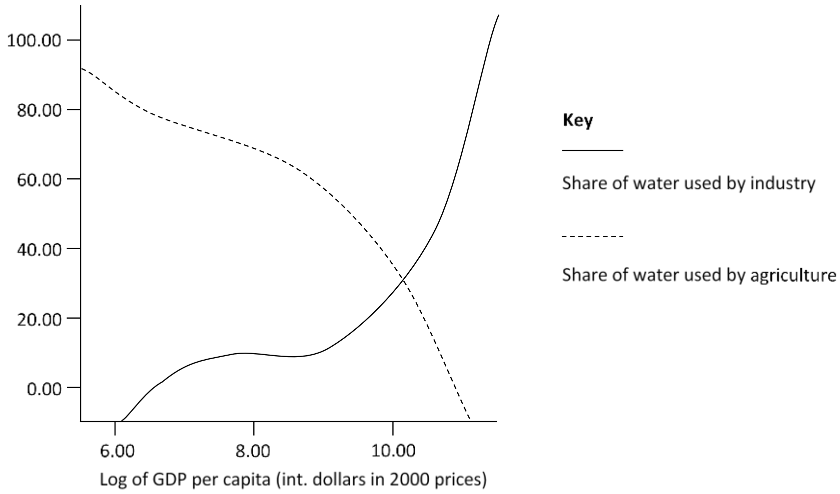
The combination of river basin development, water scarcity and river basin closure is the basis for much of the theorisation of agricultural-to-urban water transfers. However, as the following sections will show, economic development means that there are other factors at play.

1.2.2 Economic Development and Water Transfers

Water also moves out of the agricultural sector as countries transition towards greater economic development and societal preference for water-use changes. Following Anand (2007), this can be demonstrated by correlating the share of water used in agriculture versus the share of water used by industry against GDP (industry is assumed in this example to be a proxy for urban water use given the prevalence of industry in cities, particularly in China). This relationship is depicted in Figure 1, which shows that as GDP rises, the share of water used in agriculture goes down.

[5] This thesis challenges the zero-sum game concept on the basis that urbanisation occurs alongside land-use change which can 'reopen' sub-catchments by reducing the area under cultivation. This counter-narrative is developed in Chapter 5.

Figure 1. GDP per capita and share of water used for agriculture and industry.



Source: Simplified from Anand (2007, p38).

The relationship depicted in Figure 1 is not necessarily linked to water scarcity but rather to changes in the structure of the economy and preferences for water use. Hence, the movement of water away from agriculture can be viewed as an inevitable consequence of economic development. In tandem with economic development, urbanisation also plays direct and indirect roles in determining how much water is used by the agricultural sector. The role of urbanisation in changing water use in river basins and influencing water transfers is discussed in the following section.

1.3 Urbanisation

Urbanisation and its role in water transfers is the central focus of this thesis. This section sets out the key concepts related to urbanisation to support the analysis. Thus, urbanisation and important features of cities are defined, the main relationships between urbanisation and water in river basins are presented, and finally national level trends in urbanisation for India and China are described.

1.3.1.1 Defining Urbanisation

Urbanisation is defined as the demographic growth of towns and cities (McGranahan and Satterthwaite, 2014), and its continued trajectory means that today's world is increasingly an urban one, with 54% of the world's population living in urban areas in 2014 (United Nations Department of Economic and Social Affairs, 2014). Increases to urban populations arise through three different processes: natural population growth within urban boundaries; rural to urban migration; and lastly, the absorption of formerly rural areas into the urban footprint cities (McGranahan and Satterthwaite, 2014). Of these, rural-to-urban migration accounts for the most significant increase in urban populations, often causing the expansion of peri-urban areas. The peri-urban and other definitions related to cities defined in Table 1 to clarify terms used in the remainder of the thesis.

Table 1. Definitions of city components.

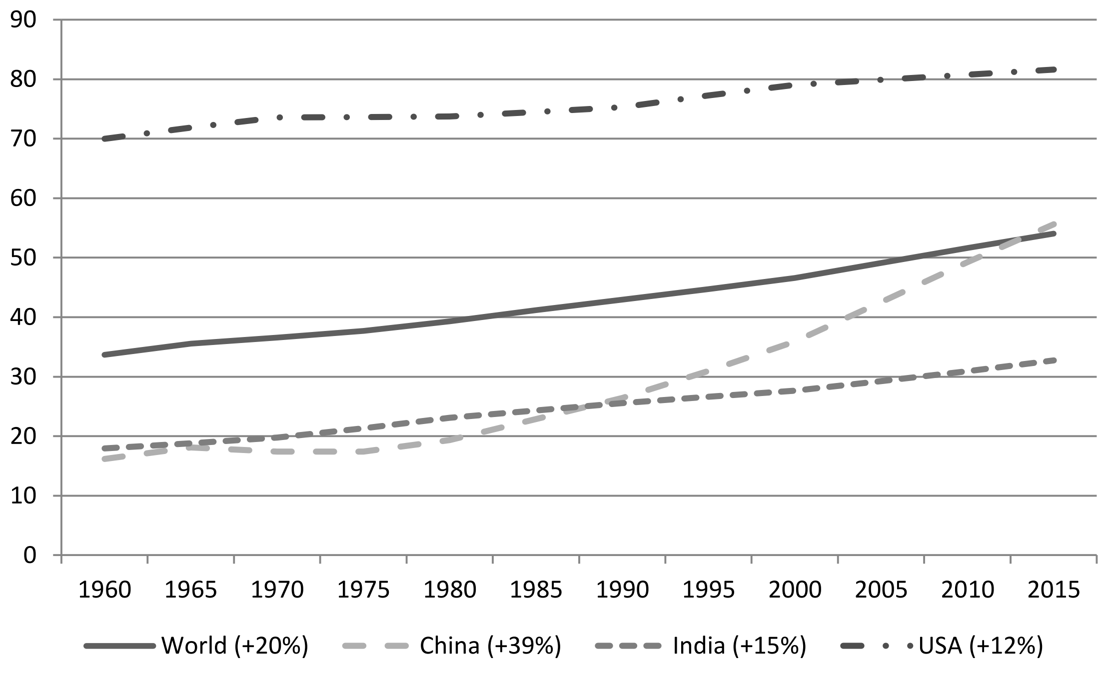
Term	Definition
City	This thesis defines a city as an administrative unit. Its area is delimited by administrative boundaries, often based on roads. This is usually a metropolitan area that contains a 'core' city and an outer periphery or peri-urban zone (OECD, 2009).
Core City	The core city is the inner part of the city that has dense transport links and urban services (OECD, 2009). In the case study cities, the water supply and distribution network often extends across the core city but not the wider metropolitan area.
Peri-urban	A detailed definition of the 'peri-urban' is given in Chapter 6 based on theoretical reviews by Adell (1999) and Marshall et al. (2009). To summarise, the peri-urban is a transitional zone at the leading edge of cities, and often lies outside the administrative urban boundary.

1.3.2 Urbanisation and River Basins

The transition towards greater levels of urbanisation affects water-use in river basins, and hence agricultural-to-urban transfers, in four key ways. The first is by changing patterns of sectoral water use. For example, as cities grow, they become points of concentrated demand that absorb water across increasingly large distances (see for example the distances across which water is pumped to Hyderabad, described in Chapter 4), thereby changing the spatial distribution of water in river basins. The second effect is felt through land-use change as urban areas expand over agricultural land (Pandey and Seto, 2014, Yan et al., 2015). This has an indirect effect on agricultural water demand as will be discussed in Chapter 5. The third effect relates to increases in the basin level intensity of water use. Use-intensity increases when urban demand is prioritised above agriculture, and the number of water-use cycles increase. The fourth effect of urbanisation on water resources is the indirect effect cities have on agricultural production. For example, urbanisation influences the price and availability of agricultural inputs such as labour (Hussain and Hanisch, 2013, Molden, 2007). Thus, urbanisation affects agricultural production and consequently the volume of water used by agriculture. It is on the basis of these four relationships, that this thesis emphasises the role of urbanisation on not only agricultural-to-urban water transfers but also in changing water use across river basins.

Despite the influence of urbanisation on water use in river basins, and therefore processes of water transfer, most research on agriculture-to-urban water transfers is based on the experiences of the United States (see Chapter 2 for the geographic distribution of transfer research). This is a highly-urbanised environment where rates of continued urbanisation have begun to stabilise. Yet, agricultural-to-urban water transfers are increasingly occurring in river basins in rapidly urbanising countries. In these countries rates of urbanisation may be higher, or the impact of urbanisation greater given the low levels from which increasing urbanisation takes place. To illustrate the significance of this different context, urbanisation levels and rates in India and China – the setting for the case studies – is compared to the United States in Figure 2. This figure presents the change in percentage urban population over time for the United States, India, and China.

Figure 2. Percentage change in urban population over time.



Source: (United Nations Department of Economic and Social Affairs Population Division, 2014).

Three points can be drawn from Figure 2. Firstly, the rate of urbanisation in China is comparatively rapid. Secondly, the United States is highly urbanised and its rate of additional urbanisation is now in line with the global average. Thirdly, India's absolute rate of urbanisation is much lower than China's, and is similar to that of the United

States. However, the relative increase in India's urbanisation is important because it starts from a lower level. Hence the relative effect of India's change in urban population over the time period is more significant than that of the United States. These observations point to the different urbanisation contexts in which agricultural-to-urban water transfers occur in the three countries. In light of the centrality of urbanisation to the thesis, the following section explores the differences in urbanisation between India and China in more detail.

1.3.3 Urbanisation in India and China

China and India are urbanising differently. India is at the beginning of its urban transition, with slower urban growth (McGranahan, 2012) and a more informal urban planning regime (Roy, 2009). China's urbanisation meanwhile is faster, more closely linked to industrialisation, and rural-to-urban migration is effectively controlled by the state. This section reviews these differences as they relate to water transfers. It begins by examining the control of rural-urban migration, which impacts urban planning and the levels of informality in agricultural-to-urban water use and transfers (Chapter 5 provides a detailed analysis of this argument).

Compared to India, Chinese authorities have far greater control over rural-urban migration (Fan et al., 2005). Local governments control flows of people using the household registration system called *hukou* (Miller, 2010). Operating as form of domestic passport, the *hukou* system designates households as 'rural' or 'urban' and links this designation to the provision of benefits such as health and education. Thus rural-to-urban migration is managed by controlling access to services. Although the *hukou* system is undergoing substantial reforms due to its role in creating inequality, it has enabled the state to exert control over urbanisation and to plan cities (World Bank and The Development Research Center of the State Council. P. R. China, 2014). In India, by contrast, the freedom to migrate is enshrined in Article 19 of the Constitution of India (The Constitution Of India, 1949). As a result, rural-urban migration constitutes a significant proportion of the growth of India's large and small cities. The unplanned nature of this influx of people contributes to informal slum settlements at the urban periphery (Srivastava, 2005). These areas tend to have limited water infrastructure, which therefore increases informal modes of water access (Eshcol et al., 2009).

A second difference between India and China's urban growth is that Chinese urbanisation is more closely linked to industrialisation. The Chinese Government has encouraged urbanisation as a means to provide cheap labour to support burgeoning industry. Where workers are needed, rules related to the temporary *hukou* are loosened thereby encouraging low wage agricultural workers to come to cities (Miller, 2010). India's urbanisation has not had quite such an industrial flavour and many rural-to-urban migrants are not able to access employment. These different levels of industrialisation affect the relative water demands of towns and cities. For example, Chinese cities with more industries are likely to require more water.

This section has introduced the links between urbanisation and water use in river basins and the differences between urbanisation in India and China. It has illustrated the importance of urban contexts for understanding agricultural-to-urban water transfers and their impacts. These preliminary observations are developed in the later chapters of the thesis, particularly the argumentation Chapters 5, 6, and 7. Moving from the relationship between urbanisation and water transfers, the following section outlines the main features of the water allocation and transfer literature. It will show that the majority of research is based on three institutional mechanisms for water allocation, which are often researched in isolation from their wider river basin contexts.

1.4 Water Allocation and Transfer Literature

This section introduces the water allocation literature as it relates to processes of intersectoral transfer at the subnational level. The research on water allocation and transfer is dominated by case studies, hence, there has been limited theoretical development at the meta level. Rather, the literature is replete with case specific examples and contributions. The notable exception is Dinar et al.'s (1997) technical working paper on institutional mechanisms. This remains the most comprehensive description of allocation theory and its technical approach to water allocation influences large parts of the academic and practitioner literatures. For instance, the prescriptive 'how to' allocation and basin planning guidelines published by donor agencies. See, ADB and WWF's guide to Basin Allocation Planning as a recent example (Speed et al., 2013).

Following from Dinar et al., (1997), this section outlines the main principles and mechanism for water allocation and transfer. The focus is limited to sub-national level allocation and transfer in terms of inter and intra allocation. Thus, the extensive trans-boundary literature is excluded because it is beyond the scope of the thesis. The second part of the section then introduces the subset of research on agricultural-to-urban water transfers. The review of the literature begins by defining key terms used in the water allocation and transfer literature.

1.4.1 Definitions

Several interchangeable terms for different aspects of water allocation and transfer are found in the literature. To guide the reader, this section provides definitions of the main terminology and concepts. These are summarised in Table 2. Of these definitions, two are emphasised because of their centrality to the thesis contentions. The first is the distinction made between water allocation and water transfer. *Water allocation* is defined as the decision-making process that determines how much water should be used by each sector. This decision is guided by an allocation principle or objective. *Water transfer,* meanwhile, is defined as the physical movement of water between or within sectors. The term transfer can also relate to the transfer of water rights. The second distinction is between *processes* of water transfer and *mechanisms* of water transfer. Processes of transfer refer to the different ways that water moves between sectors. It is an umbrella term that incorporates formal transfer processes brought about by institutional mechanisms, informal transfers and indirect processes. These are explored and defined in more detail in Chapter 5. Mechanisms of water transfer, meanwhile, refer to formal institutional mechanisms such as markets or administrative edicts discussed in section 1.4.3.

Table 2. Definition of terms related to water allocation and transfer theory.

Term	Definition
Allocation	Water allocation is the **decision-making process** to determine the volume or proportion of water available for sectors or individuals. These decisions are based on **principles** for allocation.
Principle for allocation	A principle for allocation is a goal or objective that defines how water should be allocated. Typical principles for water allocation include efficiency (maximising economic welfare), equity, or objectives such as achieving domestic food security.
Institutional mechanism for water allocation	Institutional mechanisms are defined as the rules, laws, regulations and procedures through which allocation decisions are implemented. These include water policy tools such as priority allocation, quotas, permits, licenses, and market mechanisms.
Water Transfer	The physical movement of water or the exchange of water rights.
Process of Water Transfer	An umbrella term indicating the various different ways water moves between sectors. This incorporates formal transfers through institutional mechanisms, informal transfers, and indirect processes explained in Chapter 5.
Apportionment	This term is more commonly used in North American water resource literature, see for example Heinmiller (2009). It is considered to be synonymous with 'allocation'.

Appropriation	Appropriation is defined in two different ways. Lankford states it is an '*implicit or unforeseen shift*' in water use by one group that results in reduced water use for other groups (Lankford, 2011). Meanwhile, (Celio et al., 2010), define appropriation as a deliberate strategy through which the power of one group enables a 'capture' of resources.
Reallocation	Reallocation is the process of changing water allocations. It is distinct from 'allocation' in the sense that reallocation applies to contexts where water is fully committed. Reallocation, therefore, is a politically more difficult proposition than initial allocation. Nevertheless, the terms reallocation and allocation are often used interchangeably in the literature.
Water Rights	Water rights are defined as the relationship between people and water. They have specific characteristics including: quantity, timing, location, quality, conditionality, duration, ownership and transfer and security and enforcement (Abernethy, 2005). Many analysts view secure property rights as a prerequisite for effective water resources allocation (Rosegrant and Ringler, 2000, Schlager, 2005). However, there is limited evidence to suggest that securing property rights aids transfer in regions outside of the United States, Australia, and Chile (see evidence base in Chapter 2).

1.4.2 Principles of Water Allocation

The starting point for any water allocation and transfer decision is the principle of allocation. Principles set the objective for decision-making related to how much water each sector should be given. The most commonly applied principle is economic efficiency, which seeks to deliver the greatest aggregate benefit to society. This usually entails water transfer from low-value (agriculture) to higher-value uses (Dinar et al., 1997). Other examples of allocation principles include social and environmental justice (Syme and Nancarrow, 2008, Movik, 2014, Patrick, 2013) and equity (Roa-García, 2014, Wegerich, 2007). Allocation objectives can also take the form of national goals, for instance the need for domestic food security or the human right to water.

Outwardly, principles of allocation shape decision-making, however, there are often other external factors that influence water decision-makers. These arise because allocation is an inherently political process (Allan, 2003) and is also constrained by earlier choices in river basin development. Decisions, therefore, are influenced by political economy at local and national levels and by the constraints of path dependence from river basin histories (Heinmiller, 2009, Molle, 2008). Path dependent constraints take two forms. The first is large infrastructure with long lifespans such as dams, which limit new water distribution options. The second is the power of actors seeking to maintain the status quo with respect to the distribution of water rights (Livingston, 2005). Together, the political environment and path dependence therefore modify the extent to which objectives set out using allocation principles can be achieved.

Despite the limitations placed on allocation decision-making by these two factors, a significant amount of research is nonetheless directed at establishing hypothetical optimal allocation scenarios based on principles of efficiency (see, for example, Divakar et al. (2011), Dixon et al. (2005), Grafton et al. (2011), Ho et al. (2008), Rosegrant et al. (2000), Zhu et al. (2010)). Such studies rarely consider the extent to which the allocation targets derived from optimising models are practicable given the political and infrastructural environment.

1.4.3 Institutional Mechanisms for Water Allocation

The three[6] main institutional mechanisms considered in the literature are: market mechanisms; administrative decisions; and collective demand management. These are described in turn below and summarised in Table 3, which compares their relative advantages and disadvantages. Despite their different characteristics, the choice of mechanism is dependent on several further local and national level factors including the property rights regime (private, public or collective), the level of water allocation (user-group, sub-catchment, catchment scale or national level) and existing institutional arrangements. Furthermore, mechanisms may overlap within a single river basin, be used in combination and operate at different levels (Bruns et al., 2005b).

Table 3. Overview of formal allocation mechanisms.

	Definition	Advantages	Disadvantages
Market Mechanisms	Water traded between or within sectors	Seller can increase profitability. Buyer can take advantage of increasing availability.	Conditions for efficient functioning of markets don't normally exist.
Administrative Mechanisms	The state allocates who gets water.	Theoretically Equitable.	Prone to corruption and rent-seeking
Collective action and demand management	Collective action based demand management. E.g. farmer managed irrigation	Efficient and responsible use possible.	Difficult to apply across large scales.

Source: Adapted from Dinar et al. 1997.

[6] Marginal cost pricing – a fourth possible mechanism – is not addressed in this thesis. Despite its qualified success in municipal demand management, the application of this approach to agricultural water use has proved difficult due to the problems of price setting and transaction costs of metering water to enable volumetric pricing (Ward, 2007).

1.4.3.1 Market Mechanisms

Market mechanisms allocate water by enabling the trade of private water rights. They are the most researched institutional mechanism and the literature is heavily biased towards their study. For detailed analysis, the reader is directed to comprehensive review articles (Saliba, 1987, Chong and Sunding, 2006, Garrick et al., 2013). Here, a brief review of the main features of the water market literature is presented. There are many different types of market, including: permanent versus temporary trades; transfer of outright ownership; or transfer of usufruct rights. While most research on markets examines transfers within the agricultural sector, intra-sectoral markets have also been studied, for example, in Australia (Crase et al., 2008, Crase et al., 2004, Straton et al., 2009, Zaman et al., 2009), Chile (Bauer, 2004, Bjornlund and McKay, 2002, Solanes and Jouravlev, 2006) and of course in the Western United States (Nunn, 1987, Howe and Goemans, 2003, Howe et al., 1986).

This research points to the qualified success of market mechanisms under certain conditions, nonetheless, it also highlights many challenges. These relate to transfer infrastructure (getting water from sellers to buyers) and disseminating the information needed to set appropriate prices (Bjornlund and McKay, 2002). There are also questions over the appropriate level of transaction costs (Easter et al., 1998), barriers to market implementation (Zhang, 2007) and, importantly, on the property rights which form the basis of market mechanisms (Bruns et al., 2005b, Schlager, 2005, Whitford and Clark, 2007). The establishment of water markets in developing country contexts is more patchy; nevertheless, reforms to water policies increasingly include market approaches to allocation (Bruns et al., 2005a). See for example the pilot studies of water rights transfers in the Yellow River Basin (Interview, Yellow River Basin Conservancy Commission, 2013).

1.4.3.2 Administrative Mechanisms

Administrative water transfer mechanisms are common in developing countries and transitional economies including India and China (Meinzen-Dick and Ringler, 2008). Under these systems, the State holds water rights and allocates resources using permits, rules, licenses, and quotas. Typically, administrative mechanisms give little consideration to the economic value of water; hence, administrative systems are often associated with greater equity. However they are also more prone to rent-seeking than market mechanisms (Renger, 2000). Examples of administrative mechanisms include the priority allocation policies of India that are implemented through Government

Orders and the quota systems of China's Yellow River Basin. These are described in more detail in Chapter 4. Far less research has focused on administrative mechanisms as compared to their market counterparts, despite the fact that they are arguably more common (for example given their use in world's two largest countries).

1.4.3.3 Collective Action and Demand Management

The final institutional mechanism is collective action. Typically the aim of collective action, as it relates to water allocation, is demand management. This type of allocation mechanism tends to operate at local levels, for example water users associations within irrigation systems. Despite the importance of collective action and its related institutions, exemplified by the work of Ostrom (1993), this thesis does not directly address this mechanism. This is because the urban-centred nature of the thesis means that examination of the role of collective action in agricultural water demand management is beyond the research scope.

1.4.4 The Agricultural-to-Urban Water Transfer Literature

This section introduces the agricultural to urban water transfer literature, which is a subset of the wider allocation literature discussed above. The overview given here provides the basis for the more detailed evaluation of this literature presented in the form of a systematic map in Chapter 2. The systematic map will show that the agricultural-to-urban water transfer literature mirrors many of the features of the wider allocation literature. Research focuses primarily on the role of institutional mechanisms, and is characterised by a large number of case studies and a handful of review articles. The cases span research on transfer processes, their impacts, and related issues such as conflict. Many of these case studies are based on transfer experiences in the United States, examined primarily using economic approaches. Given the detailed case review in Chapter 2, this section limits itself to an examination of the theoretical contributions made by two of the most important agricultural-to-urban water transfer review articles. These provide an overarching perspective on the literature.

The most comprehensive review article is Molle and Berkoff's analysis of intersectoral allocation between cities and agriculture (for the full report, see Molle and Berkoff (2006) or for the summary article, see Molle and Berkoff (2009)). Drawing on the water transfer and urban water supply literatures, this article makes a number of contributions to transfer theory, including the presentation of a classification system to understand the various types of agricultural-to-urban water transfer. Two of its arguments are relevant to the thesis contentions. The first is that Molle and Berkoff consider water reallocation from agriculture to be largely successful. This contrasts with many of the reported experiences of transfer in the United States. The second argument contends that urban growth is unlikely to be constrained by scarcity given that cities obtain water in different ways. This view is summarised in Kenney's observation that 'cities follow the path of least resistance' (Kenney, 2003, cited in Molle and Berkoff, 2006)).

A second review article, by Meinzen-Dick and Ringler (2008), examines the drivers and consequences of water reallocation from the agricultural sector. The article argues that there are many potential negative consequences of agricultural-to urban water transfer. For example, reduced food security and lower farmer livelihoods. The article also describes the many different transfer processes through which water leaves the agricultural sector. In addition to conventional institutional mechanisms, the authors emphasise implicit and illegal transfer processes. For example, transfers resulting from investments in industries and urban water supply systems. However, similar to the earlier review by Molle and Berkoff, no estimate of the significance of these informal, implicit, and illegal transfers is given. Therefore it is difficult to ascertain whether these processes are ad-hoc and exceptional or, as Chapter 5 will argue, systemic and determined by local conditions.

1.4.5 An Incomplete Theorisation

In light of the above introduction to the water allocation literature and the earlier discussion on economic development and urbanisation, this thesis argues that the theorisation of agricultural-to-urban water transfers is incomplete. The current research framework focuses not on the broader question of how sectoral water share changes and the processes by which water moves from one use to another in response to relative shifts in demand, but instead largely limits itself to the examination of the institutional mechanisms that facilitate transfers. For relatively stable river basins where the institutional environment for water management is strong, for example the Western United States, this framing of transfers is appropriate. However, for river basins where economic, urban, and agricultural transitions exert a powerful influence over land and water use, the potentially significant role of non-formal water transfers (the informal and indirect processes described in Chapter 5) is overlooked. Furthermore, this narrow view of agricultural-to-urban water transfers affects not only the theorisation of water transfer processes, but, as will be shown in Chapters 6 and 7, also affects the analysis of impacts, both to water-donating regions and at the level of the river basin. It is this incompleteness that motivates the research objectives of thesis.

1.5 Research Contentions and Themes

By focusing on the influence of urban contexts and urbanisation processes, this thesis develops a broader theorisation of agricultural-to-urban water transfers. This is achieved through the following research contentions.

RC1. The attributes of urban areas influence the types of transfer processes bringing water to growing cities.

This contention links the attributes of urban areas – planning regimes, urban water governance, groundwater availability and growth rates – to types of water transfer process. It argues that transfers arising through informal and indirect means are systemic and linked to urban contexts. This contention is examined in Chapter 5.

RC2. The application of conventional economic modelling to agricultural-to-urban water transfer impact analysis results in highly uncertain outcomes in rapidly urbanising river basins.

This contention relates to the economic frameworks used to estimate transfer impacts in water donating regions. It argues that because urbanisation and agricultural modernisation affect agricultural inputs and outputs, conventional approaches to estimation are subject to the problems of effect attribution. This contention is examined in Chapter 6.

RC3. Urban attributes determine whether urban wastewater can mitigate losses in upstream agricultural production caused by water transfers.

This contention relates to emerging research regarding the potential for urban wastewater to mitigate transfer impacts on agricultural production by enabling wastewater irrigation downstream of cities. The chapter examines the conditions required for the expansion of wastewater irrigation and emphasises the importance of choosing the appropriate scale and scope to understand the wider impacts of transfers and include return flows into analysis. This contention is examined in Chapter 7.

In addition to the research contentions listed above, a number of crosscutting themes run through the thesis. These are outlined in the following section.

1.5.1 Research Themes

Four themes thread through the chapters of this thesis where they contribute to a revised and extended theorisation of agricultural-to- urban water transfers. The first and most significant is the importance of the urban context, its attributes and processes of urbanisation. The second reoccurring theme is that of the complexity of river basins and the interrelationships between their constituent subunits. This is exemplified by the idea of the increasing 'interconnectedness' of water users in closing river basins (Molle, 2008), and by the set of ideas proposed by Lankford (2013) regarding the nestedness and neighbourliness of river basin components. These interrelationships underpin the theorisation of water transfers because transfer impacts travel through nested scales – from farm to basin – or between neighbouring water systems – agricultural areas, cities, industrial zones – in unexpected ways, particularly once return flows are included in the analysis. This theme is most relevant to Chapters 6 and 7.

The third theme relates to the framing of research. In particular, the lens through which water transfers are understood. In countries such as India and China, where economic development and urbanisation are rapid, river basins are experiencing profound change. Therefore, limiting analysis to consider only the role of water policy results in a partial conceptualisation. Hence this thesis advocates a broader research framing to understand how water moves between sectors and the impacts of the informal and indirect processes that operate alongside mainstream institutional mechanisms. This theme is relevant to Chapters 5, 6, and 7.

The final theme is the link between theorisation, evidence, and methods. In short, the question of how research design affects the validity and robustness of studies of water transfers and wider questions surrounding how the share of water between sectors changes in dynamic river basins. This theme emerges from the systematic map presented in Chapter 2 where we see that some aspects of theorisation are less robust than might be expected because of methodological limitations. For example, case study selection criteria are rarely reported, which in turn limits the scope for generalisation across an extensive evidence base. The question of research design is raised again in Chapter 6 where the focus is effect attribution in dynamic systems and finally in Chapter 7 where the question of whether cases studies are representative of wider phenomena is raised.

1.6 Structure of Thesis

The remainder of the thesis comprises seven chapters. Based on empirical evidence from the case studies in Chapter 4, the main theoretical arguments are presented in Chapters 5, 6, and 7. These chapters stand semi-independently with their own conceptual frameworks, evidence, and analysis.

Chapter 2: Evaluating the Agricultural-to-Urban Water Transfer Literature

Chapter 2 presents a systematic map of the agricultural-urban water transfer literature. This is a form of meta-analysis that shows the extent and focus of the research literature. The aim of the systematic map is to evaluate the evidence on agricultural-to-urban water transfers and how evidence links to theory. This provides the conceptual basis for argumentation presented in later chapters and offers a detailed theoretical foundation for understanding transfer processes and impacts.

Chapter 3: Methodology and Methods

Chapter 3 describes the comparative research approach and the processes of casing and comparative analysis. This chapter also presents the research methods applied in the field.

Chapter 4: Introduction to Case Studies

Chapter 4 presents the case studies of Hyderabad, Coimbatore, and Kaifeng. These analytical descriptions outline the main attributes of each case, including a review of previous agricultural-to-urban water transfer scholarship. The descriptions also include the local and national water policy contexts, profiles of each city, and evidence about the amount of water flowing to each case study site through formal and informal means.

Chapter 5: Water Transfer Processes and Urban Attributes

Chapter 5 addresses the relationship between the attributes of urban areas – the biophysical and institutional attributes that make up the urban context – and water transfer processes. It develops a typology linking attributes to the relative contribution of three types of water transfer: formal, informal, and indirect processes of transfer.

Chapter 6: Estimating Water Transfer Impacts

Chapter 6 examines the use of standard economic methods (for example, residual imputation approaches) to estimate forgone direct benefits to agricultural producers in the context of river basins experiencing rapid urbanisation. It argues that when transfers occurs in the context of rapidly urbanising river basins, the assumptions underpinning these models are broken, leading to high levels of uncertainty in impact estimation.

Chapter 7: On the Potential for Urban Wastewater to Mitigate Agricultural-to-Urban Water Transfer Impacts

Chapter 7 examines whether wastewater irrigation using urban return flows can mitigate the impact of water transfers on agricultural production. By comparing the status of wastewater irrigation in Hyderabad, Coimbatore, and Kaifeng, it shows how urban attributes shape the extent to which mitigation can occur. The analysis also highlights how agricultural-to-urban water transfers can raise the economic productivity of water use in agriculture when assessed at a system level. For example, when upstream paddy cultivation is substituted for downstream cash crop cultivation. This results in an unexpected gain in allocation efficiency.

1.7 Summary of Conclusions

Chapter 8 presents the conclusions, which synthesise the main thesis findings and draw together implications for agricultural-to-urban water transfer theory, policy, and research methodologies. The overarching conclusion drawn from this study is that physical and governance attributes of urbanising areas (identified through comparative case research), influence how growing towns and cities gain water share from the agricultural sector. This conclusion emerges from the categorisation of water flows to the case cities as formal, informal, and indirect transfers, and an assessment of the determinants of each type of transfer process.

Equally, the thesis finds that for Hyderabad, Coimbatore, and Kaifeng, urban attributes also influence the fate of urban wastewater return flows, and how they are returned to downstream sectors and the wider river basin. Hence, when reviewing how water flows from the agricultural sector, to the urban sector and vice versa, the thesis argues that greater emphasis should be placed on the role of the urban context, in addition to the existing emphasis given to institutional frameworks for water allocation and transfer.

Thus, the thesis proposes a revised and extended framework for the analysis of agriculture-to-urban water transfers.

Further conclusions drawn from research on agricultural-to-urban water transfers to Hyderabad, Coimbatore, and Kaifeng, relate to the mixed impacts of intersectoral water transfers in urbanising river basins. The research highlights the importance of analysing transfers at the system level as well as the local level to understand the widespread scope of impact. For example, by including additional transfer beneficiaries – those downstream of cities who receive urban return flows – in the analysis of those who gain and those who lose water share.

The conclusions also consider water transfer research methodologies. Given the context dependence of transfer processes and their impacts, this thesis argues that the scope of research should be broadened to allow transfers and their impacts to be understood within the environment of their basin. This requires research designs that reflect this broader scope, for example the use of baselines, triangulation, and comparative research. Furthermore, given the interdisciplinary nature of transfer drivers, mixed methods and rich data are required. Therefore, greater attention should be directed at the consideration of rival explanations by using baselines and counterfactual cases where available.

In light of the research design and findings, this thesis makes several original contributions. These relate to both methodology and theory. In terms of methodology, the thesis applies the systematic mapping method to the agricultural-to-urban water transfer literature for the first time. This advances knowledge by analysing how evidence is used in water transfer theory. It also applies the stepwise comparative method to the issue of agricultural-to-urban water transfers for the first time. Finally, a number of case-specific empirical contributions add to knowledge in this field. The most significant are linked to the finding that water transfers to Hyderabad raise economic productivity in the agricultural sector.

2 Evaluating Agricultural-to-Urban Water Transfer Research: A Systematic Map of the Literature

Summary

This chapter uses a systematic map to evaluate the academic research on agricultural-to-urban water transfers. The map identifies 80 papers and from these, reveals which aspects of water transfers have been studied, in which regions, and using which methods. The map shows that there is considerable bias in the available evidence on agricultural-to-urban water transfers because of the dominance of research related to the water markets of the western United States. The characteristics of the map are used to make inferences about water transfer research and the potential for theory building at two levels. The first level examines internal validity (Yin, 2009). The second level addresses the extent to which the findings from individual articles can be extrapolated to general theories. This is known as external validity (ibid.). One key issue is that in a field where case study research is the norm, few studies report their case selection criteria, meaning that case specific findings cannot readily be combined to build general theory. The map concludes that many aspects of agricultural-to-urban water transfers are underrepresented in the evidence base and that theorisation is incomplete. Of particular interest to this thesis is the limited amount of research on broader questions of how water moves between sectors in response to urbanisation and what this implies for impacts at local and basin levels. For example, the informal and indirect transfer processes operating outside the sphere of institutional mechanisms.

2.1 Introduction

Despite the large number of articles addressing agricultural-to-urban water transfers, this chapter contends that the evidence base is limited by the narrow set of research designs and case examples it contains. Consequently, the theorisation of agricultural-to-urban water transfers is incomplete. To understand how the scope of available evidence links to theory and the implications for the broader conceptualisation of transfers, this chapter systematically evaluates the literature to show its extent and focus. Evaluation is performed using a systematic map – a tool that delimits the extent of the literature and its contents. Systematic maps take the form of coded databases of globally available evidence on a specified research topic populated by research articles. They help researchers to understand the aggregate state of knowledge by classifying studies to show what, where, and how research has been conducted. This allows an examination of the robustness of the evidence supporting various aspects of transfer theory and claims regarding water transfer processes and their impacts in different settings[7].

Researchers, therefore, can use the information derived from systematic maps to see where the main research gaps lie, and to determine whether current evidence can support policy decisions regarding transfer processes and their socioeconomic and biophysical impacts. For example questions related to the ability to: measure impacts from the farm to the basin level; address concerns related to fairness or compensation; and answer policy questions about institutional design and efficacy. Thus, the findings from the systematic map provide justification for the research aims of this thesis (to show how processes of urbanisation modify transfer processes and their impacts) and support the use of a comparative, interdisciplinary research design, which hitherto has been underutilised in the field.

2.1.1 Chapter Structure

The chapter is structured as follows: section 2.2 describes the systematic mapping method showing how it differs from standard literature reviews given procedures to prevent 'cherry-picking'. Section 2.3 outlines the characteristics of the map highlighting the main subjects of research, their global distribution and emerging research trends. Section 2.4 discusses the internal validity of theories of water transfer by examining the robustness of reported causal relationships and the scope of analysis. Section 2.5 extends the discussion of theory-building to the problem of external generalisation and external validity. Section 2.6 reflects on the gaps in the evidence base and the incomplete nature of theorisation. This forms the rational for the approach adopted in the empirical chapters of the thesis. Section 2.7 concludes the chapter.

2.2 Mapping Methods

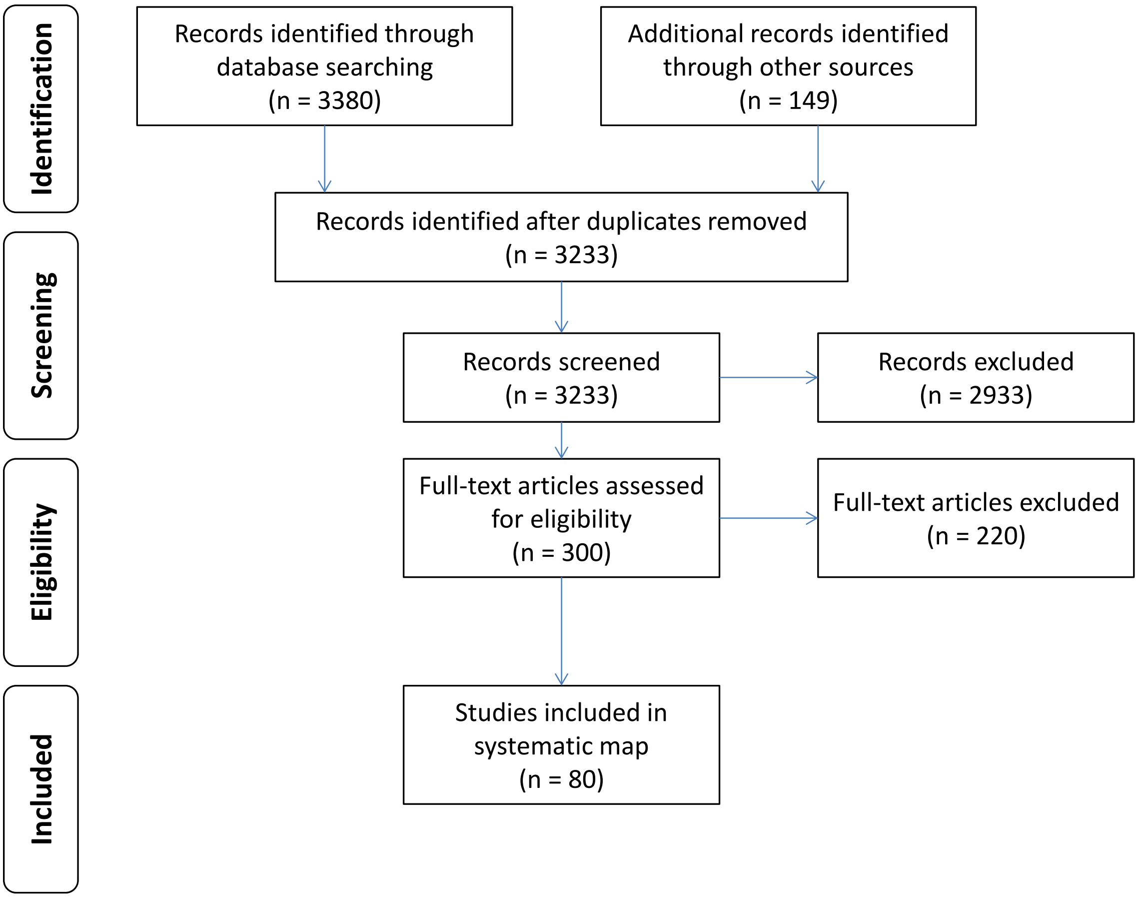
Methods and guidelines for compiling systematic maps are produced by research collaborations – the groups of scientists who oversee the synthesis of evidence for different disciplines. For the water resources management literature, the guidelines from the EPPI-Centre (2007) and the Collaboration for Environmental Evidence (2013) are the most relevant. Notwithstanding small differences in disciplinary approach, the objective of any systematic map is to follow a transparent and replicable procedure to identify all available studies linked to the research topic. The techniques advocated by

[7] The reader should note that this is not a systematic review and as such, this chapter does not fully assess the quality and risk of research bias in each article. Instead the focus is on discovering what is known about water transfers and the nature evidence to support these claims.

the research collaborations, for example, the use of exclusion criteria defined *a priori*, reduce bias, and allows an objective compilation of data. The process is thought to lessen the likelihood of 'cherry-picking' papers. This differentiates systematic maps from literature reviews such as those by Molle and Berkoff (2009), Meinzen-Dick and Ringler (2008) and Rosegrant and Ringler (2000) where the criteria for article selection are unclear and authors may choose papers to support their own theoretical and ideological positions.

The methods used in this chapter borrow heavily from recent systematic maps addressing other aspects of water resources literature by Hepworth et al. (2012) and Johnson et al. (2011). These follow four main steps: 1) scoping the literature and developing a search strategy, 2) implementing the search strategy to identify articles, 3) screening irrelevant articles using predetermined criteria, and 4) coding the remaining papers to produce a database of research characteristics. This process is summarised in Figure 3, which also gives the details of the volume of material reviewed at each stage of the process.

Figure 3. PRISMA Flow Diagram.



PRISMA diagrams summarise the stages of article selection. Here, the screening and filtering stages for literature identification are presented showing that the pool of papers is reduced from 3,233 to the final 80 included in the database. Source: Moher et al. (2009).

This chapter follows a scaled-down version of the standard systematic method to reflect the constraints of a single researcher. As a result, this 'light' systematic map does not adhere to conventional practice such as the publication of a protocol and expert stakeholder consultation. Moreover, limits were placed on the number of databases searched (limited to Scopus and Web of Knowledge) and the number of records (results sorted by relevance) was limited to 2,000 records per database. In addition to papers from Scopus and Web of Knowledge, papers were also identified by searching the bibliographies of existing review articles and taken from the author's library of papers collected during earlier thesis research.

Most articles were identified through the Boolean search of Scopus and Web of Knowledge. The Boolean search string was developed by breaking down the research subject (agricultural-to-urban water transfers) into its constituent components and then sensitivity testing iterations compiled from synonyms of terms related to water allocation and transfer. The final iteration of the search-string, used to identify literature published before July 2013, is given below:

> *‘Water AND (reallocation OR allocation OR sector OR intersectoral OR transfer OR competition OR conflict OR supply) AND (agriculture OR rural OR hinterland) AND (urban OR city OR municipal OR domestic OR industry)’*

The screening process, depicted in Figure 3, excludes irrelevant studies using predefined criteria. These criteria define the limits of the systematic map and are presented in Table 4. Papers reaching the final stage and included in the map were then analysed, coded and their relevant data extracted. The codes were chosen to represent many different aspects of the content of the research, for example: location; subject matter; study design; and discipline. In addition, indicators were chosen to illustrate methodological rigour and the use of evidence to support claims. These indicators were adopted from guidelines by the Eppi-Centre and CEE and range from simple assessments of whether methods and research questions are reported through to discipline specific indicators such as the use of controls, baselines, or triangulation. The final map showing all 80 studies is presented in the Appendix: Systematic Map. This provides the selected highlights of the map’s main features to illustrate the level of data extraction from each paper.

Table 4. Systematic map inclusion criteria.

Criterion	Definition
Language	English language only.
Article Type	Academic research only: journal articles, conference proceedings and theses. Grey literature such as blogs, reports, books, and chapters are excluded.
Subject	Agricultural to urban/industrial water transfers. Articles are required to have a specific focus this topic. Papers with a general allocation focus – sectoral demand management, allocation in the context of IWRM, transfers to the environment – which make passing reference to agricultural-urban water transfers are excluded.
Research Design	Any (primary and secondary data, modelling, literature reviews, and opinion pieces).
Geographic Area	All.
Not available	Articles where the full text is not available, for example older publications that are not digitised.

2.3 Characteristics of the Systematic Map

The systematic map consists of 80 studies[8] published between 1987 and 2013. These articles are found in 38 different journals, the most popular of which are *Paddy and Water Environment* (due to a dedicated special issue on agricultural to urban water transfers in 2007), *Water Policy*, *Water Resources Research*, *Agricultural Water Management* and *Irrigation and Drainage*. This section reports the main features of the dataset in terms of 'what' the research community knows about water transfers. This includes a review of research subjects, the global distribution of research and trends over time. The results illustrate a bias towards research in the United States, although the number of studies from China has increased markedly since 2000. The review also notes that despite a relatively large number of individual articles, many popular research locations are revisited and serve as the basis for repeated analysis. This speaks to the limited breadth of understanding of water transfers in different contexts.

2.3.1 Research Subject

Papers in the systematic map address different subjects within the research scope of agricultural-to-urban water transfers. The subject range includes papers on transfer processes, transfer impacts, and research on related issues such as peri-urban areas, the role of cities, and conflict. However, many articles often have more than one focus. The following section provides an overview of each of these key research areas and uses this to understand the extent to which available research can support contemporary debates in the field of water allocation and transfer.

2.3.1.1 Transfer Processes

Two thirds of the articles set out to describe transfer processes, defined as the ways water moves from agriculture to urbanising areas. Many of these articles are purely descriptive and offer limited analysis beyond reporting the characteristics of the relevant institutional mechanisms. Examples include Matsuno et al. (2007), Shively (2001), Leidner et al. (2011), and Wang (2012). Yet, water transfers are multifaceted; and as will be argued in Chapter 4, different types of transfer process can operate simultaneously. Thus, trying to distinguish between transfer types quickly becomes complicated. In this context, classification systems help to provide an organising

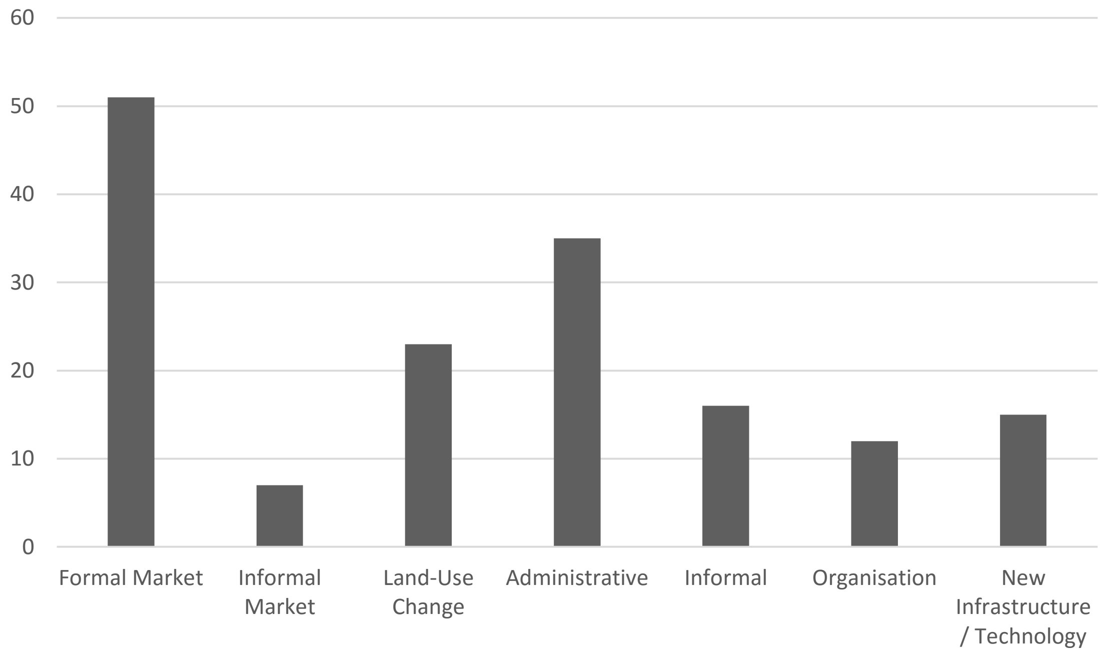
[8] Most of the entries in the map represent one paper; however, where authors publish multiple articles from the same research an entry may incorporate multiple papers. Articles from the same research are entered separately where they present new evidence or analysis but are merged if the key findings are repeated for the same time period.

framework to give clarity to the range of transfer processes observed at different case sites. Different authors have developed different classifications using various conceptual distinctions between transfers. These systems are presented in the handful of available multi-country research articles or literature reviews of transfer cases (Molle and Berkoff, 2009, Levine et al., 2007, Meinzen-Dick and Ringler, 2008). These classifications focus on transfer features including, transfer duration (permanent or temporary), the source of water (groundwater or surface water), whether compensation is provided, or the type of the transfer mechanism.

Of these transfer features, the differences between transfer mechanisms are the most commonly used basis for distinguishing between transfers. Accordingly, the systematic map presents the distribution of research by transfer mechanism in Figure 4. This shows formal institutional mechanisms (markets and administrative mechanisms shown separately); informal markets; and other informal processes (stealth and implicit reallocation processes) as well as material causes of transfer such as land-use change. Note that many articles focus on more than one main transfer mechanism (normally a market or administrative fiat) and refer to others in passing. This is particularly true for cursory references made to informal transfers and land-use change in many research articles. Figure 4 also notes where studies have examined the role of new organisations and the building of new transfer infrastructure.

The most important finding shown in Figure 4 is that formal mechanisms receive the most research attention. These are markets and different forms of administrative strategy for moving water between sectors. See for example key papers on the formal water markets of the United States and Chile (Brewer et al., 2008, Chang and Griffin, 1992, Leidner et al., 2011) and various administrative mechanisms (Huang et al., 2007, Levine, 2007a). Informal water transfer processes receive less attention, although notable exceptions include the peri-urban water markets in India (Packialakshmi et al., 2011, Ruet et al., 2007, Srinivasan et al., 2013), and informal / implicit processes (Chiueh, 2012, Sajor and Ongsakul, 2007).

Figure 4. Bar chart to show the number of studies by water transfer mechanism.



Of the non-formal transfer processes, land-use change is perhaps the most conceptually problematic because it is both a transfer process *and* a potential transfer impact. For example, Hearne (2007, p272) observes that the reason 'noteworthy intersectoral transfers of water are not common in Chile is that the less dramatic transfer of irrigated land with its irrigation water to urban uses is relatively common'. Similarly Kendy et al. (2007) observe that urbanisation in China may reduce water stress as land-use change from agricultural to urban mean reductions in net water consumption. In these two cases, water transfer is the unintended consequence of moving land from agricultural to urban uses. This process will be discussed in Chapter 5, where land-use change caused by urban expansion is designated as an indirect type of water transfer that suppresses local agricultural water demand. By contrast, land-use change can also be a deliberate and explicit form of water transfer mechanism. See for example the policy of water-farming / ranching in the United States – the purchase of farmland for the express purpose of exploiting its water resources – where a purposive transfer of water on the basis of a land-based market mechanism and fallowing causes land-use change (McEntire, 1989). This shows that agricultural-to-urban water transfer processes and impacts are often inextricably linked to land allocation policies.

2.3.1.2 Transfer Impacts

Transfer impacts are the effects of agricultural-to-urban water transfers in water-donating or -receiving regions. Negative impacts (or forgone benefits) mainly accrue to agricultural producers and rural economies, whereas positive impacts (benefits) accrue to urbanising areas. The complex issue of transfer impact identification and estimation is the subject of Chapter 6 and so only a brief outline of the impact research identified in the map will be provided in this section. Half of the papers in the map (53%) address water transfer impacts with varying degrees of rigour, using some qualitative but mainly quantitative approaches. Many articles assess impacts using agro-economic models. Some consider compensation arrangements for farmers from whom water is taken. Most, however, focus on the problem of identifying third party impacts and spill-over effects. Important examples are papers by Taylor and Young (1995), Howe and Goemans (2003), and Howe et al. (1990).

Comparing the results of all the water transfer impact studies shows that the conclusions on impacts are mixed. Some papers show negligible or even positive impacts for agricultural producers, while others outline serious consequences for food security and local agricultural economies. These divergent outcomes are perhaps a reflection of the context dependence of transfers in different locations, for example the size of a transfer compared to water availability at the source. They also may reflect the methodological difficulties of tracing and quantifying impacts in dynamic systems.

An interesting observation is that, despite these mixed impacts, the characterisation of transfers is often negative, exemplified by vivid descriptions of 'water grabbing' (Kay and Franco, 2012), 'appropriating' (Celio et al., 2010), and 'stealth' (Meinzen-Dick and Ringler, 2008). Whittlesey (1990) also notes this disparity in his observation that transfer researchers are too quick to describe negative impacts without accounting for possible positive externalities. There are many reasons for the negative reputation aside from the fact that controversial cases make for more interesting research subjects than the slow increments of water allocations to growing urban areas. One of the most significant is the influence of a phenomenon termed 'Owens Valley Syndrome' (Libecap, 2005, McMahon and Smith, 2013), whereby the reputation of the water transfers to Los Angeles (see for example their negative portrayal in the film *Chinatown* (Polanski, 1974)) shapes current perceptions of transfer. This narrative perpetuates despite evidence that historical events did not live up to their popular culture portrayal (Libecap, 2009). A second issue is the symbolic nature of water for local communities. This is demonstrated by Solís (2005) who found that the community sense of loss over water transfers contributes to resistance even where the likely impacts are negligible or even positive.

2.3.1.3 Peri-Urban Areas, the Role of Cities, and Conflict

Aside from impacts and processes, three further research areas are shown to be significant. These are: the role of peri-urban areas in agricultural to urban water transfers; the function of cities as proprietary actors; and conflicts over water transfers. Peri-urban areas, the transitional zones at the urban fringe, and the processes they support, are central to this thesis and will be defined and revisited in different forms in Chapters 5, 6 and 7. In the map, they are examined in only a handful of articles, from which emerge two important concepts. Firstly, Díaz-Caravantes and Sánchez-Flores (2011) describe a 'peri-urban waterscape' to distinguish the conventional urban footprint from this much larger space across which a city influences water in terms of transfers and wastewater releases. Secondly, Ruet et al. (2007), Packialakshmi et al. (2011), and (Srinivasan et al., 2013) examine, to varying extents, the role of informal peri-urban water markets. These papers document the flow of water from the urban fringe to the core urban areas, thereby transferring water across urban spaces as well as between the agricultural and urban sectors.

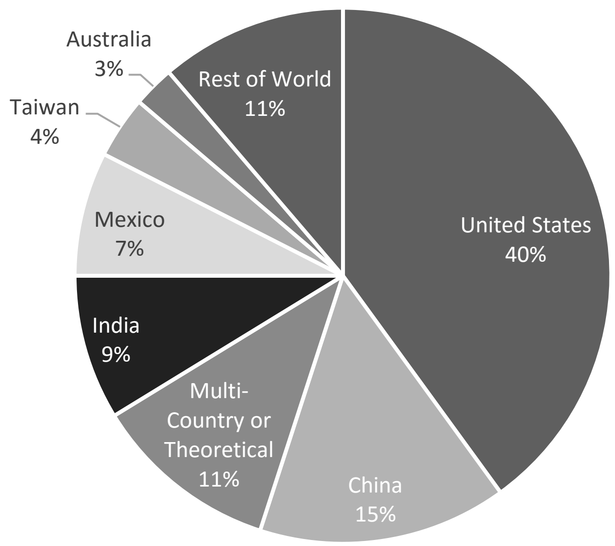
The role of the 'urban' and the influence of cities are explored by papers that adopt a broadly political ecology approach. Examples include Celio et al. (2010), which focuses on 'appropriation' by urban centres, and Feldman (2009), which examines urban water capture disputes in Atlanta and Los Angeles. This significance of this research in terms of understanding the role of urbanisation and urban attributes in water transfers is the theme of Chapter 5 and is explored in detail there. The main observation is that research on the role of urbanising areas is limited to social, economic, and political analysis and little attention is given to the influence of material processes of urbanisation, such as the effect of rapid growth on water infrastructure or the impact of the style of urban planning.

Conflict is addressed by more than 20% of the sample which document either the potential for, or the existence of, conflict and protest over water transfers from agriculture (see Komakech et al. (2012), Strauss (2011) and Wagle et al. (2012)). These studies focus on the ways that historical water rights have been undermined, the use of stealth and the lack of appropriate compensation to farmers losing water to growing cities.

2.3.2 Geographical Research Distribution

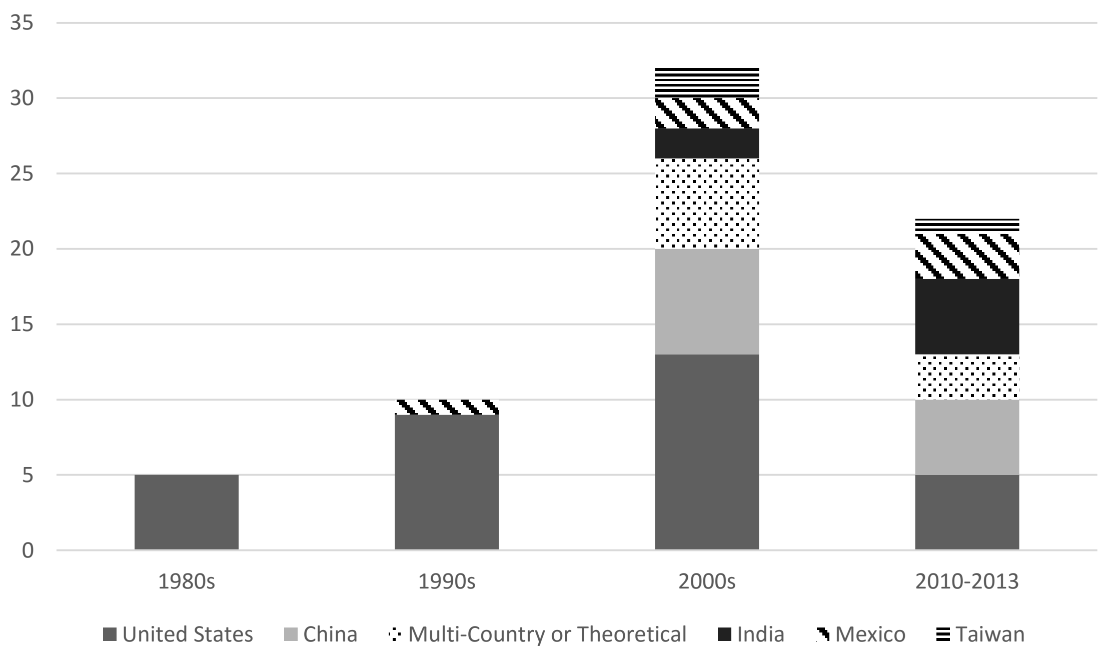
Analysis of the location of research highlights the limited extent of the available evidence on agricultural to urban water transfers. Figure 5 shows that 40% of research is based on water transfers in the United States, followed some distance behind – particularly when the relative water volumes and population size are considered – by China[9] at 15% and India at 9%. However, trends in research are changing as shown by Figure 6. This illustrates how research in geographical areas other than the United States has emerged only in the last 15 years – particularly striking is the rise in research on transfers in China. Figure 6 also highlights that the volume of research on water transfers has increased over time. This is perhaps in response to growing scarcity and rising transfer frequency, and also the increasing tendency for research in China to be published in English.

Figure 5. Pie chart showing the distribution of studies by country.



[9] This distribution may result from the exclusion of studies in languages other than English. Some locations are likely better represented by articles written in relevant national languages.

Figure 6. Bar chart of distribution of research location by country by decade.



The national level analysis presented in Figure 5 and Figure 6 hides the extent to which cases are revisited. For instance, the Rio Grande in New Mexico and Texas represent almost a third of the research from the United States. Research around the groundwater markets and 'water-farming' of Arizona, centred on Phoenix, and the Arkansas River in Colorado also make significant contributions. This repetition of research location is also found outside the United States; for example of the seven studies in India, three studies focus on Hyderabad, three focus on Chennai, and one examines water allocation from large dams in the State of Maharashtra. This repetition further indicates the limitations in the global coverage of transfer evidence.

2.3.2.1 Many Closing River Basins are Underrepresented

Comparing the geographical distribution of transfer research to the distribution of closing river basins reveals which regions are underrepresented (in the English language transfer literature). Although it is not possible to observe all transfers, we can hypothesise the extent to which the available evidence is representative of different types of transfers and their contexts by using the location of closed river basins as a proxy for likely sites of water transfer. A recent study by Falkenmark and Molden (2008) lists the following major closed or partially closed river basins outside the United States: the Yellow; the Jordan; the Krishna; the Lerma-Chapala; the Murray-Darling; and the Indus. These are likely locations of agricultural to urban water transfer given rising urban populations in these basins. Yet while some of these river basins feature in the systematic map, their contribution to the evidence base is outnumbered by research from the United States, and some, for example the Jordan, do not feature at all.

2.3.3 Emerging Trends in the Study of Agricultural-to-Urban Water Transfers

The systematic map reveals emerging conceptual trends in water transfer analysis. One of the most important relates to a shift in the scale and scope of research. Whereas earlier work focused exclusively on the transfer of water from one component entity to another – from agriculture to cities – several recent papers situate transfers within networks of 'inter-connected' water users (Molle, 2008). These papers increasingly analyse water transfers to urbanising areas at a system level that addresses the downstream impacts of changes to sectoral water allocations in river basins. This broader scope requires theoretical frameworks that make reference to concepts such as consumptive use, urban return flows, and wastewater reuse. For example, the significance of water consumption is noted by Squillace (2013), who examines the concept in relation to water transfer law.

Extending the analysis of consumptive to include urban return flows, Van Rooijen et al. (2005) and Van Rooijen (2011) explore the relationship between urban growth and wastewater generation. These ideas also form the basis of research in Mexico by Scott and Pablos (2011) and in Spain and Mexico by Heinz et al. (2011a) and Heinz et al. (2011b). By explicitly linking urbanisation and water transfers to wastewater generation, this emerging literature changes our understanding of sectoral water competition. Furthermore this gradual evolution, from research that isolates processes of water transfers towards research that treats water transfers as an inseparable part of a wider dynamic system, is vital for the theorisation of water transfers across scales. These themes are revisited in Section 2.4.1, where this system-level analysis is explored with respect to the internal validity of water transfer research. These ideas also form the basis for Chapter 6.

2.3.4 A Limited Evidence Base

The limited extent of the evidence based is revealed by comparing the contents of the systematic map to contemporary water transfer debates. For example, areas of concern to researchers and decision-makers include: making transfer impacts explicit for policy decisions; choosing the most appropriate institutional frameworks to apply in particular contexts (for instance are secure property rights always necessary); or whether agricultural water efficiency interventions enable intersectoral transfers (as currently advocated by the Yellow River Conservancy Commission, see Chapter 3). Yet an initial assessment suggests that the available evidence can only strongly support the institutional elements of water transfer theory for the western United States. It therefore offers little in the way of guidance outside the realm of water marketing in highly-regulated environments. This means there are significant research opportunities to explore water transfers outside the United States and the large number of reasons why water moves out of agriculture that unrelated to water policy and river basin planning.

Moving from the above assessment of the extent and focus of the map, the following sections analyses *how* research has been conducted and what this means for water transfer theory. Section 2.4 examines the internal validity of water transfer studies and the implications for the conceptualisation of water transfer processes and impacts. Section 2.5 examines the external validity of the studies and the extent to which general theories of water transfer can emerge from the available evidence. Together these sections show that there are many areas where theory is underdeveloped and that caution is required when extrapolating from the experiences of the United States.

2.4 Theory-Building Part I: Internal Validity

Internal Validity (IV) refers to the reliability of the relationships between causes and observed or inferred effects (also called dependent and independent variables) within an individual study (Yin, 2009). IV, therefore, indicates the conceptual robustness of proposed causal mechanisms and the theories these support. Case studies are examples of high-IV research designs, particularly where their findings are triangulated using different methods. See for example Solís (2005) and the selection of studies on various aspects of water transfers to Hermosillo in Mexico by Díaz-Caravantes and Sánchez-Flores (2011) and Díaz-Caravantes (2012). To ascertain how well water transfers in their broadest sense are understood and conceptualised, this section evaluates levels of IV in the studies populating the systematic map. The aim is not to unduly criticise the research designs of individual studies, but rather to understand how choices about scope and discipline narrowly delimit how transfers are theorised and how the causal relationships between transfer processes and water outcomes are understood.

The IV of the transfer studies in the systematic map can be evaluated from four perspectives. The first is to assess the scope and scale of analysis. The aim is to understand whether all relevant parts of the transfer system have been included in the analysis and at the appropriate scale. Secondly is the question of bias arising from the dominance of particular disciplinary perspectives and how this narrows the lens through which transfers are understood. The third perspective is to consider the role of data sources – primary, secondary, expert opinion for example – and their role in theory building. Finally, this section briefly reviews research quality of the studies in the map. Simple criteria, for example whether the methods have been reported, provide an indication of methodological rigour and the likely reliability of research findings.

2.4.1 Scope and Scale of Analysis

Robust theory development is predicated on the scope and scale of analysis. Appropriately delimiting the study scope increases the likelihood that alternative explanations for proposed causal relationships are examined and discounted. Furthermore, the scale at which transfers are examined influences how findings are contextualised. This is particularly important for river basins where water users are interconnected, which results in changes in one part of the river basin having consequences elsewhere. The nested scales of systems within river basins and the links between water using neighbours exacerbate this effect (Lankford, 2013). Transfers and their impacts are understood differently at the scale of the farm, city, river basin, and economy – the nested scales of the river basin. They can also be viewed from the varying perspectives of different subcomponents of the transfer system: the water-donating agricultural component; the urbanising area; or the sectors downstream of cities. The systematic map shows that few studies adopt a systems level perspective – only eight of the 80 articles – however, as described in Section 2.3.3, these are also some of the most recent studies (see for example, Díaz-Caravantes and Sánchez-Flores (2011) and Karimi and Ardakanian (2010)), which suggests that this is an emerging research trend, changing the perception of transfers and their impacts.

2.4.2 Research Discipline

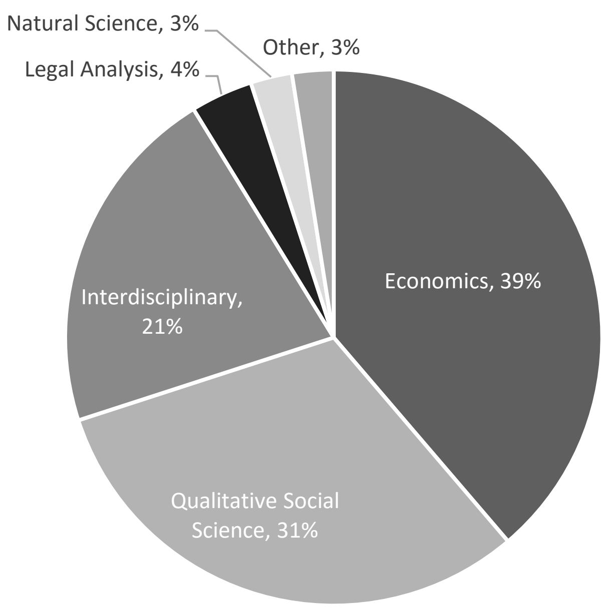
Disciplinary perspectives frame water transfer studies and shape the theoretical contributions of research. Despite water transfers being an inherently interdisciplinary phenomenon – their drivers, processes and impacts touch on aspects of hydrology, institutional analysis, politics, economics and urban studies –most research is based on economics or qualitative social sciences[10]. This is shown in Figure 7. The influence of economics is perhaps unsurprising given its use in the assessment of transfer impacts, and the study of transfer feasibility. Nevertheless, using a predominantly economics

[10] The category qualitative social science includes studies that describe water transfers and their social, political, and economic contexts.

lens to understand the flows of water between sectors means that transfers are regarded as linear entities and are subject to the rigid assumptions of economic and agro-economic models. An economic viewpoint also brings with it a particular ontology that shapes the portrayal of water transfers in the literature.

In contrast to the dominance of economics, Figure 7 shows the limited input from natural sciences in the study of water transfers. Little evidence is therefore available on how much water flows between sectors in response to different approaches to water transfer. For example, the water outcomes of policies such as water banking or measures to improve agricultural water use efficiency are often unknown. This observation validates earlier commentaries on the study of water transfer, for example Bauer (2004, cited in Celio (2011)) who notes that 'researchers have paid so much attention to the economic and legal aspects of water rights trading that they have virtually ignored … issues of water management and institutions'.

Figure 7. Pie chart to show the breakdown of disciplines.

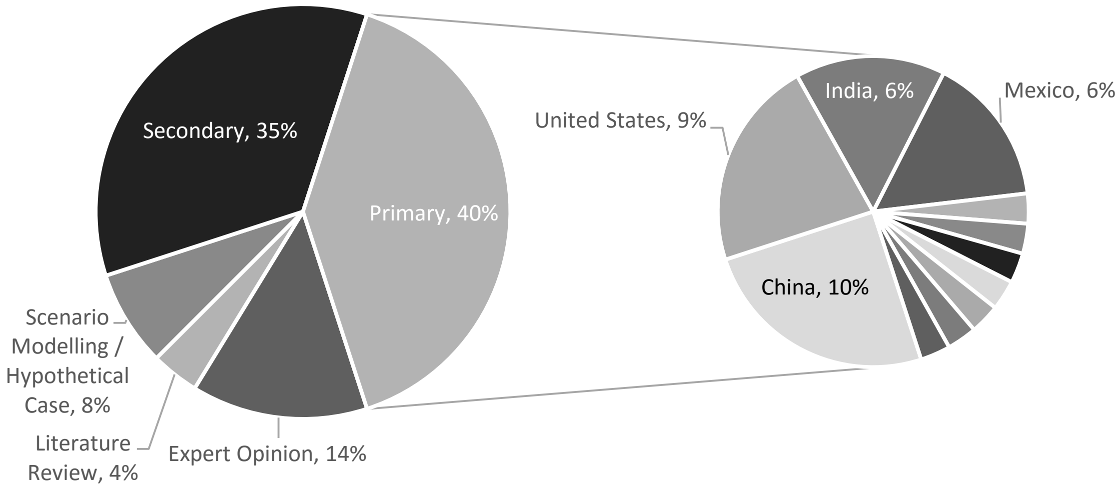


2.4.3 Data Sources

The section explores the issue of IV from the perspective of the data sources of water transfer evidence. To understand the types of data used as evidence in water transfer theory, the systematic map classifies data used in articles as: primary; secondary; scenario; expert opinion; or literature review. Primary data is defined as anything measured, collected, observed, or recorded by the researcher. Secondary data is drawn from existing databases and publications, for example records of water transfers, reference crop data or economic statistics compiled by local governments. This classification does not privilege one form of data above another, particularly as primary and secondary data often serve different purposes. Nevertheless, documenting the different data sources helps understand *how* the research community builds theory with respect to water transfers. Where more than one data source is included in analysis, the map codes articles such that they are only categorised once. For example, a paper with primary and secondary data is counted in the primary category only.

Figure 8 presents these results and shows that fewer than half of the studies are based on primary evidence, and that almost a quarter of articles are based on hypothetical models, opinion, or literature reviews. The subset of papers using primary data are then analysed by location in a pie of pie also shown in Figure 8. This reveals although overall, most research has been conducted in the United States, most primary research took place in China. Studies from India and Mexico also contribute significantly to the body of primary research on water transfers. This suggests that there is more localised and contextual information available for water transfers in these countries as compared to studies in the United States.

Figure 8. Pie chart to show data sources.



Note. The location of primary research is also shown in a 'pie of pie'.

2.4.4 Research Quality

Research quality determines the likely reliability of research conclusions and therefore affects the internal validity of water transfer studies. The analysis in this section stops short of a full systematic review of quality and bias; however, by assessing whether best practice methods have been applied in the research design (these vary according to discipline and approach and are normally listed by the relevant research collaboration) and gauging the completeness of research reporting, inferences regarding quality can be drawn. The systematic map shows that many studies do not report basic research elements. For example, most articles did not report their methods (62%), nor state their assumptions and limitations (65%), nor consider alternative explanations (77%). This suggests that caution should be taken with respect the theoretical inferences drawn from large parts of the literature. One particularly important methodological aspect of research affecting the IV of water transfer research is the management of complexity and covariance in river basin systems. This is explored in the section below.

2.4.4.1 Complexity, Covariance and Internal Validity

The treatment of the complexity arising from covariance between drivers and outcomes in river basins is an indicator of research quality. It is an issue that presents significant methodological challenge for water transfer analysts, particularly in contexts where data availability is poor. For example, changes in agricultural production in water-donating regions can be attributed to many causes including, labour availability, climate, market fluctuations, as well as water. This idea is exemplified in an observation by Mitchell (1993) cited in McMahon and Smith (2013, p.153), regarding water transfers and California's Central Valley. He states that 'other factors, such as crop prices, weather, and government programs, impact farm communities more significantly than water transfers'. Furthermore, the baseline against which water transfer impacts are measured is continually moving, given the macro-drivers of population growth and economic development in regions experiencing water transfers. So how do researchers isolate the signal of water transfers from this noise? This is a complex undertaking. The degree to which it can be achieved is subject not only to the practical limitations of data collection where primary data is used, but also to the use of robust research designs, which can help to clarify uncertainty in understanding causal mechanisms and effect attribution.

Where available, baselines and counterfactuals are two research design tools that can help to overcome the problem of effect attribution. By showing conditions before water transfers are implemented (baselines), or the counterfactual case where transfers are not implemented, these design approaches provide a comparator for researchers to isolate and quantify transfer impacts. For example, Nunn (1987) examined the socioeconomic impacts of transfers on rural areas and noted the baseline of rural community decline and the negative influence of agribusiness on the structure of agriculture. This provided a context for assessments of transfer impacts and allowed relevant contextualisation. Counterfactual cases have also been used. For example, Libecap (2005) examines the Owens Valley water transfer through the lens of the experience of a similar, adjacent valley that was not subject to water transfers. This enables transfer impacts to be understood relative to the status quo.

All too often, however, water transfer analysis proceeds without due consideration of alternative explanations or wider context. This can be due to no baseline data or counterfactual availability. In these instances, the use of mixed-methods and an interdisciplinary perspective for effective data triangulation will offset potential bias. A good example of the use of triangulation in the sample of studies from the map is Díaz-Caravantes who uses interviews combined with land-use cover assessments to investigate the impacts of water transfers in Mexico (Díaz-Caravantes, 2012, Díaz-Caravantes and Sánchez-Flores, 2011).

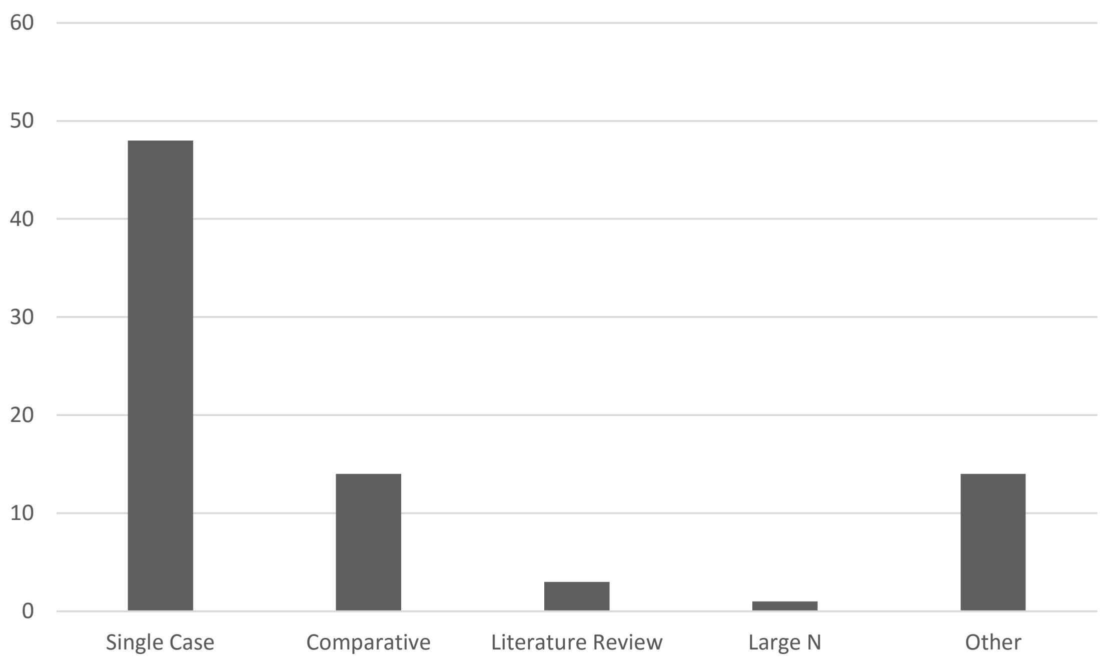
2.5 Theory-Building Part II: External Validity

This section examines water transfer research by considering External Validity (EV), or the extent to which research findings can be generalised beyond an individual study. Generalisation enables the formulation of more complete water transfer theory. One of the key determinants of EV is research design. The water transfer literature, as will be demonstrated, is made up of a large number of single case studies. The issue is the findings of these numerous cases often cannot be combined to provide a comprehensive assessment.

2.5.1 Research Design

Research design determines the extent to which theoretical insights can be extended beyond an original study. For example, large-N quantitative research often produces general trends whereas single-case research contributes to theory building by examining causal relationships between variables within cases. The systematic map shows that most agricultural-to-urban water transfer research uses single case studies. This is illustrated by Figure 9, which presents the different research designs adopted to study water transfers. Single case studies are the most commonly adopted water transfer research method because experimental approaches are not practicable, nor in most instances is the use of comparative 'before and after water transfer' or 'with and without water transfer' frameworks (due to the lack of available data for baselines and counterfactuals as discussed earlier). The strength of single-case research lies in its ability to shed light on causal relationships, but it can form the basis of generalisation if cases representative cases are selected. Case selection criteria, therefore, are critical for assessing the level of external validity of single case study research. The relationship between single case studies and theory-building is discussed in more detail in section 2.5.2.

Figure 9. Bar chart to show the frequency of different research designs.



Comparative research is the next most popular research design and has much greater potential to contribute to theory than single-case research. This is because it enables a limited form of generalisation and reveals the relationship between variables in different contexts. This approach is used in the empirical chapters of this thesis and discussed in detail in Chapter 3; therefore, this section limits itself to presenting a handful of illustrative examples. These include Nunn and Ingram (1988) who compare the use of markets and legislation for transferring water in the United States; Levine et al. (2007) compare nine cases of water transfer but gives little analysis of which components of each case determine the success of the transfer; Huang et al. (2007) compare emergency and 'normal' mechanisms for water transfer in Taiwan; Matsuno et al. (2007) compare four different examples of water transfer by agricultural water reorganisation in Japan; and finally the most influential paper on water markets in the United States by Howe and Goemans (2003). The 'other' category represents studies including discussion pieces, editorials, and legal analysis that are not confined to a specific case.

2.5.2 Combining Research Findings

A further consideration for theory building is whether the evidence from single case studies can be combined to make generalisations about agricultural-to-urban water transfers. Locally-specific case studies do not readily allow for the development of wider theory unless they are selected to be representative examples (Seawright and

Gerring, 2008). To enable generalisation from single cases, the researcher must establish whether a case study is representative of the general population of cases, or whether the example is unique and an outlier (Yin, 2009, Gondhalekar and Mollinga, 2011). Where cases are unique, the case specific contributions cannot be extrapolated beyond the single study. Whereas, if a case is selected as a standard, representative example, then the case contributions can be used to draw inferences with which to build theory.

Only half of case studies in the systematic map describe why the transfer example has been selected. Moreover, many of the cases describe unique examples that are unlikely to be widely applicable outside their specific contexts. For instance, 15% of the research from the United States focuses on the atypical Lower Rio Grande water market[11]. Taking the lack of selection frameworks and the number of outlier cases into account, it seems there is not yet sufficient information to generalise from the available agricultural to urban water transfer cases studies. To generate a more complete theoretical framework, evidence from a wider variety of case studies (in terms of discipline, location, and scope) are required in addition to more widespread reporting of case selection criteria.

2.6 Summarising the Systematic Map

The contents of the systematic map enable a general characterisation of the agricultural-to-urban water transfer literature across the range of different research elements encoded into the map's database. The map shows that the evidence contains biases in terms of the location, the focus of research, and research design. This shapes the theorisation of agricultural-to-urban water transfers. For example, theory is weighted towards the United States where property rights regimes, the wider institutional environment for water management, and levels of urbanisation are starkly different to those found in water-scarce river basins in many other parts of the world. Bias towards the United States is problematic given that rates of urbanisation in the Global South would suggest that agricultural-to-urban water transfers in the river basins of countries like India, China, and Central Asia will necessarily become more frequent. Thus, theoretical frameworks derived from contexts similar to the United States are likely to be inappropriate for these vastly different institutional, cultural, and

[11] Market transactions in the Lower Rio Grande are atypical because the downstream location of the market simplifies the management of returns flows. This reduces the complexity of monitoring third party effects with implications for transaction costs (Chang and Griffin, 1992).

economic environments. In recent years, however, increased levels of research in China, India, and Mexico have begun to redress this imbalance.

Analysis of research designs and methods suggests that theorisation is also incomplete from a methodological perspective. For example, there is a proliferation of single case studies examining transfers in similar contexts using tools from a limited number of disciplines. Moreover, the map shows that earlier research designs tended to isolate transfer processes and impacts from the wider river basin context. Latterly, however, the emphasis has changed towards a new focus, examining transfers from a systems perspective. This change in perspective is also likely to redress the underrepresentation of the effects of 'non-water' processes such as the material effects of urbanisation that causes water to move between sectors. Drawing together the characteristics of the map shows the need for interdisciplinary analysis to understand how drivers from beyond water policy affect the movement of water between sectors. This requires the analysis of water transfers from a systems level and research designs that move beyond single case studies.

2.7 Conclusions

This chapter set out to evaluate the agricultural-to-urban water transfer literature using a systematic mapping approach. It found 80 studies focusing on different aspects of transfers and their impacts. Analysis of the articles and their research designs shows that the following of aspects water transfers are well-studied: water markets in the United States; and the identification and the modelling of forgone direct benefits to farms, also in the United States. Whereas the following aspects suggest the more research is required: the limited geographic scope; the limited disciplinary scope; and the narrow framing of transfer research which examines donor areas, transfer processes, and recipient areas in isolation. The poor reporting of case selection criteria compounds the narrowness of the evidence base and means that existing knowledge cannot readily be combined to draw greater theoretical inferences.

This thesis aims to address some of these research gaps by focusing on agricultural-to-urban water transfers in rapidly urbanising river basins in India and China. The comparative study examines three areas of water transfers with an explicit focus on how processes of urbanisation and the attributes of the case study cities shape processes and impacts. The first area is processes of agricultural-to-urban water transfers beyond those arising from formal institutional mechanisms. This analysis considers the multiple ways water flows to urbanising areas and how these processes are influenced by the attributes of towns and cities. The second area is water transfer impacts and how these are modified by the highly dynamic environments in which transfers occur. The third area is the relationship between water transfers, urbanisation, and urban wastewater which illuminates the question of water transfer impacts from a systems level. Finally, the use of a comparative research approach allows the identification of alternative rival explanations in lieu of baseline data or counterfactuals. The details of the comparative case study framework, and how this provides a starting point for generalisation with respect to the role of 'the urban' in agricultural-to-urban water transfers, are described in detail in Chapter 3.

3 Comparative Case Study Methodology

Summary

This chapter serves two functions. Firstly it presents the comparative research framework used in this thesis; and secondly it describes the research methods and process of comparative analysis used to understand the case studies of water transfers to Hyderabad, Coimbatore, and Kaifeng. The thesis applies a simplified version of Levi-Faur's stepwise comparative method (2004, 2006). This form of comparative framework allows theoretical insights from the primary case study of water transfers to Hyderabad to evolve as secondary and tertiary cases are added to the analysis. The methods described in this chapter support the comparative framework, and include interviews and simple hydrological analysis based on secondary data sources.

3.1 Introduction

Comparative research provides a methodological bridge to connect two opposing features of the water resources management literature. The first is the emphasis placed on the context dependence of water management and the importance of local factors. The second is the desire to learn from the extensive evidence base and to distil from it policy relevant general explanations. These features give rise to a body of water research which Mollinga and Gondhalekar (2014, p182) label as prone to both 'overgeneralisation and over-contextualisation'. The water allocation and transfer literature also exhibits the tendency to concentrate on either end of this spectrum. For instance, Dinar et al.'s (1997) work on water allocation principles and mechanisms, represents the tendency to overgeneralise and the large number of single case studies highlighted in Chapter 2 represents the tendency towards over-contextualisation.

Comparative research provides a pragmatic way to move beyond these extremes of research style. Detailed case studies, designed to highlight contextually dependent causal mechanisms, can also reveal general principles when incorporated into a comparative framework. As more case studies are added to comparative research frameworks, a typology of different sorts of cases begins to emerge, which represents the 'structured diversity' of the case population (Mollinga and Gondhalekar, 2014). Typologies, therefore, are an expression of theoretical generalisation, and a product of the application of comparative research, an example of which is shown in Chapter 5 of this thesis. Thus, comparative research has the potential to strengthen the theorisation of water transfers in different contexts by enabling general theory to evolve.

Building on this introduction to comparative research, the chapter is structured as follows: the remainder of section 3.1 provides further rationale for comparative case study research. Section 3.2 describes the small-N stepwise comparative approach used in the thesis. This includes a review of case definition, selection criteria, and comparative analysis. Section 3.3 describes the research methods and the process of comparative case study analysis. Finally, section 3.4 outlines the key limitations of the comparative approach.

3.1.1 Rationale for Comparative Case Study Research

The use of comparative research in this thesis is justified not only by its ability to reconcile opposing characteristics of water transfer research, as outlined above. But also because of its alignment with the author's ontological position – beliefs about the nature of the world – and because it addresses some of the methodological research gaps within the field of water transfer research, that are shown in the systematic map in Chapter 2.

3.1.1.1 Ontology

Ontology influences methodological choices because it shapes how researchers conceptualise reality and their research subjects. This thesis is written from the perspective of critical realism. Critical realism aligns with the social and material elements of water transfer drivers, processes, and impacts because it acknowledges that, while much of the world is socially constructed, there remain aspects that are 'real' (Sayer, 1984). Critical realism therefore supports the author's view that water allocation and transfers are inherently political and influenced by social relations of power (Allan, 2003) in addition to being shaped by material and physical factors. Furthermore, critical realism supports the use of comparative case methodologies. This is because an important aim of the critical realist movement is explanation and retroduction – the process of identifying causal mechanisms (Geoff, 2010) – a key objective of case study research.

3.1.1.2 Methodological Research Gaps

Comparative research addresses two methodological gaps in the water transfer literature. The first relates to the quality of existing comparative water research which has been described as being loose and implicit, relying for example on the juxtaposition of material, rather than the application of robust comparative methods (Wescoat, 2009). This suggests that there is scope for research that applies a more explicit comparative approach. The second gap relates to the relatively small number of comparative studies on water transfers, as shown by the systematic map in Chapter 2. This implies that there is space for the wider application of comparative methods to learn from water transfers occurring in different contexts.

3.2 Stepwise Comparative Research

This section describes the comparative research approach used in the thesis. It starts by introducing the main features of comparative research, then moves to the specific characteristics of the stepwise framework. This is followed by a discussion of the processes of casing and case selection – integral components of comparative analysis.

Comparative research takes many forms according to the number of cases analysed (small- versus large-N), disciplinary approach (qualitative, quantitative, or mixed methods), and comparative logic. Of the possible combinations, qualitative, small-N research dominates the comparative water literature. Often, this uses a 'most similar' or 'most different' comparative logic. To more fully capture the potential for theory building, this thesis uses a small-N empirical *stepwise* comparative framework developed by Levi-Faur (2004, 2006). This has been advocated as a research method for water resources research by Mollinga and Gondhalekar (2014). The stepwise framework differs from standard small-N qualitative approaches through its approach to systematically increasing the scope of research using two forms of comparative logic. The main characteristics of the stepwise method are presented below.

3.2.1 Applying a Stepwise Comparative Framework

The stepwise comparative case method focuses on the relationship between case selection and theory development. Two features distinguish it from other comparative approaches. The first is its emphasis on case definition and redefinition as knowledge accumulates through the research process. The second is the use of a matrix to aid the systematic selection of cases and their analysis. This is shown in Table 5. The matrix is based on two forms of comparative logic that are combined to maximise the potential for theory building. The first comparative logic is Mill's (1843) inductive method of agreement and difference. This forms the horizontal axis. The second is the logical comparative framework of Przeworski and Teune (1970), otherwise known as the 'most similar' and 'most different' comparative logic, and is presented on the vertical axis.

The application of the matrix is illustrated in Table 5 using the cases of Hyderabad, Coimbatore, and Kaifeng. Research proceeds 'stepwise' from the primary case to secondary and tertiary cases that increase both internal (understanding of causal relationships) and external (generalisability) validity of the theoretical findings. By adding more cases, a typology of cases emerges.

Table 5. Stepwise comparative research matrix.

		Mill's Method of Difference	Mill's Method of Agreement
Przeworski and Teune (1970)	Most Similar Research Design	Development of a conceptual model PRIMARY CASE: HYDERABAD **STEP 1** →	Assessing the robustness of the conceptual model in similar situations by dealing with similarities in similar cases HYDERABAD + COIMBATORE **STEP 2**
	Most Different System Research Design	**STEP 3** → Develop a typology by comparing elements of the conceptual model with different situations by dealing with differences in different cases. KAIFENG + SYSTEMATIC MAP	**STEP 4** Develop theory reflecting structured diversity by dealing with similarities in different cases. KAIFENG + SYSTEMATIC MAP

Source: Adapted from Levi-Faur (2004, 2006) and Mollinga and Gondhalekar (2014).

3.2.2 Casing

Casing is the iterative process of defining and selecting cases to explore research contentions in comparative research. It begins by analysing what constitutes a case. Cases are not 'things', such as a countries or river basins, but incorporate a configuration of attributes (Gondhalekar and Mollinga, 2011). This perspective on the nature of a case study is similar to Brady and Collier's (Brady and Collier, 2010) definition of a case as a 'bounded incidence of a specified phenomenon'. As research progresses, the definition of the case and its attributes evolves as new explanatory variables and causal relationships are identified and others discounted.

The focus of the thesis is water transfers from agriculture to urban sectors in closed or closing river basins. Hence, the case is defined as: *processes and impacts of water transfer from agriculture to urbanising areas in closing river basins*. These processes are not limited to institutional mechanisms and the politics of allocation but encompass material processes such as urbanisation that cause water to flow from one sector to another.

Case study research also requires that the unit of analysis be defined. This is the level at which research is conducted. To answer the research contentions posed by the thesis, the unit of analysis is defined as the *agriculture-urban system of water-donating and water-receiving sectors embedded in the wider river basin*. Because the thesis adopts a predominantly urban perspective, less attention is directed at the water-donating agricultural region. However, in Chapter 7, the unit of analysis is extended to include downstream agricultural water use in wastewater irrigation.

3.2.2.1 Case Selection

Cases were selected on the basis of theoretical insights derived from the systematic map in Chapter 2 and on the basis of the overarching research contentions. Thus, to understand the importance of urbanisation and urban contexts for agricultural-to-urban water transfer analysis, the thesis design sought cases meeting the following criteria: 1) urbanising towns or cities; 2) located in developing or transition economies; 3) located within closed river basins; and 4) a documented history of water transfers from the agricultural sector.

In additional to theoretical selection criteria, a number of logistical factors were also considered. For example, the research design required that there be existing research on water transfers to provide a starting point for comparison; and that fieldwork was feasible in terms of local support and contact networks. Using the systematic map as a database of potential studies, Hyderabad in the Krishna river Basin, Coimbatore in the Cauvery River Basin and Kaifeng in the Yellow River Basin were selected. Table 6 shows the main selection criteria for the three case studies.

Table 6. Case selection criteria.

Criterion	Hyderabad	Coimbatore	Kaifeng
Country	India	India	China
Closing River Basin	Krishna (Musi sub-catchment)	Cauvery (Noyyal sub-catchment)	Yellow River Basin
Documented history of water transfer	(George et al., 2011a, Van Rooijen et al., 2005, Celio et al., 2010)	(Saravanan and Appasamy, 1999)	(Loeve et al., 2004)
Institutional mechanism	Priority allocation system and Government Orders	Priority allocation system and Government Orders	Basin allocation plan, quotas, and nascent water rights trading schemes.
Urban growth p.a.	3.3%[1]	1.4%[2]	1.6%[3]
Population (million)	7.9[4]	1.2[5]	1[6]
Host Organisation	IWMI	TNAU	Wuhan University

Sources: (1) Yellapantula (2014) (2) Urban-LEDS (2015) (3, 6) Interview, Interview, Kaifeng Office of Town Planning, (2013) (4, 5) Census Organization of India (2011).

3.2.3 Data Analysis within a Comparative Framework

The comparative research framework also determines how data is analysed. Analysis was undertaken by comparing the similarities and differences across the cases to help identify causal mechanisms between independent variables and dependent variables. While not explicitly using process tracing methods and its formal tests for causation, the analysis was influenced by the concept of 'diagnostic pieces of evidence' to enable causal attribution (Brady and Collier, 2010). Diagnostic evidence allows contentions to be supported or refuted. For example, the similar growth rates of Coimbatore and Kaifeng described in Chapters 4 and 5 enables reflection on the power of 'rate of urbanisation' as an explanatory variable in the context of understanding the determinants of types of water transfer.

Determining which pieces of evidence are diagnostic involved the compilation of case study databases to enable comparison. Field data for each case was categorised in terms of case attributes and potential independent variables such as land-use, demographics, institutional mechanisms for transfer, groundwater availability, urban water governance, and urban planning regimes. These categories were then compared across each case study's database and the systematic map. From these explicit attempts to compare evidence, the arguments presented in Chapters 5-7 emerge.

3.3 Field Methods

This thesis uses mixed methods, an approach where the researcher combines quantitative and qualitative research methods within a single study (Johnson and Onwuegbuzie, 2004). Combining different data collection methods and sources enables an interdisciplinary overview of water transfer processes and impacts in the context of rapid urbanisation. Methods included interviews and the interpretation of hydrological data to understand likely water flow pathways. Moreover, using different sources of data and a mixed methods approach is useful to overcome the problem limited data availability because it enables triangulation (Gerring, 2007). The issue of limited data availability is discussed below, after which methods and sources of data are described.

3.3.1 Implications of Data Paucity in Water Transfer Research

This section discusses the issue of data paucity and the limitations this places on water transfer research. Understanding how water flows between the agricultural and urban sectors is hugely challenging. This is because water flows, dissipates, changes state, changes quality, undergoes multiple use cycles and its availability varies both seasonally and inter-annually; measuring it is not a simple task. The data fuzziness this produces is so problematic that it is thought to contribute to river basin overdevelopment (Molle, 2008, Molle, 2009). And even in mature water economies, seemingly straightforward tasks such as compiling urban water balances are hindered by incomplete datasets (see for example Kenway et al.'s (2011) attempts to model water budgets in Australian cities). In developing and transition economies, the challenge of collecting data is compounded by the relative lack of monitoring and the political sensitivity of some water data. For field researchers, this presents two problems: data availability and data reliability.

Coping with poor data availability – the absence of information – entails finding proxies or making standard assumptions. For example, urban runoff can be estimated using the curve number method (SCS, 1985) and evaporation derived from Penman-Monteith equations (Monteith, 1973). Whereas, coping with poor data reliability presents a different problem because the level of uncertainty is unknown. The following anonymous interview quotes from staff responsible for collecting hydrological data in the case cities exemplify the potential uncertainties: '*we don't really know how much water we are using because of groundwater pumping*' and '*we can't publish the real* *numbers in the data booklet – we keep them in the (locked) cupboard*' (Research Interviews, 2012). Moreover, some uncertainty arises not from the lack of information, but because of competing claims from different sources.

While problems of data paucity are surmountable, for example urban water balances for Hyderabad have been successfully compiled in the past (see Van Rooijen et al. (2005) and George et al. (2009)), this thesis views the lack of data as an integral part of the character of water transfers. Therefore the research design does not attempt to mask the data availability problem, particularly for informal water transfers, by modelling the different flows of water to growing cities based on assumptions. Instead it relies on triangulated data to infer broad processes of water transfer and to suggest their level of significance.

3.3.2 Logistics

Fieldwork was conducted in 2012 and 2013 as shown in Table 7, which also summarises the main research logistics. Details of living arrangements are included because host families in Coimbatore and Kaifeng provided local contextual insights that shaped data analysis and interpretation. The remainder of the section then presents the main field methods: interviews, direct observation, and simplified water budgeting.

Table 7. Fieldwork logistics.

Case	Dates of fieldwork	Host Institution	Living Arrangement
Hyderabad	July – August 2012 October – November 2012	International Water Management Institute (c/o ICRISAT)	ICRISAT Campus
Coimbatore	December 2012 – February 2013	Tamil Nadu Agricultural University (TNAU)	Host Family
Kaifeng	September 2013 – December 2013	Wuhan University	Host Family

3.3.3 Interviews

Interviews sought information on multiple aspects of water transfers including: institutional mechanisms; trends in urban water demand, water use in agriculture; relationships between administrative departments; and subjective perspectives on urbanisation, local agriculture, and water transfers. The interview scope and form varied depending on the interviewee's role and relationship established. In Hyderabad, Coimbatore and Kaifeng, a small number of key informants were identified on the basis of their knowledge and willingness to take part in the research. Key informants were interviewed numerous times using an unstructured approach. Further detailed guidance was obtained from researchers at host institutions who provided large amounts of background information and with whom numerous discussions were undertaken. Most remaining interviews were semi-structured and followed an interview guide.

3.3.3.1 Sampling

Interviews were conducted with stakeholders and linked to water transfer processes. These included: government departments related to water, agriculture and urban planning; engineering consultancy firms; NGOs; local academics; peri-urban farmers (predominantly in Coimbatore and Kaifeng); and also with water tanker drivers in Hyderabad. Sampling was primarily purposive and directed by a stakeholder mapping exercise based on the methods of earlier researchers (see for example Van Rooijen (2011)). As fieldwork continued, more stakeholders were identified using snowball techniques. The number of interviews conducted at each case study site is summarised in Table 8 below.

Table 8. Number of interviews by case.

Stakeholder	Hyderabad	Coimbatore	Kaifeng
Institutional	18	16	16
Other	6 (water tanker drivers)	3 (peri-urban farmers, group-to-one)	15 (peri-urban farmers, group-to-one)

3.3.3.2 Interview Transcripts

Only cursory notes, for example numerical data such as flow rates or volumes, were taken during interviews. This approach aided the rapid development of a rapport with interview subjects. To ensure that accurate records of the interviews were kept, summaries were written immediately after the interview. Many interviewees also provided clarification and additional information via email or during second interviews. For interviews requiring interpretation, both the researcher and the interpreter prepared interview notes, which were then compared and discussed.

3.3.3.3 Interpretation

Most interviews in Hyderabad and Coimbatore were conducted in English (except those with farmers and water tanker drivers), whereas most interviews in Kaifeng were conducted in a dialect of Mandarin local to Henan Province. Hence, a dedicated interpreter was employed in Kaifeng. In Coimbatore, this role was undertaken by a key informant and, in Hyderabad, by a research assistant from IWMI. Conducting interviews using an interpreter introduces additional bias and the potential for an 'interpreter version' where interview questions and responses are filtered through the interpreter's own assumptions (Temple and Edwards, 2002). A further issue is the scope for more complex power relations between interviewee, interviewer, and translator. This was mitigated to an extent by training the interpreter prior to data collection and by conducting post-interview discussions.

3.3.4 Secondary Data

Alongside qualitative data from interviews, meetings often coincided with the collection of secondary data. For example, groundwater levels, precipitation records, land-use maps, and schematics of the urban water network. One of the most important sources of data collected were detailed project reports (DPR) for infrastructure development projects. Written by consultancy firms, these are used to justify costs and the scope of work for large infrastructure projects. Examples include an analysis of surface water drainage in Hyderabad or assessments of sewerage requirements for Coimbatore. In Hyderabad, interviews were conducted with two consultancy firms involved in preparing DPRs, which gave a useful insight into the challenges of designing and managing large water infrastructure projects in these institutional settings.

3.3.5 Direct Observation

Direct observation is a research method implicit in case-study data collection and involves the researcher observing actions, events, behaviours and processes during fieldwork and recording these in notebooks and photographs (Pauly, 2010). Data from direct observation contributes to a better understanding of local contexts and the dynamics of organisations and processes of management by supplementing what is verbalised in interviews. For example, a more complete understanding of the workings of one administrative department was gained by attending the office celebration party for Pongal, a local festival.

3.3.5.1 Transects

Transect drives helped to contextualise characteristics of the urban area such as changes to housing density and land-use, and situate the research in a physical reality rather than relying on maps and other spatial data. Transect drives were also useful to orient urban features with respect to the topography, drainage channels, and wastewater treatment plants. Drives were also taken parallel to major urban drains to observe changes downstream of discharge points, and to observe farmland adjacent to these sources of wastewater.

3.3.6 Hydrological Data

This thesis uses hydrological data to draw inferences about different types of transfer processes. For example, to indicate the balance between bulk surface water transfers and transfers arising from informal water use. This approach was adopted as an alternative to compiling water balances because of limited data related to many of the urban balance inflow and outflow terms. Instead, data was collected show the different sources of water and to infer the significance of different types of transfer process. This is described below.

3.3.6.1 Urban Water Sources

Sources of urban water dictate water transfer processes. Sources include: surface water from rivers, reservoirs, and urban tanks; groundwater; rainwater harvesting; and water reuse occurring within the urban boundary. This thesis limits analysis to groundwater and surface water because field data indicates that contributions from wastewater reuse and rainwater harvesting are negligible in the case cities.

3.3.6.2 Inferring Types of Transfer Process

Quantifying the contribution of informal water transfers to urban water budgets is difficult because these processes are inherently decentralised and there is rarely data to document the volumes of water involved. To circumvent the data gap, this thesis exploits the fact that most informal water transfer processes rely on groundwater, whereas formally sanctioned transfers to Hyderabad, Coimbatore, and Kaifeng are predominantly sourced from surface water. This means that the relative contribution of informal and formal water flows to urban budgets can be approximated by comparing bulk surface water transfers – for which there is available data with estimates of overall urban water demand – and assuming that groundwater (derived through predominantly informal means) fills the demand gap. Where groundwater data is available, these estimates can be triangulated. However, there remains a great deal of uncertainty regarding how much water flows to the urban area from groundwater.

3.3.7 Contextual Data

Contextual data to supplement interviews and triangulate data was drawn from newspapers articles. In the Indian case studies, this was a particularly rich source of information given the daily publication of local English Language papers. Further contextual insights were drawn from experiences of living in the case cities for a number of months, and for Kaifeng and Coimbatore, living with host families.

3.3.8 Research Ethics

Research ethics were considered separately for each case study, to reflect differing cultural settings and levels of involvement of host institutions. The main ethical considerations were: to ensure informed consent of interviewees; to determine the level of data attribution the interviewee was comfortable with; and to acknowledge the power relations between interview subjects, the researcher and the host organisation, which can create a sense of obligation to take part in the research.

3.4 Limitations and Sources of Research Bias

This section considers five limitations of the comparative research approach used in this thesis. The first relates to the issue of selection bias, a common criticism of comparative methodologies wherein researchers focus predominantly on cases that exemplify the phenomenon of interest. The implication is that comparative research over-emphasises the significance of the research phenomenon within the total population of cases. This type of criticism has its roots in positivist traditions, where, unlike in comparative research, generalisations emerge from statistical relationships. In statistical analysis, selection bias is minimised by random sampling and large sample sizes. Whereas, in case study research, sampling strategies are purposive, and generalisation emerges from logical rather than statistical argument (Yin, 2009). Cases are selected according to their expected properties, for example, cases are chosen because they are paradigmatic (typical of a phenomenon), critical (enables falsification or other forms of logical deduction), represent the maximum or minimum values of variable of interest, or are unique exceptions (Flyvbjerg, 2006). Case selection frameworks are therefore an important element of comparative research design and determine the extent to which findings can be generalised beyond the initial findings.

A second limitation of comparative case study research is the implicit assumption that there are commonalities between the cases from which generalisation can be sought. This thesis is based on three cases of water transfer, situated in the very different country contexts of India and China. The research design therefore assumes that despite these vastly different settings, that generalisation can nevertheless be made. The implicit assumption that commonalities are present shapes the approach to data analysis and is therefore an underlying source of research bias. This is because the data analysis is seeking causal mechanisms, and the small number of cases readily allows the inference of relationships.

A third limitation, is the difficulty of isolating causal mechanisms from their case study contexts. In the three cases study regions, the contexts in which water transfers occur are dynamic and complex. Therefore, causal mechanism identification presents a considerable methodological challenge. This difficulty is exemplified by the typologies generated in Chapter 5. The urban attributes used to indicate water transfer regimes are interrelated and a product of the local context. Hence isolating the effect of any individual attribute is not possible using the methods employed in this thesis. Furthermore, this problem is compounded by the lack of reliable hydrological data to enable a more definitive assessment of water transfers between the agricultural and urban sectors.

A fourth limitation is the bias introduced by the asymmetry of knowledge that often occurs between case studies in comparative research designs (Azarian, 2011). This is particularly relevant to this thesis, not only because two of the case studies are based in the India as opposed to only a single study in China, but also because of the author's previous research on water management in India. Consequently, the Indian context is much more familiar to the researcher than the Chinese context. This asymmetry affects data analysis and interpretation and acts as a source of bias in this thesis.

A fifth limitation of this comparative study is the small number of cases. This thesis examines only three case studies, each of which embodied similarities and differences across several dependent and independent variables. Dependent variables include the type of water transfer or extent of wastewater irrigation, and independent variables include the various urban attributes presented in Chapter 5. Thus, none of the cases are likely to be fully representative of a particular class of 'case'. The problem of case selection, and whether cases are representative, is an artefact of the iterative case study approach. As research develops and the definition of the case evolves, the interpretation of causal mechanisms observed at each case alters. Therefore, despite attempts to select cases according to certain criteria (as per the stepwise method), any generalisations emerging from this thesis should be treated cautiously.

A final, and more practical limitation of approach used in this thesis, is the trade-off between additional empirical case studies and the quantity and quality of primary data collected. Fieldwork across three study sites cannot deliver the same level of richness of detail as the same amount of time dedicated to only one field study. However, this loss of richness is compensated by the additional insights generated through the comparative method and from observing similar processes in different contexts. This trade-off is acknowledged to be a limiting constraint on the findings of this thesis, particularly given the challenges of understanding multiple water transfer pathways to each case study site in a relatively short amount of time.

This chapter has presented the comparative framework and methods applied in this thesis, alongside the main limitations of empirical comparative case study research. The following chapter presents the comparative case studies and the overarching findings from fieldwork. This serves as the basis for the argumentation provided in Chapters 5-7.

4 Introduction to Case Studies

4.1 Introduction

This chapter presents the three empirical case studies of water transfers to Hyderabad, Coimbatore, and Kaifeng. The aim is to give an analytical description of each case study, setting out the findings, compiled from primary and secondary data sources, alongside insights from existing published research. This combination of evidence, woven together from different sources, allows the development of an indicative picture of how each city increases its share of water resources. Each case study includes a description of the local water policy and management context, including the different urban water management frameworks, in addition to observations related to urbanisation. This proceeds a summary of the main types of transfer process at each case. The chapter also introduces the water and urban planning policy landscape at a national and state levels India and China. These country-level summaries enable evidence from Hyderabad, Coimbatore, and Kaifeng to be assessed against national frameworks for institutional mechanisms for water allocation and urban planning.

Together, the national contexts and case descriptions, provide the empirical basis for the argumentation presented in Chapters 5, 6, and 7, in which different aspects of agricultural-to-urban water transfers are explored. To avoid undue repetition across the thesis, descriptions of specific elements of transfer processes and impacts are reserved for the later chapters, as indicated by the cross references given in the text.

The chapter is structured as follows: section 4.2 reviews Indian and Chinese experience of agricultural-to-urban water transfers. This review provides a foundation for the case descriptions and shows where and how the case studies of Hyderabad, Coimbatore and Kaifeng fit in to and extend existing research; section 4.3 outlines national and state level water policy, law and regulatory from works in India; sections 4.4 and 4.5 present the case studies of Hyderabad and Coimbatore and respectively; section 4.6 summarises Chinese water management policy, law, and regulatory frameworks; and finally section 4.7 presents findings from Kaifeng.

4.2 Review of Indian and Chinese Agricultural-to-Urban Water Transfers

The agriculture-to-urban water allocation and transfer literatures for India and China focus on different aspects of the movement of water between these two sectors. While the main focus of the Chinese literature is the impact on donor agricultural areas, the literature from India emphasises the different mechanisms moving water from the agricultural sector to growing towns and cities. This section reviews the country specific literatures using the papers identified in Chapter 2's systematic map.

The agricultural-to-urban water transfer literature for India comprises seven papers; three of which examine water flows to the city of Chennai, three examine Hyderabad and one looks at water allocation in the state of Maharashtra. Thus, the current evidence-base, with only three case studies, is somewhat limited in its scope.

Research on Chennai focuses predominantly on groundwater and highlights the importance of groundwater as a water supply source for growing cities. Two of the Chennai papers focus on the groundwater markets between the city and peri-urban farming communities. This transfer mechanism incorporates both formal and informal elements, which operate in tandem. This is shown by the different forms of market examined by the papers. Ruet et al. (2007) outline the quasi-formal tripartite agreement between borewell owning farmers and Chennai's water and electricity boards. The authors note that this agreement grants de-facto water rights to landowners. Packialakshmi et al. (2011), meanwhile, look at the more informal elements of groundwater markets and are able to indicate the scale of these transfers using data on water tanker visits from peri-urban villages to the city. The final paper on Chennai, by Srinivasan et al. (2013), proposes a relationship between how cities grow and the mechanisms through which urban residents are able to obtain water. This conceptualisation has important implications for the study of water allocation and transfer, and its contribution is reviewed in more detail in Chapter 5.

Hyderabad is a second key case study for the Indian literature on agricultural-to-urban water transfers. Two of the three papers on Hyderabad examine its growing urban water demand and look at the sources of water that are required to keep up with the expansion of the city. These sources are often derived from the agricultural sector. For example, Van Rooijen et al. (2005) shows the quantity of water flowing in to and out of Hyderabad, linking the findings to questions of allocation, whereas George et al. (2011) present possible for allocation strategies by considering Hyderabad's water demand in the context of basin water availability. The final paper, by Celio et al. (2010) proposes a new conceptual model explaining how cities are able to take water from farmers. The authors argue that cities like Hyderabad are able to subsume the institutions and infrastructure of pre-existing users to facilitate transfers. Celio et al.'s work focuses mainly on the co-option of formal institutional mechanisms for water allocation and as a result does not touch on the issue of groundwater supplies – despite the highly visible trade in groundwater conducted through Hyderabad's tanker schemes.

Lastly, the case study on Maharashtra uses a political economy perspective to analyse the 'water grabbing' of surface water from dams meant for irrigation, by industrial interests (Wagle et al. 2012). The research points to the emergence of new institutions that enable these transfers, such as the recent introduction of proto market mechanisms. The authors argue that through a combination of policy obscurity, illegal activities, and political influence, water reallocation undertaken in this manner is becoming more hidden.

The English language research on agricultural-to-urban water transfers in China focuses predominantly the impact of agricultural-to-urban water transfers on water-donating regions. The literature comprises 12 papers, most of which examine impacts; in additional to studies focusing on market mechanisms, and one presenting an important conceptual contribution related to the role of cities in influencing transfers processes. The main contributions are reviewed below.

Using farmer surveys, Wu et al. (2013), Zhou et al. (2009) and Huang et al. (2012) attempt to unpick the effects of reallocation policies on the agricultural sector. The results are mixed, with farmers largely being happy with levels of compensation offered in lieu of water, but questions remain over the effectiveness of reallocation policy. For example, Huang et al. (2012) argue that the effect of the policy of reducing cultivated areas to release water for Beijing, is offset by farmers intensifying cultivation on remaining land. The issue of impacts is also addressed by Loeve et al. (2007), which shows that despite transferring water to higher value uses, there has been no significant fall in rice production from the Zhange Irrigation System (ZIS). This counterintuitive result is attributed to changing cultivation practices and rice varieties in the ZIS command area.

Two papers examine market-based mechanisms for agricultural-to-urban water transfers. Zhang et al. (2007) finds that the success of a pilot scheme to Zhange city is limited and attributes this is administrative and managerial factors rather than technical factors. In a simulation of market mechanisms for intersectoral allocation from agriculture, Wang (2012) shows that the agricultural sector is the most sensitive to transactions costs and that this can impact the efficacy of market transfer mechanisms.

The most significant conceptual contribution from the agricultural-to-urban water literature in China highlights the wider impacts of urbanisation on allocation through its effects on land-use. Kendy et al. (2007) use a water balance approach to show how the transfer of agricultural land to urban land can lessen the pressure on water resources due to the differences between urban and agricultural levels of consumptive water use. This concept provides the basis for discussion in Chapter 5 and Chapter 7 of this thesis and the paper is reviewed in more detail in these chapters.

This review of the available literature on agricultural-to-urban water transfers in India and China has shown that there are large gaps in the understanding of how water flows to cities. In particular, most studies focus on one type of mechanism and do not explicitly address water flows to urban areas in a holistic way; for example, most studies examine groundwater or surface water but not both. The literature also reveals significant uncertainty about the form and magnitude of the impacts of agricultural-to-urban water transfers at the system and farm levels (see Chapter 6). These gaps are borne from the technical and political complexity of studying these systems in the context of the difficulties in understanding hydrological pathways and the way they change in dynamic environments.

4.3 Water Management in India

Water in India is predominantly managed at the level of the state, although a national water policy guides the formulation of state approaches. This section describes the national water policy (NWP) and the state water policies of Andhra Pradesh and Tamil Nadu as they relate to water allocation and transfer. The section also emphasises the vastly different regulation of surface water versus groundwater in India, and how this facilitates the informal mechanisms through which the share of water used by the agricultural and urban sectors can change. Finally, the section highlights an important initiative outside water policy, which affects how cities in India can gain water. This is the Jawaharlal Nehru National Urban Renewal Mission (JnNURM) scheme, which has played an important role in the provision and financing of urban water infrastructure thereby facilitating many bulk surface water transfer schemes across the country.

4.3.1.1 National Water Policy (2002) and the Priority Allocation System

The NWP (2002) addresses multiple aspects of water management across India, the most relevant of which for agricultural-to-urban water transfers, is the priority allocation system. This policy guides decision-makers as to how water should be allocated between different water-using sectors. The NWP prioritises water according to a hierarchy of priority uses. At the national level, these are: drinking water; irrigation; hydropower; navigation and industrial use. An important implication of the priority allocation system is that agriculture is a *residual* water-using sector. This means that it receives the volume of water available once drinking water demands are met. Moreover, under this system, farmers do not receive compensation when allocations of water for irrigation are reduced, unless reductions occur partway through a cropping season (Interview, Public Works Department, 2013).

As a policy tool to manage competing water demands and allocating water between sectors, the priority allocation system, when applied at the State level, is often unwieldy. This is for two main reasons. The first reason is that growing urban water demand comprises both municipal users (mainly household water demand) and also water for urban industry. These different uses of water are closely clustered in urban spaces and distinguishing between them can be difficult, particularly in areas where there are many different types of water supplier (see Chapter 5). This combined demand profile is problematic because municipal water (for drinking and bathing) and water for industry are situated at opposing ends of the priority allocation hierarchy. Thus for practical purposes, industrial water demand and municipal demand, particularly for smaller industries and industries, is conflated in many towns and cities (Interview, Public Works Department, 2013).

The second difficulty with the priority allocation system is the disparity between political economy considerations and the stipulated hierarchy of water uses. For example, the large electrical power deficits and frequent power cuts that affect industrial output in Andhra Pradesh and Tamil Nadu mean that water availability for hydropower generation is politically sensitive (Interview, Government of Andhra Pradesh, 2012). This political sensitivity was exemplified by interviews with business leaders in Coimbatore who perceived power outages as a far more significant constraint on their activities than water shortages. For the local irrigation departments responsible for managing reservoir releases and implementing the priority allocation system, there is therefore considerable pressure from the industrial lobby to ensure that hydropower generation is not limited. Thus, hydropower may be unofficially raised up the priority allocation hierarchy list at times when water supply is at its lowest and energy demand highest – the summer months. Similarly, demands for water by industries may be granted out of turn due to pressure applied to irrigation department officials through '*money men and muscle men*' (Interview, Public Works Department, 2013).

4.3.1.2 State Water Policy

In India, legislative and administrative responsibility for water lies at the state level rather than with the central government or river basin organisations. However, the state water policies of Andhra Pradesh and Tamil Nadu echo the National Water Policy (2002) and use the same priority allocation system. Thus, Andhra Pradesh's 2008 water policy for example, privileges drinking water in its priority allocation list. Similarly, in Tamil Nadu, which has not revised its water policy since 1994, but issued a draft for consultation for a new policy in 2007, also stipulates that drinking water remain the priority for water allocation. This means that in both states, when cities request additional water supplies, their demands are prioritised above other sectors in accordance with state and national level water policies.

Despite the devolution of water management responsibility to the state level, there are no organisations or departments that have sole oversight of water resources management and planning. Instead, the main management responsibility lies with the departments tasked with managing water for the agricultural sector (the Public Works Department in Tamil Nadu and the Irrigation and Command Area Development Department in Andhra Pradesh). However, the focus of these departments is normally civil engineering approaches to meeting irrigation demand rather than holistic or integrated water management objectives. Nevertheless, the fragmented institutional environment for water management is beginning to change. For example, in 2012, a draft revision of the national water policy was released which removes the priority allocation system and advocates new organisations for integrated water management at the state and river basin levels (Institute for Agriculture and Trade Policy, 2012).

4.3.1.3 Surface Water versus Groundwater Management

There are significant differences in the treatment of surface water and groundwater in Indian water law and policy. This has wide-ranging implications for water management and the extent to which water flows between sectors can be controlled. Surface water is subject to management by the State and is largely managed through irrigation legislation. Groundwater rights meanwhile are linked to land ownership[12] and the State has limited control over abstraction on private land. This has profound implications for the sustainability of water use across India, particularly in irrigated agriculture, but is also a critical consideration in understanding how the large water supply deficits of Indian cities are met.

This difference in the treatment of surface versus groundwater is also reflected in the emphasis given to peri-urban informal groundwater markets, as shown in the review of Indian agricultural-to-urban water transfer literature highlighted earlier in this chapter. Nevertheless, the institutional environment for groundwater management is evolving rapidly (Kulkarni and Shankar, 2014). While extensive analysis of the wide-ranging and fast-paced groundwater governance debate in India is beyond the scope of this thesis, the role of weak groundwater regulation in driving informal water transfer processes is discussed further in Chapter 5.

4.3.1.4 The Jawaharlal Nehru National Urban Renewal Mission

Water supply to the water boards of Indian cities (much of it derived from bulk surface water transfers) is also influenced by initiatives beyond state and central water policy frameworks. One of the most influential is the Jawaharlal Nehru National Urban Renewal Mission (JnNURM). JnNURM was a central government initiative launched by the Ministries of Urban Development and Urban Employment and Poverty alleviation in 2005 (Ministry of Urban Development, 2011). The scheme objective was to finance and fast-track urban infrastructure including water supply and sanitation projects in 63 cities across India. JnNURM is an important consideration in the analysis of bulk surface water agricultural-to-urban transfers analysis because it funds and technically supports projects commissioned by urban water boards and municipal corporations. This includes transfers to both the case study cities of Hyderabad and Coimbatore. JnNURM therefore facilitates water allocation choices that might otherwise be rejected due to their expense and exemplifies how cities can leverage funding for water transfer schemes and effectively increase the area over which they can extend their water infrastructure footprint.

[12] In Andhra Pradesh, groundwater is ostensibly regulated through the Water Land and Trees Act (2002), and in Tamil Nadu regulation is through the Groundwater (Development and Management) Act (2003), although these regulations are not widely enforced (Sakthivel et al., 2014).

The ability of urban water boards and municipal corporation planners to leverage money for infrastructure through schemes such as JnNURM, was cited in interviews with the Public Works Department in Coimbatore (2013) as being an important factor in signing-off requests for increased urban water allocation (see section 4.5.5 for details). Thus, non-water related schemes, such as JnNURM, are important enablers of formal water transfers to India's towns and cities.

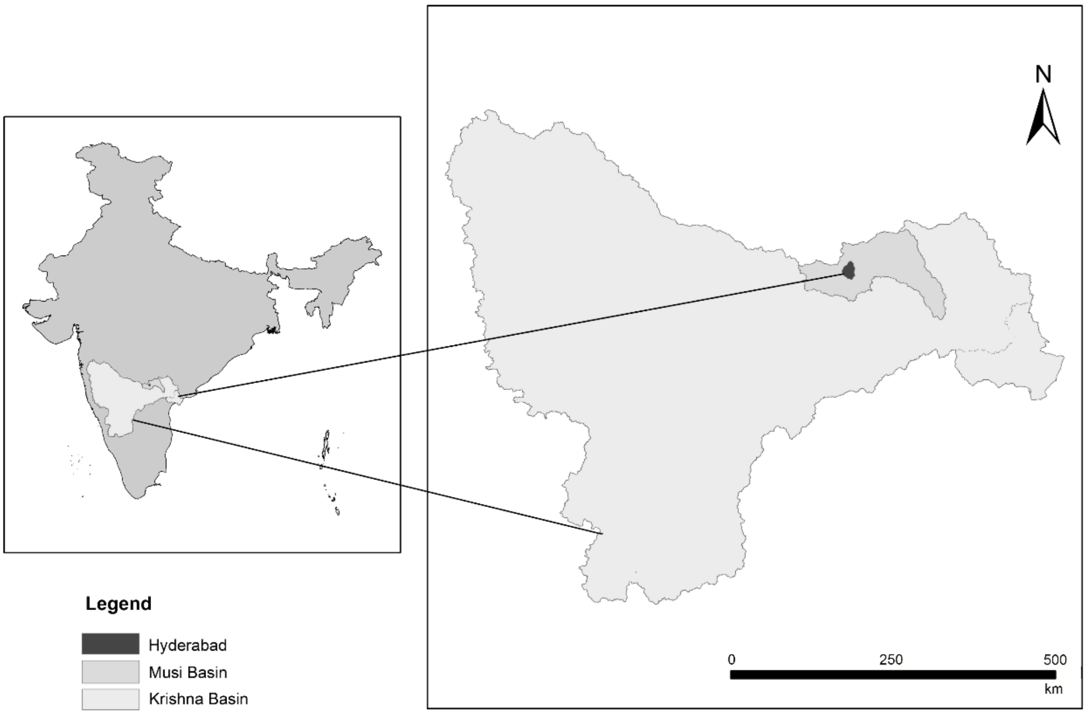
This overview of water allocation policy in India reveals an institutional environment that focuses almost exclusively on bulk surface water transfers overseen at the state level. Decisions regarding water transfers to India's growing cities are made using the priority allocation system and often funded through central government schemes, such as JnNURM, that support the development of urban infrastructure. However, as the cases of Hyderabad and Coimbatore will illustrate, India's cities gain water share through a variety of mechanisms, many of which rely on groundwater abstraction and the informal water supply sector. Understanding these varied mechanisms for water transfer is crucial to creating a more complete picture of the influence of rising urban water demand on water availability for the agricultural sector.

4.4 Hyderabad Case Profile

Hyderabad, home to 6.9 million people (7.8 million in the wider Hyderabad Metropolitan Development Area (HMDA)), is India's fourth most populous city and is growing fast (Census Organization of India, 2011). An IT hub and the joint capital of the new state of Telangana and Andhra Pradesh[13], it lies in the Musi river basin, a sub-catchment of the much larger and water stressed Krishna Basin. The location of Hyderabad and the Musi Basin are shown in Figure 10. Hyderabad, and the areas from it obtains its water, have a semiarid climate with annual average precipitation of 787mm. This rainfall occurs mainly during the summer monsoon, where intense precipitation frequently leads to flooding (Ahmed et al., 2013).

[13] The state of Telangana was officially formed in June 2014 as a result of the bifurcation of Andhra Pradesh. Given that fieldwork was conducted in 2012 and early 2013, this thesis will refer only to the former state of Andhra Pradesh.

Figure 10. Location map of the Krishna River Basin, Musi sub-catchment, and Hyderabad.



Hyderabad's growth-driven water demand mirrors the increasing water demand from non-agricultural sectors seen across the State of Andhra Pradesh. This is causing water competition between cities, towns, industries and the agricultural sector. The supply crunches seen at local levels are a reflection of pressure on supply at the river basin level, driven by the approaching closure of the Krishna Basin (Biggs et al., 2007). River basin closure is also seen in the Musi sub-catchment of the Krishna, in which Hyderabad is located (Rao et al., 2011). In this water scarce environment, where the use of water by different sectors is interconnected, increases to the share of water taken by Hyderabad and its surroundings, infer a reduction in water availability for the agricultural sector.

4.4.1.1 Case Selection Justification

Hyderabad was chosen as a case study because it meets the selection criteria described in Chapter 3. Moreover, it serves as a useful primary case given the large amount of available literature on its water allocation history, urban, and peri-urban environment, and downstream wastewater irrigated area. This existing body of work provides a framework for understanding the interaction between the city and its water environment.

4.4.2 Urban Profile

Hyderabad has an annual rate of demographic growth of 3.3% (Yellapantula, 2014), and is the most rapidly growing of the three case studies, in terms of population. This growth is driven in part by the rise of the IT sector and pharmaceutical industries. However, there are many thousands of businesses and industries of different types fuelling urban expansion. Indeed, Hyderabad hosts more than 8,000 industries within the wider metropolitan area (Interview, Directorate of Economics and Statistics, 2012), many of which are clustered in industrial zones on the outskirts of the city. Nominally, some of these industrial zones receive water from Hyderabad's water board (HMWSSB), but, as later sections of this case study will show, the majority of the city's industries are supplied informally through their own private borewells, or through the water tanker market, which distributes groundwater (The Hindu, 2014).

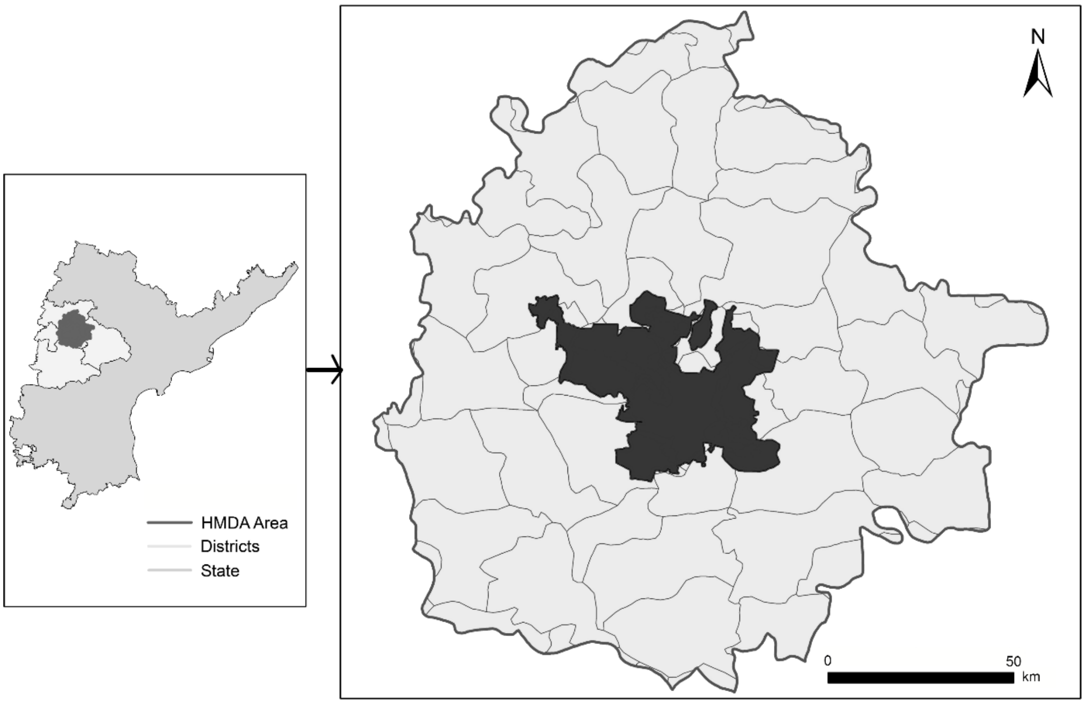
Hyderabad's demographic growth is accompanied by spatial expansion and the outward movement of the urban boundary over time. This boundary shift and the growing urban footprint mean that departmental responsibilities for planning, including for water infrastructure, evolve and change over time. It also complicates attempts to trace the history of water supply and infrastructure development as the names and responsibilities of administrative areas change periodically. To understand the current planning arrangements, Table 9 presents the main urban planning areas and the institutions responsible for each, plus the water service area and the urban drainage area. Administrative planning boundaries – the HMDA and GHMC – are also presented graphically in Figure 11. This figure highlights the nested relationship between what is effectively a core urban area in which many residents (although by no means all) are provided with water and sewerage services, and its dynamic outer peri-urban zone in which informal water service provision (see Chapter 5 for definitions of informality and its links to water transfer), is commonplace.

Table 9. Definition of administrative and physical urban boundaries for Hyderabad.

City Area (km^2)	Administrative/Physical Area	Description
7,000	Hyderabad Metropolitan Development (HMDA)	HMDA is the planning and coordinating body responsible for the total development area. The development area is large and includes large swathes of agricultural land.
650	Greater Hyderabad Municipal Corporation (GHMC)	The GHMC is the governing administrative agency that, amongst other responsibilities, manages the provision of basic infrastructure, including water and sanitation. The GHMC area incorporates the 'core' city.
680	HMWSSB's service coverage area	Area served by HMWSSB includes the core GHMC and 11 further municipalities
746	Urban drainage area	Drainage area contributing to GHMC runoff (Interview, Voyants Consulting Ltd, 2013)

Source: Compiled from information from interviews (Voyants Consulting Ltd, 2013 and HMWSSB, 2012), and from the GHMC website.

Figure 11. Map to show the core GHMC of Hyderabad nested within the larger HMDA area.



Description: The left-hand map shows the HMDA area within the State of Andhra Pradesh. The right-hand map shows the nested relationship between the smaller, denser urban area of the GHMC and the sprawling and extensive HMDA which covers more than 7,000 km^2. Much of the GHMC is served by HMWSSB. Communities outside the GHMC service area rely on Gram Panchayats, a form of rural local government, to provide water supply, normally from village borewells. Source: Adapted from IWMI, Hyderabad Office stock images.

As with many rapidly growing cities in Asia, the rate of expansion of Hyderabad and its wider metropolitan area has engendered social inequality, particularly with respect to the provision of municipal services. Approximately a third of the urban population are thought to live in slum areas, which are dotted throughout the city and in the urban periphery (Kit et al., 2012). These residents are rarely connected to formal municipal water networks; instead, they access water through informal water vendors. The consequence is that, Hyderabad's large numbers of new residents and their water use are often not reflected in official statistics for current urban water consumption but instead are included as contributing to the deficit between current supply and the total urban population (Interview, HMWSSB, 2012).

4.4.3 Urban Water Management

The main responsibility for supplying the city with urban water services lies with the Hyderabad Water Supply and Sewerage Board (HMWSSB). This is the institution responsible for supplying drinking water, collecting and treating wastewater, and planning municipal water infrastructure within its service area (Interview, HMWSSB, 2012). The service area however, does not cover the full HMDA area. Instead, it includes the central urban core of the GHMC (shown in Figure 11 above) plus a further 11 surrounding municipalities. This means that there are large areas of urban residential, commercial, and industrial development, which are not connected to the centralised water distribution network.

In terms of wastewater treatment, approximately half of the city's wastewater continues to be discharged directly to the environment without treatment. The result is that the Musi River, the main water artery running west-east through the city is highly polluted. Nevertheless, investment in sewerage infrastructure means that the network is being extended and connected to new households, plus new treatment plants are being built leading to an improvement in the wastewater treatment status (Starkl et al., 2015). More detail and primary data on wastewater flows in the Musi, and their significance in the assessment of agricultural-to-urban water transfers and their impacts, is presented in Chapter 7.

4.4.4 HMWSSB's Water Sources and Supply Schemes

Several bulk surface water transfer schemes, from some of the largest, multiple-use reservoirs, in the Krishna and Godavari river basins, supply water to HMWSSB, which is then distributed around the city. This includes three schemes from the vast Nagarjunasagar Reservoir (over 400 TMC) on the Krishna River (Krishna Phase I, II, and III). The various transfer schemes are listed in Table 10, which illustrates not only the regularity with which Hyderabad builds new water transfer projects, but also how the distance over which water is pumped to the city, has increased over time. Schemes since 1965 represent de-facto transfers from the agricultural sector. This history of bulk surface water transfers, and the mechanisms through which these have been sanctioned, has been addressed elsewhere in the literature, particularly in Celio et al. (2010), which focuses on Hyderabad's influence over institutions for water allocation.

In addition to these bulk surface water supplies, HMWSSB also formally abstracts small volumes of groundwater. This water is pumped from groundwater wells owned and maintained by HMWSSB, and distributed across the city through a network of approximately 500 water tankers as part of the GHMC/HMWSSB 'dial-a-tanker' water delivery scheme. The HMWSSB also maintains public fountains and supplies standpipes to slum areas.

Table 10. Bulk surface water transfers to Hyderabad.

Transfer Scheme	Year	Distance from Hyderabad (Km)	Transfer capacity (MCM/YEAR)
Osmansagar	1920	15	41.5†
Himayatsagar	1927	9	24.9†
Manjira – Phase I (Manjira Barrage)	1965	59	24.9
Manjira – Phase II (Manjira Barrage)	1981	59	49.8
Manjira Phase III (Singur Reservoir)	1991	80	61.3
Manjira Phase IV (Singur Reservoir)	1993	80	63.0
Krishna Phase I	2004	114	149.3
Krishna Phase II	2009	114	149.3
Godavari Phase I (Yellampalli Barrage)	2014‡	186	285
Krishna Phase III	2014‡	114	149.3

Sources: HMWSSB Interview (2012), Celio, M. (2009), † currently only 40% reliable withdrawal; ‡ schemes are not yet complete.

4.4.5 Poor Levels of Water Service

Despite the regular bulk surface water transfers shown above, and the formal, sanctioned groundwater abstraction carried out by HMWSSB, the levels of water service provided to the residents of Hyderabad, by HMWSSB are poor. This is in part driven by a significant water supply deficit –there is not enough water to meet current and future demand. The size of the deficit is shown in Table 11. The data in the table, which compares water demand with, supply, suggests that by 2014, there should have been a surplus in HMWSSB's service area. However, the two large schemes expected to fill this gap – Godavari Phase 1 and Krishna Phase 3 – remain incomplete, leaving Hyderabad with an even larger water supply shortfall.

Table 11. Greater Hyderabad Municipal Corporation water demand and supply data.

Year	Projected Population in GHMC Area (Million)	Projected Water Demand (MGD)	Dependable supply from existing sources (MGD)	Proposed Augmentation (MGD)	(Deficit) / Surplus (MGD)
2011	8.8	459	271.5	----	(187.50)
2013	9.0	480	443.5	172.00†	(36.7)
2014	9.2	491	533.50	90.00‡	42.70
2017	10.0	523	533.50	----	10.90

Source: (Interview, HMWSSB, 2012). †Addition subject to commissioning of Godavari Phase-1 Project. ‡ Addition subject to Commissioning of Krishna Phase III Project. Note that the transfers proposed to augment the deficit are, at the time of writing in summer 2014, not yet complete due to financial shortfalls (Express News Service, 2015).

The water supply deficit illustrated in Table 11 contributes to Hyderabad's infamously poor level of water service (Bachan and Singh, 2014, Mukherjee et al., 2010, Nastar, 2014). Customers often wait many days between scheduled supplies and the quality of water received is low due to contamination (Shaban, 2008). This problem is exacerbated during the summer as reservoir levels drop, municipal supplies becomes more unreliable and customers increasingly look to Hyderabad's informal water suppliers to fill the gap.

Poor, intermittent water service is caused not only by the supply deficit, but also by a host of other factors, of which high leakage rates are perhaps the most significant. For example, a recent pilot project in one part of Hyderabad found that 42% of water was lost to unauthorised consumption and 21% from leaks (Sargaonkar et al., 2013). These figures indicate that very large volumes of water are unaccounted for in the water supply system. Another important contributor to intermittent service is electrical power blackouts, which affect the ability of HMWSSB to maintain network pressure in the distribution network (Interview, HMWSSB, 2012).

4.4.6 Hyderabad's Geology and Groundwater

Although Hyderabad's residents are increasingly reliant on groundwater supplies (as will be shown in the following section), the hydrogeology underlying the city is not conducive to producing high yields of water from borewells. This geological context drives the outward rather than downward expansion of the city's search for water, and amplifies the impact of urbanisation on land-use adjacent to the city boundary.

Hyderabad sits above a granitic-gneiss geology (Sukhija et al., 2006). Due to the impervious characteristics of this type of geological formation, the rocks below the city do not store very much water. Indeed, they make relatively poor aquifers. Nevertheless, where the rock is weathered, closer to the surface, and where it is locally fractured at depth, water can be stored and groundwater is available. Thus, Hyderabad's main groundwater reservoir sits in the topmost weathered layer, where it forms a shallow aquifer approximately 3-15m deep (Interview, Voyants Solutions Pvt Ltd, 2012). Smaller reserves of water are available at depth where the basement is fractured, but these deep-water pockets are haphazardly located across the city and are not easily recharged. The consequence is that the shallow aquifer is relatively quickly exhausted in summer months as reservoir levels drop and pumping from borewells across the city increases. Many residents are then left with either no, or poor service from their HMWSSB connections, and with bores that do not yield water. This drives an increased market for water tankers in the summer months. This interplay between local hydrogeology and types of water supply (and thus types of water transfer) is explored in more detail in Chapter 5.

4.4.7 Overview of Water Transfer Processes

The earlier description of Hyderabad's water supplies, deficit, and continued rising water demand indicate that demand for water is met not only through bulk surface water transfers, but also by different processes that result in flows from the agricultural sector to the city. Thus, in addition to the formal institutional mechanisms allocating significant quantities of bulk surface water to HMWSSB, several types of informal water transfer processes, that effectively increase the share of water used by the urban area, can be observed. These transfer types are reviewed in turn below.

The descriptions are based on evidence collated from interviews, observations, data from administrative documents, and literature. The overview of transfer processes begins by summarising formal mechanisms that enable bulk surface water transfers and moves to informal water transfers. In addition, cities such as Hyderabad also suppress local agricultural water use through their influence of land-use. This aspect of water transfer will be examined separately in Chapter 5.

4.4.7.1 Institutional Mechanisms for Water Allocation

The main institutional mechanism transferring surface water to Hyderabad is the administrative Government Order (GO). This policy tool is used for a variety of purposes including: to commission new reservoirs for urban water supply; commission pipelines to bring water from existing sources; and to alter reservoir operating rules to change allocations. Government Orders are therefore the basis for the transfer schemes listed in Table 10. In Andhra Pradesh, GOs for large-scale water allocation are usually issued on the basis of the priority allocation system, and supported by findings from expert commissions, which are then approved by the Irrigation Department. For example, Government Orders sanctioning water transfers from The Nagarjunasagar reservoir on the Krishna River, endorsed the earlier findings of the Sri J. Raja Rao expert commission that had suggested Nagarjunasagar as a viable water source for Hyderabad (Celio et al., 2010). For a detailed review of the institutional mechanisms bringing water to Hyderabad and the use of GOs for this purpose, see Celio (2009).

4.4.7.2 Informal Mechanisms for Water Transfer

Hyderabad is served by three main informal water supply processes, which bring water from the environment, and the agricultural sector surrounding the city, to its residents. These include: the informal water tanker trade, which is a highly visible and colourful presence on the city's congested roads; borewells in homes and businesses; and water kiosks in peri-urban areas. The prevalence of these informal water supply services has two important implications for the study of water transfers and the ways that growing cities increase their respective share of available water resources. The first is that most of the informal ways of accessing water rely on the presence of groundwater. The second is that the urban periphery becomes an important source of water. Abstraction from peripheral areas where agricultural was often previously undertaken represents both a form of agricultural-to-urban water transfer and, at the city scale, a transfer of water from the urban periphery to the urban centre (Prakash, 2014).

Quantifying the volume of water derived from informal groundwater abstraction, and understanding the consequences for other water using sectors, is difficult, particularly because available datasets contradict each other. In total, five different urban groundwater abstraction estimates were identified from different sources (officially published groundwater abstraction estimates versus the private, off-the-record estimates cited by interview respondents) during the course of fieldwork. These estimates covered an almost fivefold range in magnitude for abstraction across the same approximate urban area and time period. This includes estimates from the Groundwater Department of 74 MCM/year (Government of Andhra Pradesh Groundwater Department, 2011) and an estimate of 310 MCM/year based on the gap between bulk water supply and urban water demand (supply and demand data from HMWSSB, 2012).

This thesis assumes that groundwater abstraction bridges the city's water supply deficit of 310MCM/year (Interview, HMWSSB, 2012). Thus, the thesis estimates that as much as 40% of Hyderabad's total water supply is from informal, groundwater based water supply sources. This is a considerable volume of water and one that demands more attention from the literature on how growing cities increase their share of water resources.

There are many reasons that groundwater data estimates vary. These include: the decentralised nature of groundwater abstraction; differences in modelling assumptions; the limited number of measuring wells across a hydro-geologically heterogeneous terrain, and differences in the assumed boundaries of the urban area. This variation in groundwater data shows not only that the reliability of groundwater data is inherently low, but that the level of uncertainty – the error – it also difficult to estimate.

4.4.7.3 Hyderabad's Tanker Market

Hyderabad's extensive water tanker market pumps groundwater and sells it to residents and industries across the city. It operates in different forms, under varying levels of administrative control. This ranges from HMWSSB/GHMC official tanker trucks pumping water from borewells owned by the city - the official GHMC's 'dial-a-tanker' scheme (Interview, HMWSSB, 2012) – to the tankers workers operating independently under various business models. In between, are the HMWSSB drivers who 'moonlight' in the private sector and compete with the large fleets of tankers that transport water across the city (Interview, Water Tanker Driver, 2012)[14]. Tanker business models range from large multi-vehicle operations to small businesses, some started by non-resident Indians (those who live overseas) who view the purchase of land and the sale of its groundwater, as an investment opportunity (Interview, Water Tanker Driver, 2012). There are also tanker drivers who provide 'in-house' water services and are employed directly by businesses such as cinemas or apartment blocks.

[14] Interviews undertaken in Mallampet, a peri-urban area to the northwest of Hyderabad where many water tankers operate. Drivers and borewell operators were interviewed in November 2012.

Interviews with tanker drivers reveal the complexity of the water tanker network which comprises an extensive network of drivers, fleet owners, borewell owners, industries, security guards, officials, and politicians, all of whom profit from continued groundwater abstraction. There is fierce competition for 'water business', particularly those supplying industry where higher prices can be charged. The supply of water tankers to some of the larger industries in the industrial parks entails the employment of complicit security guards, who ensure that only certain companies supply water to particular businesses. Despite the competition, the tanker trade continues to attract new workers, who feel that it offers better pay than jobs in construction or driving other types of vehicle.

Moreover, the tanker industry is spatially mobile and reacts to the changing urban environment. For example, as the city grows, and formerly peri-urban areas become more residential and urbanised, it becomes more difficult for water tankers to operate. This is because, roads become congested, residents begin to complain about the noise and mud that accompanies the larger tanker trucks, and well yields begin to drop as tanker borewells compete with those inside private residences. Thus, over time, operators move to new borewell sites, closer to the urban periphery, and with better well yields, thereby expanding the area across which the city abstracts its water resources.

Interviews with tanker drivers in a formally agricultural peri-urban community to the northwest of the city suggest that much of the tanker trade operates outside the official remit of the water administration (although local state officials may give tacit permission for groundwater pumps). This finding supports evidence from the literature, which shows that informal water providers are often aligned with water administrations and political elites (Swyngedouw, 2004, Ranganathan, 2014). This is likely to be as true for Hyderabad as it is for the studies of tanker trades conducted elsewhere in India (see for example, Ranganathan, 2014). It can be argued therefore, that the profit making nature of the tanker market and the purported links to the administration increase the prevalence of this type of informal transfer process – a theme revisited in Chapter 5.

4.4.7.4 Kiosks and Domestic Borewells

Informal water supplies also come through the private, domestic borewells that people operate in residential apartment complexes and blocks, and also from water kiosks found predominantly in peri-urban areas. The extent and volume of water pumped through private borewells is largely unknown due to the number of unlicensed wells, and the variation in well yields throughout the year (in the summer months, many private borewells run dry).

Water kiosks pump groundwater and treat it on-site, to sell to local residents. These small businesses are increasingly a feature of peri-urban areas. However, there is little data however, on the number of kiosks, or the volumes of water they pump. Thus, the main focus of the informal water supply sector in Hyderabad is the water tanker trade, which moves water from borewells formerly agricultural areas and distributes it across the city.

4.4.8 Water flows from Hyderabad

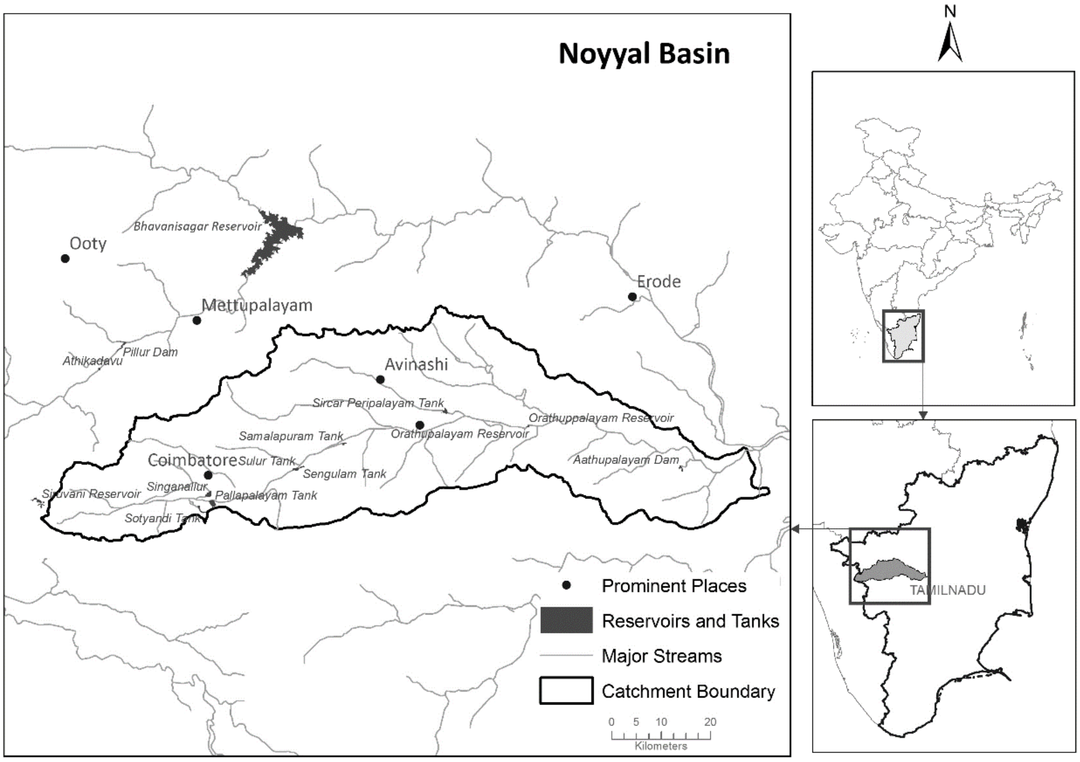
The ever-increasing flows of water into Hyderabad's urban area result in ever-increasing return flows to downstream sectors. In Hyderabad, much of this wastewater and runoff flows to the Musi River channel – either in the form of untreated effluent or as discharge from wastewater treatment plants – and then on to downstream agricultural areas. The extensive literature on the use of Hyderabad's urban return flow in wastewater irrigation, and the implications for the conceptualisation for agricultural-to-urban water transfers and their impacts is presented in Chapter 7. The analysis presented in Chapter 7 is supported by additional insights and evidence from field data.

4.5 Coimbatore Case Profile

Coimbatore is a city of approximately 1 million inhabitants (Census Organisation of India, 2011), located in the southern Indian state of Tamil Nadu. As it grows, it needs more water for its rising population, its industries and to improve its intermittent municipal water supply. Known locally as 'South India's Manchester', because of its cotton processing plants, it forms part of the Coimbatore-Tiruppur industrial corridor, which focuses mainly on the textiles industry. The city sits on the banks of the Noyyal River, a tributary of the large Cauvery River, which drains the states of Tamil Nadu, Karnataka, and Kerala. Coimbatore, and its position in the Noyyal Basin, is given in the location map in Figure 12.

Coimbatore's climate is semiarid and has an average annual rainfall of 647mm. The region, as is the case across the state of Tamil Nadu, is considered to be water scarce (Interview, Public Works Department, 2012). For example, Tamil Nadu contains 4% of India's land area, 6% of the population and has 2% of the country's available water resources. The Public Works Department (PWD), which manages water for irrigation, estimates that the deficit between total state water demand from all sectors and available water resources stands at 800TMC per year (Interview, Public Works Department, 2013).

Figure 12. Location map of Coimbatore within the Noyyal River Basin.



The location of the Pillur Dam and Siruvani Reservoir, the main water supply reservoirs that serve Coimbatore, are also shown. Source: Ecoinformatic Lab, Atree, 2014.

4.5.1.1 Case Selection Justification

Coimbatore was chosen as a case study because it represents how an industrialising and urbanising city of medium size obtains water in a water scarce region. It serves as a 'different' case to Hyderabad in terms of the rate of urbanisation, the population size, and the more fragmented approach to urban water management. Conversely, it is similar to Hyderabad in its approach to urban planning and the levels of urban water service for businesses and residents.

4.5.2 Urban Profile

The population of Coimbatore is growing at 1.4% (Urban-LEDS, 2015), fuelled by migration of labourers from North India to support the growth in the manufacturing sector and the increasing number of cotton processing plants. The influx of migrant workers contributes to a significant slum population, estimated at 16% of the total urban population (Tamil Nadu Slum Clearance Board, 2011). The urban footprint of the city is also increasing and expanding outward as the Municipal Corporation claims additional urban land. For example, in 2010, the area of the Coimbatore Municipal Corporation was extended from 105 to 265km^2. This growth reflects the inclusion of formerly rural wards into the urban area and also the expansion of residential and urban land-uses along radial roads and transport links (Interview, Coimbatore Municipal Corporation, Planning Department, 2013). The land-use prior to urbanisation along these transport links was predominantly agricultural, with sugarcane, banana and coconut tree stands being important local crops which are both rain-fed and irrigated (Interview, Department for Agriculture, 2013).

4.5.3 Urban Water Management

In contrast to Hyderabad, responsibility for water management at Coimbatore's urban level, is fragmented across several different departments. There are different organisations responsible for bulk surface water transfers, the urban water distribution network, wastewater management, industrial water allocation, and public health. The departments and their responsibilities are shown in Table 12. Furthermore, Coimbatore's urban growth is causing a continued evolution of urban water management responsibility, with Coimbatore Municipal Corporation (CMC) taking responsibility away from the Public Works Department (PWD) and Tamil Nadu Water and Drainage Board (TWAD). This transition is supported by funding from the JnNURM scheme, and has resulted in tension between staff working in the different organisations, the duplication of management roles, and the duplication of infrastructure such as pump-houses and some bulk water transfer pipelines (author's observation). Thus some investment in capital infrastructure is entirely redundant and wasted.

Table 12. Departmental water management responsibilities in Coimbatore.

Organisation	Responsibilities
Tamil Nadu Public Works Department (PWD)	Implementation and maintenance of irrigation schemes; managing industrial water abstraction permits; assessing applications for water transfers to Coimbatore Municipal Corporation.
Tamil Nadu Water and Drainage Board (TWAD)	Bulk water supply and infrastructure schemes across the state except Chennai. Some TWAD responsibilities for supply to Coimbatore are now being transferred to the CMC.
Coimbatore Municipal Corporation (CMC)	Manages urban wastewater treatment and maintains the water distribution network. Has recently taken over bulk water supply projects such as Pillur Phase II and management of water bodies within the municipal area.
Local Planning Authority	Resource planning
Directorate of Public Health and Preventive Medicine	Water quality testing

A further complicating factor for water management in Coimbatore is the additional vertical layer of water management. Unlike Hyderabad, Coimbatore is not a state capital and does not host the headquarters of decision-making departments. Instead, these are located in the state capital of Chennai. This means that, in addition to horizontal fragmentation of urban water management responsibility, there is also a vertical fragmentation, particularly for local TWAD and PWD departments. Engineers from the municipal corporation and the PWD, therefore, frequently commute to Chennai to make important decisions. This complexity adds to the difficulty of local management, and arguably exacerbates some of the urban water supply challenges faced by the city.

4.5.4 Urban Water Supply Sources and Water Service Levels

Much of Coimbatore's municipal, water supply is sourced through bulk surface water transfers from the adjacent Bhavani River Basin via the Siruvani and Pillur Reservoirs (location shown in Figure 12 and volumes of water shown in Table 13). In addition, a small amount of water is also taken from the Aliyar Basin to the south of Coimbatore. The Siruvani is a gravity fed water supply scheme whereas water from Pillur is pumped to the city (Interview, TWAD, 2013).

These bulk surface water transfers represent agricultural-to-urban water transfers because the prior use of the water in the reservoirs is for irrigated agriculture (Saravanan and Appasamy, 1999, Lannerstad, 2008). Recently, an additional Phase II transfer from the Pillur Reservoir was completed and the prospect of a further Phase III transfer was openly discussed by TWAD, the PWD, and CMC in 2013. Thus, the history of managing Coimbatore's growing water demand through formal bulk surface water transfers is likely to continue. Thus, Coimbatore's continued demand for water results in further transfers from the agricultural sector.

Table 13. Water supply schemes serving Coimbatore Municipal Corporation.

Reservoir	River Basin	Transfer Volume (MLD)	Responsible Organisation
Siruvani	Bhavani	87	TWAD
Aliyar	Aliyar	7.6	TWAD
Pillur I	Bhavani	50	TWAD
Pillur II	Bhavani	63	CMC
Pillur III (proposed scheme)	Bhavani	Unknown	CMC

Source: Interviews with PWD, CMC, and TWAD (2013).

The water transferred to the city from the schemes in Table 13 is distributed around the urban area by the CMC. However, the service levels to urban residents are highly intermittent and many families are not connected to the distribution network. The causes of intermittent supply are very similar to those in Hyderabad, with the CMC attributing difficulties to a water supply deficit, low network pressure caused by ad-hoc maintenance strategies, illegal tapping of mains, and inadequate distribution infrastructure for the size of the network (Fichtner Consulting Engineers Pvt Ltd, 2010). The situation is further exacerbated by electrical power outages that affect the ability of the state to distribute water because pumping stations cannot operate without power.

In response to concerns over water supply, the CMC has commissioned a project to upgrade the water supply system to provide a 24×7 service within the corporation area, however this remains some years from implementation (Interview, CMC, 2012). Nevertheless, Coimbatore's continued growth means that the CMC's wide-ranging programme to improve its water and wastewater treatment provision includes not only schemes to increase the total water supply to the city through water transfers, but also various changes to the urban water management distribution network to make the supply system more resilient to fluctuations in reservoir levels. For example, enabling better inter-linkages between parts of the network supplied by each of the different transfer schemes.

Water also flows to Coimbatore via industrial water abstraction. Applications by industries to pump water from the Noyyal, and pump groundwater are made to the PWD, who sanction abstractions. In 2012-2013, 54 industries were abstracting water with official approval (Interview, PWD, 2013). However, interviews with the PWD suggest that industrial water abstraction is poorly regulated and monitored. Thus, total volumes of water withdrawn by industries are unknown.

4.5.4.1 Coimbatore's Groundwater

Coimbatore sits above weathered crystalline basement rocks and alluvium. Both of these formations allow the storage of water, albeit in different aquifer systems. The groundwater table varies across the city from 10-80m (Central Groundwater Board, 2008). Calculating the total volume of groundwater abstraction across the municipal area is difficult because of there is not enough data available from the numerous borewells located in private residences compared to the small number of borewells owned by the CMC from which data can be accessed (Natesan, 2013, pers. comm.). Nevertheless, local hydrological experts suggest that most of Coimbatore's residents have domestic groundwater pumps and storage tanks to augment municipal supplies. This assertion is based on observations by local hydrogeologists who suggest that more than 70% of the residences have private borewells (ibid.).

Data from the CMC's borewells suggest that the urban water table is relatively high, as compared to wells in agricultural areas (Interview, Department for Agriculture, 2013). This high water table is attributed to the tendency for domestic wastewater to be diverted to pits in the ground of residential properties, allowing for recharge (ibid.). The consequences of this domestic wastewater disposal strategy are explored in Chapter 7 where agricultural-urban water transfer impacts are examined at the system level in the context of wastewater irrigation.

4.5.5 Overview of Water Transfer Processes to Coimbatore

This section describes the main water transfer processes observed during fieldwork. This includes the formal processes through which additional inter-basin transfers from the Bhavani River are agreed, but also reflects on the informal water supply mechanisms used by urban residents that result in de-facto water transfers from Coimbatore's agricultural sector.

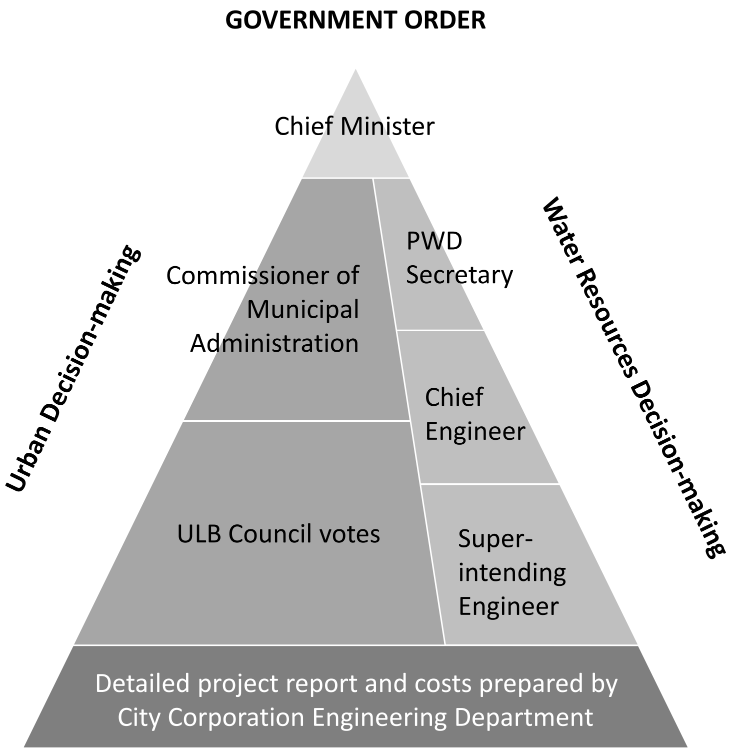
4.5.5.1 Formal Transfers through Institutional Mechanisms

The main institutional mechanism for formal transfers to Coimbatore is the Government Order (GO). These are issued on the basis of two separate approval processes, the difference in respective significance of which, infers that decision-making related to agricultural-to-urban water transfer schemes for Coimbatore is a very urban-centric affair.

The first process is the approval procedure within the Public Works Department (the 'water' management component of the allocation and transfer decision-making process). Here, applications for increased water allocation to Coimbatore are assessed in terms of water availability. Interviews with the PWD suggest that this process is often a formality. This is because the priority allocation system, based on the state water policy, dictates that drinking water be prioritised above other uses. Moreover, there is a large amount of money available for urban water infrastructure projects, including building infrastructure for bulk surface water transfers, through the JnNURM scheme. The availability of urban finance adds to the incentive for the PWD to approve transfer schemes.

The second approval process occurs within the urban-planning system hosted by the CMC. Interviews with engineers and planners in the CMC suggested that urban decision-making was the most critical part of the water transfer approval process because transfer schemes could be rejected at the early council voting stage due to costs. The dual process of PWD and urban planning approval is shown in Figure 13. This figure highlights the importance of the urban decision-making process, compared to the water resources decision process, by weighting the proportion of the diagram towards the urban (to the left of the diagram).

Figure 13. Approval process for GOs to transfer water to Coimbatore.



Source: Author's compilation from interviews with the Coimbatore Municipal Corporation and Public Works Department, 2013.

4.5.5.2 Informal Transfer Processes

High levels of informal water-use, and thus, informal forms of water transfer, occur because fewer than half of Coimbatore's households are connected to the municipal piped network (Government of Tamil Nadu, 2006). Those that are connected, face an intermittent supply with service interruptions of up to five days at a time, particularly during the summer months (Fichtner Consulting Engineers Pvt Ltd, 2010). To supplement supplies, residents use water from different sources for different uses within the household. For example, during the time spent the host family, the author observed that water for bathing and toilet flushing was groundwater pumped from the family borewell and stored in a large tank; municipal water was also stored (in a separate tank) and used for kitchen activities; and water for drinking was purchased in 10 litre dispensers. Thus private groundwater pumping was integral to urban water supply. Coimbatore also has a nascent water tanker network, however, in contrast to Hyderabad, the size of the informal water tanker industry was small and few private water tankers were observed serving urban households.

Despite the widespread reliance on informal water supplies, abstracted from groundwater, there is little data with which to estimate the volume of water used informally by residents and businesses. Hence, the wider impact of Coimbatore's urban expansion on water availability in the agricultural sector is unknown.

4.5.6 Water Flows from Coimbatore

Like Hyderabad, additional bulk water supply schemes and high levels of private groundwater abstraction generate increased volumes of urban wastewater – the return flow from reallocation to cities. The fate of these flows however is unclear. For example, a 70 MLD wastewater treatment plant opened in 2010, was only treating 20 MLD per day in 2012 because the sewerage network across the city, connecting households and industries was incomplete (Interview, PWD, 2013 and field visit to treatment works). Thus, only a small portion of wastewater is discharged by the treatment plant. Moreover, an interview with a farmer irrigating downstream of Coimbatore and interviews with staff from the PWD suggest that the outflow of the Noyyal downstream of the city had not noticeably risen, thus it is difficult to trace flows from the city back to the basin.

Possible explanations for the fate of urban wastewater are: storage in the network of large urban water ponds surrounding the city, where much wastewater is discharged and levels fluctuate; and the high urban groundwater levels driven by recharge from household wastewater storage pits. The fate of Coimbatore's urban return flows and the consequences for agricultural-to-urban water transfer impacts at the system level, is considered further in Chapter 7.

4.6 Water Management in China

This section describes national level water policies, regulations, and laws related to water allocation in China. This provides background for the case description for Kaifeng, which follows in section 4.7.

China's approach to water management differs significantly from India's. The water management framework incorporates two complex, parallel systems that share responsibility for water. The first system is an intricate administrative framework operating vertically across five levels of governance (from the central government down to the local) and horizontally between the eight central government departments involved in different aspects of water management. The second system operates through river basin commissions including the Yellow River Conservancy Commission (YRCC). The sharing of roles and responsibilities between these two systems, gives rise to ambiguity and a lack of direct accountability, and this is mirrored at the local level in Kaifeng's approach to urban water management (see section 4.7.5).

To draw out the main water policy, regulation, and laws most relevant to the question of allocation and transfer, the remainder of this section limits itself to only those elements of the wider water management framework with most relevance to water transfers to Kaifeng. These are: the Water Law 2002; the 'red line' targets for water management; and the operation and responsibilities of river basin commissions towards the issue of allocation (based on interview data provided by representatives of the YRCC).

4.6.1.1 The Water Law 2002

The *Water Law of the People's Republic of China (The Water Law 2002)* is the main instrument for water management and is broad ranging in its scope. The most relevant aspect for intersectoral water transfers, relates to the use of water permits, which control water abstraction. Despite the large number of permits (in 2011, 440,000 water permits were issued), there are significant weaknesses with the system, not least that agriculture, the main user of water, is not included in the permit system. Furthermore, many regions do not have the institutional and technological capacity to effectively manage and monitor the permitting system, which renders it ineffective (Griffiths et al., 2013).

4.6.1.2 Red Line Targets

Red line policy targets are a relatively new feature of the national approach to water management and are based on the idea of threshold targets (they are also used in other sectors). They were introduced in the No. 1 Policy Document from the central government in 2011 (Xia et al., 2012). For water, these include three targets set at regional, provincial, and national levels. The first red line relates to limiting abstraction and sets target for rivers, lakes, and groundwater. The second red line target relates to water use efficiency and the third relates to water quality. Despite the ambitious nature of these targets, and widespread reference made to them in discussions of water management, their effect on water transfers and how they are incorporated into basin allocation plans remains unclear.

4.6.1.3 River Basin Commissions

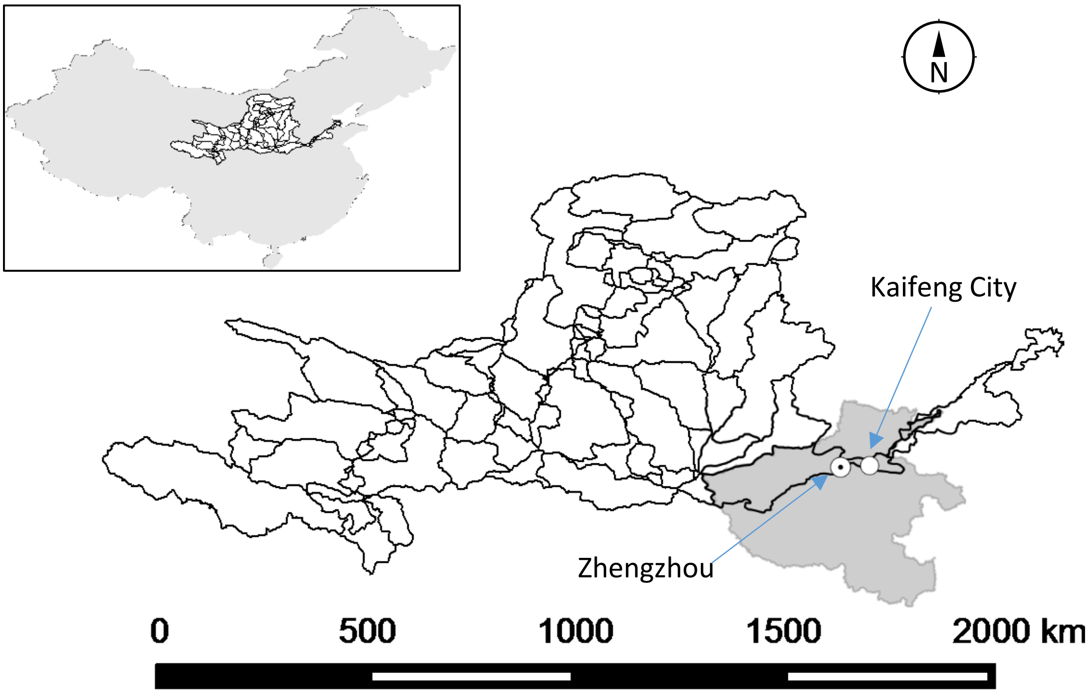
River basin commissions are water management institutions that operate alongside national provincial and regional water management structures. The Yellow River Basin Conservancy Commission, which oversees the management of the Yellow River, the source of water for the third case study, Kaifeng, is an example. River basin commissions, such as the YRCC, shape water transfers through river basin water allocation plans and the setting of provincial water quotas. However, their ability to enforce basin allocation plans is hampered because they share basin management with provincial governments (which manage water under the complex vertical and horizontal system of government described above). Furthermore, many river basin commissions lack suitable systems for data collection and management (Griffiths et al., 2013). This view is supported by interview data with staff from the YRCC who stated that obtaining provincial level data was a significant management obstacle to the effective management of water in the basin (Interview, YRCC, 2013). More detail on the YRCC is given in the case study profile of Kaifeng presented below.

4.7 Kaifeng Case Profile

Kaifeng, a dusty city of approximately 1 million inhabitants (Interview, Office of Town Planning, 2013), sits in the lower reach of the vast Yellow River in central China's Henan Province. Its location with respect to the Yellow River Basin and Henan Province is shown in Figure 14. Kaifeng has a rich cultural history as the capital of the former Song Dynasty and is an important centre for Judaism in China. Its economic development is based on tourism related to this cultural history, plus more conventional industrial growth linked to chemical manufacturing and cash crop agriculture.

Kaifeng's growing population and industrialisation leads to increasing water demand from the Yellow River, which is the main source of water for urban supply. However, the Yellow River Basin is administratively closed to new allocations, so rising urban demand represents a de-facto transfer from other water users – and given the importance of Henan Province's agricultural sector, this implies a reduction in water for agriculture. In contrast to the Indian case studies where formal transfers derive from multiple use reservoirs, the precise donor-agricultural areas losing water to Kaifeng are unclear. This is because the impact of increased diversions from the Yellow River to Kaifeng is distributed across many agricultural users downstream of the diversion point.

Figure 14. Location map showing Kaifeng, the regional capital Zhengzhou, Henan province and The Yellow River Basin.



4.7.1.1 *Case Selection Justification*

Kaifeng was selected as a case study because, alongside meeting the main case selection criteria outlined in Chapter 3, it represents the muddled reality of meeting increased urban and industrial water demand in closed river basins. It also provides a contrast to the Indian case studies due to stark differences in modes of urban planning, urban water service levels, and water resources management institutions. However it is a similar size and has a comparable growth rate to Coimbatore. This enables an interesting comparison between the three case studies allowing a mixture of similar and different case study characteristics to be compared across the cases.

4.7.2 Climate and Environment

Kaifeng's climate is semiarid with continental monsoonal characteristics and an average annual rainfall of 663mm (Kaifeng City Hydrographic Information Bureau, 2012). The city and its surrounding agricultural command areas (for example, the extensive Liuyuankou Irrigation System which features prominently in the Chinese agricultural water productivity literature (Loeve et al., 2003)) sit on sandy soils adjacent to the south bank of Yellow River.

The proximity of the river channel to Kaifeng (less than 10km to the North of the city) shapes water availability in two ways. Firstly, surface water from the river is diverted for urban and agricultural use through off-takes and canals and stored in local reservoirs. Secondly, the unusual 'hanging' river channel of the Yellow's lower reach (described below) recharges shallow groundwater aquifers. Therefore, groundwater is abundant across Kaifeng and its surrounding areas, although groundwater quality is low making it unsuitable for many uses (Interview, Hydrographic Information Bureau, 2013).

A hanging channel is a feature of the lower reaches of the Yellow River Basin, and means that the channel sits above the surrounding plain. This feature of the river is caused by two phenomena: one natural and one manmade. The first phenomenon is the naturally high level of silt deposition caused by the river's unusual geomorphic characteristics – it carries large loads of sediment picked up from the Loess Plateau, which is dropped when the river meets the changed terrain of its middle and lower reaches. The second phenomenon is levee building, which has exacerbated sedimentation within a narrow area either side of the river channel. The consequence is that over time, the height of the channel relative to the plain has been raised. Gravity driven seepage from the raised channel leads to a shallow water table and high levels of groundwater evaporation near Kaifeng (Loeve et al., 2004). The counterintuitive implication of the proximity of the Yellow River to the city and the availability of groundwater is that the city of Kaifeng has access to large quantities of water, despite well-documented water stress in the Yellow River Basin and in Henan Province.

4.7.3 Water Availability in Henan Province

Water demand and competition between sectors in Henan province is rising. This statement can be illustrated through two datasets. The first is the long-term trend in sectoral water use in Kaifeng Prefecture documented by Loeve et al. (2004). This shows that industrial and municipal water use has increased relative to agricultural water use over time. This trend is summarised in Table 14. Much of the reduction in agricultural water use is explained by the reductions in water diversions from the Yellow River driven by the Yellow River Conservancy Commission (YRCC) allocation plan.

Table 14. Average Sectoral Water Use for Kaifeng City Prefecture (MCM).

Year	Irrigation	Municipal	Industry	Livestock
1968-1978	1090	44	52	18
1979-1988	749	54	109	22
1989-2000	881	68	273	44

Source: Adapted from Loeve et al. (2003).

The second dataset to illustrate the limited availability of water in Henan shows Henan Province's water withdrawals versus the provincial quota set by the YRCC. Table 15 gives the data for 2006-2011, which shows that Henan Province is exceeding its YRCC provincial quota. The supply crunch that this situation gives rise to is exacerbated by the rising number of industrial water permit requests in the lower reaches of the Yellow River (including Henan Province) (Griffiths et al., 2013). Together these data sources show increasing competition and suggest that the growth in water demand fuelled by Kaifeng's expansion must be met by transferring water from other users in the Yellow River Basin.

Table 15. Henan Province water quota versus actual withdrawal.

Year	Actual Withdrawal	Quota	Difference
2006-2007	15.81	29.89	(14.08)
2007-2008	18.52	32.78	(14.26)
2008-2009	24.83	30.85	(6.02)
2009-2010	26.24	29.75	(3.51)
2010-2011	32.46	31.02	0.64

Source: Yellow River Basin Conservancy Commission (2012).

4.7.4 Urban Growth Profile

Kaifeng city has an urban footprint of $93km^2$, and is growing at approximately 667 ha (10,000 Mu) per year (Interview, Design Institute for City Planning Bureau, 2013). This urban expansion mirrors urban development in many of China's towns and cities, and follows an intensive infrastructure development agenda that shapes Kaifeng's growth and modernisation. Growth extends predominantly (although not exclusively) westwards, towards the much larger provincial capital of Zhengzhou (population 8.6 million), which is 70km away.

Planners envisage that the cities of Kaifeng and Zhengzhou will eventually merge (Interview, Land and Resources Bureau, 2013) thereby stimulating Kaifeng's projected population growth rates from the current 1.6% per year to over 3% in the medium term (Interview, Design Institute for City Planning Bureau, 2013). This rising city population is driving up urban water demand, leading to the expansion of Kaifeng's urban water distribution network, new water diversions from the Yellow River and the construction of new drinking water treatment plants.

4.7.5 Water Management

This section describes several aspects of water management affecting water supply to Kaifeng. It begins by reviewing the two different institutional frameworks for water management in Kaifeng and Henan Province. The interplay between these frameworks shapes the formal processes through which the city gains water. These are the Yellow River Basin Conservancy Commission and the provincial level water administration. This is followed by a description of urban water management and the status of urban water service levels.

4.7.5.1 Yellow River Conservancy Commission (YRCC)

The Yellow River Conservancy Commission, the river basin organisation that manages basin allocation planning in the Yellow catchment, plays an important role in overseeing the supply of water to Kaifeng and its surrounding irrigated areas. This section provides an overview of the YRCC and the links to water transfers to Kaifeng.

The YRCC is a vast organisation of more than 40,000 employees, which oversees water management in northern China's largest river basin. The Yellow, supports five million hectares of irrigated agriculture, and has a population in excess of 110 million. The river passes through nine provinces and has a mean annual runoff of 53.5km^2 (Ringler et al., 2010). Historically, the main water management objective in the basin was flood control. However, the combination of reduced runoff, increased sediment loads, and increasing demand switched the focus towards managing scarcity.

The most obvious manifestation of this scarcity were extended periods of flow cut-offs between 1972-1998. In response, an allocation plan was developed in 1987 (the *Available Water Allocation Program of Yellow River),* which allocated water rights to basin's nine provinces. The plan's objective was to ensure a minimum environmental flow through the use of quotas. The implementation of quotas administered by the YRCC has effectively ended the physical closure of the river basin yet the river remains administratively over-allocated (Interview, YRCC, 2013). Today, demand for water from the Yellow River continues to increase, particularly as a result of rising demand from the coal mining industry and cities.

4.7.5.2 Provincial Level Water Administration

Provincial level water management is undertaken through the Henan Water Resources Bureau. This is responsible for: provincial water policy, planning and management; formulating water saving measures such as drip irrigation, plastic film mulching and lining canals; organising water administrative enforcement and supervision; maintaining water conservancy projects and protecting water areas; leading water conservancy works in rural areas; and soil and water conservation (Interview, Henan Water Resources Bureau, 2013). The Henan Water Resources Bureau is also linked to the YRCC as it is involved in the application for urban water transfers.

4.7.5.3 Urban Water Management

At the urban level, water management in Kaifeng is fragmented across multiple departments with competing, overlapping, and frequently duplicated sets of responsibilities. These different departments and their responsibilities are shown in Table 16. One of the most influential departments is the Water Resources Bureau (WRB), which manages water and hydraulic projects. Although this is predominantly an agricultural water management organisation, it is responsible for ensuring that the local agricultural water quota is not exceeded and therefore is involved in decisions regarding strategies to increase urban water supplies. A second influential department is the Hydrographic Information Bureau (HIB), which compiles data for the provincial Henan Water Resources Bureau and for yearly data-books of water statistics including information on urban water consumption. Field observations suggest that the HIB is particularly influential because it acts as a gatekeeper of information and most interviewees questioned during the research process, took permission from the HIB office before consenting to take part in this study.

Table 16. Departmental responsibilities for water management in Kaifeng.

Department	Responsibilities	Reports to
Water Resources Bureau	Hydraulic projects for agriculture	Kaifeng Municipal government
Environmental Protection Bureau	Monitoring the water quality, air quality, and pollution	Kaifeng Municipal Government
Urban Administration Bureau	Urban Water Supply and Sewage Treatment	Kaifeng Municipal Government
Hydrographic Information Bureau	Monitors and collects data on precipitation, groundwater, surface water, water pollution, water use	Henan Water Resource Bureau (attached to the Ministry of Water Resources)

4.7.5.4 Urban Water Supply and Service Levels

Kaifeng's urban water board obtains most of its supply from the Yellow River and provides a 24-hour constant water service covering 98% of the urban area (Interview, Urban Water Department, 2013). This claim was triangulated by the author's experience of living with a host family and receiving constant water supply for the duration of fieldwork. However, despite the continuous municipal supply, residents in some of the city's older residential buildings continue to use groundwater. This is undertaken as a strategy to reduce water tariffs (Interview, Resident of Kaifeng, 2013).

The main surface water supply from the Yellow River is supplemented by relatively small volumes of groundwater pumped to two of the city's three water treatment plants. To meet Kaifeng's growing water demand, a new drinking water facility is being planned. This will be supplied by additional diversions from the Yellow River (Interview, Urban Water Department, 2013).

In contrast to the drinking water supply situation, wastewater services are not as comprehensive. Many areas of the city lack connections to sewerage and wastewater discharges to local water bodies. At the time of research, only one of three wastewater treatment plants was functioning. Industrial wastewater treatment is equally patchy and many chemical companies do not adhere to industrial effluent treatment guidelines. For example, a recent study shows that many industries discharge untreated effluent directly to Kaifeng's various water bodies (Lifeng, 2014) and interview data from the

Environmental Control Board suggests that many industries have neither the technical capacity nor financial inclination to comply with the wastewater discharge standards.

4.7.6 Water Transfers to Kaifeng

Kaifeng obtains most of its water through formal water transfer mechanisms, a contrast to its Indian counterpart cases. The primary process for increasing water availability to the city is through the urban water administration's requests to increase diversions from the Yellow River. A secondary process is to increase groundwater abstraction at drinking water treatment plants, however the municipal authority is under pressure to reduce its reliance on groundwater (Interview, Hydrographic Information Bureau, 2013).

Informal water supplies, and thus informal processes of transfer seem to account for only a small portion of urban water use. Data from the local Hydrographic Information Office, indicates that the contribution of unregulated and informal groundwater abstraction is only approximately 10% of the urban water budget however there is a great deal of uncertainty over informal groundwater abstraction (Interview, Hydrographic Information Office, 2013). Groundwater is also the main source of drinking water for peri-urban communities not yet connected to the centralised distribution network.

4.7.6.1 Formal Allocating Mechanisms to Transfer Water to Kaifeng

The main mechanism allocating additional water to Kaifeng is achieved by increasing the urban quota for water from the YRCC. Permission for increased diversions from the Yellow River is decided in conjunction with urban planning officials and sanctioned through the application process to the YRCC. Officials do not foresee any barrier to obtaining additional water supplies to support Kaifeng's growth, because urban water use is prioritised above agriculture. This application process for re-allocation to the city involves three stages:

1. Application from the city to the local Water Resources Bureau (the organisation responsible for local irrigated agriculture and the utilisation of the water quota);
2. Application passed to the provincial water resources bureau (HRB) for assessment;
3. Application is delivered to the YRCC. Here, the application is assessed according to the following criteria: firstly, whether the application is 'sensible'; secondly,

whether the water use is efficient; and lastly whether the area is exceeding its water quota as stipulated in the YRCC allocation plan (Interview, YRCC, 2013).

A second emerging formal mechanism for transfer is a nascent water rights trading scheme. While not observed directly in the field, interviews at YRCC indicated that water rights transfers between the agricultural sector and local industries are likely to be implemented in the future given successful pilot studies elsewhere in the basin. While formal water rights transfer schemes are not yet a viable mechanism for transferring water between sectors near Kaifeng, these schemes are viewed as potential solutions to intersectoral water tensions. Proponents argue that they represent a 'win-win' solution by providing industry with the water resources they require for production and local water resources bureaus with the income required to modernise and improve local irrigation infrastructure (Interview, YRCC, 2013).

4.7.6.2 Informal Groundwater Abstraction

In addition to water delivered through the centralised water distribution network, individual households and industries also abstract groundwater. There is little quantitative data available to gauge the magnitude of this informal water use, however household groundwater pumps were observed in areas of the city with older housing stock. New apartment blocks are connected directly to the water distribution system, whereas older residences, particularly in the area to the east of the city, use both tap water and groundwater pumps. Groundwater is used for laundry and cleaning as this is cheaper than paying water tariffs (Interview, Host Family, 2013).

4.7.6.3 Water Source Substitution

While not strictly a water transfer process, urbanisation is causing the substitution of surface water from the Yellow River for groundwater in the agricultural command areas surrounding Kaifeng. Thus, the impact of urbanisation on water availability in the agricultural sector is more profound that might initially be estimated by examining surface water allocations from the Yellow River alone. Two processes drive the substitution of canal irrigation water for groundwater. The first is the impact of new urban infrastructure on the complex network of surface water canals that are used to supply water for agriculture. In interviews, farmers in peri-urban villages surrounding Kaifeng, complained that road building and construction projects blocked irrigation canals and stopped the flow of water thereby forcing villagers to install groundwater pumps (Farmer Interview, Kaifeng Prefecture, 2013).

The second cause of water source substitution is pollution. Farmers in three of Kaifeng's peri-urban villages described how water from local stream and canals has become too polluted to use and forced them to switch to groundwater irrigation. Moreover, farmers stated that for cash crop cultivation, groundwater was often preferred to water from the Yellow River. This is because surface water from the Yellow River has a high silt content, which makes irrigation difficult and covers the leaves of cash crops. Thus, although the silt is reportedly good for the soil, it was not suitable for irrigating leafy vegetables because it damages the leaves. These insights from local farming communities illustrate some of the wider impacts that urbanisation in Henan Province exerts on water resources and the challenges this poses for controlling and managing sectoral water use.

4.7.7 Water Flows from Kaifeng

Increasing urban water demand as Kaifeng grows is resulting is increased levels of wastewater generation. However, these increased outflows have not resulted in significant increases in the flow of the channels draining the city, or discharges from the intermittently functioning wastewater treatment plants. More details of Kaifeng's wastewater generation and the implications for the impacts of agricultural-to-urban water transfers, will be presented in Chapter 7.

4.8 Conclusions

This chapter has presented the main features of urban growth, urban water use and water transfers to the case cities of Hyderabad, Coimbatore, and Kaifeng. This information provides the basis for the argumentation given in the following three chapters. The contentions and findings of these later chapters are based not only on Chapter 4's data, but also on additional topic argument specific evidence, which is incorporated in to each chapter to support the framing of agricultural-to-urban water transfers and their impacts.

5 Water Transfer Processes and Urban Attributes

Summary

This chapter shows how urban attributes – characteristics of urban areas including, groundwater availability, urban planning, rates of urbanisation, urban water governance, and spatial expansion rates – influence **how** growing cities increase their share of water resources in terms of different types of transfer process. The analysis distinguishes between three main types of transfer process: formal transfers; informal transfers; and indirect transfers. Using evidence from the three case studies, the chapter highlights causal relationships between urban attributes and types of water transfer process. On this basis, two typologies are developed. The first typology addresses the level of formality in water transfer processes and the second addresses the level of indirect transfer as urban areas grow across agricultural land. Insights from the typologies can aid allocation planning and water transfer management, by highlighting circumstances in which formal water transfers are likely to underrepresent how much water flows to urbanising areas from agriculture.

5.1 Introduction

Cities, particularly those in the Global South, obtain water share through multiple flow pathways (Molle and Berkoff, 2009, Ahlers et al., 2014). Consequently, several types of water transfer coexist, simultaneously bringing water to growing cities in different ways. This raises questions as to the determinants of how growing urban areas get their water and whether this changes systematically in different contexts. Yet, conventional agricultural-to-urban water transfer theory focuses predominantly on the role of water policy - the institutional mechanisms of formal allocation and the political environments in which these transfers are implemented – and tends not to look at other, unconventional water flows to urban areas. Thus, less visible processes, which change the respective share of water between sectors, particularly between cities and their hydrologically connected agricultural hinterlands, are largely overlooked[15].

The result of this oversight in the scope of agricultural-to-urban water transfer research, is that the impact of urbanisation on water availability for the agricultural sector is often underestimated. This chapter addresses this research gap by examining

[15] The exception is the brief references made to implicit, stealth and illegal transfers in review articles seeking to classify different transfer types, see for example Meinzen-Dick and Ringler (2008) and Molle and Berkoff (2009).

how urban attributes – biophysical and institutional indicators that characterise urbanising areas – influence how cities obtain water share in terms of different types of water transfer process.

Three different types of transfer process are distinguished: firstly, formal transfers resulting from institutional mechanisms (see, Dinar et al., 1997); secondly, the aggregate transfer effect of informal water use as urban residents and businesses seek supplies in the absence of reliable centralised systems (see, Srinivasan et al., 2013); and thirdly, indirect transfers as land-use change suppresses local agricultural water demand (see, Kendy et al., 2007, Yan et al., 2015). By identifying causal relationships between urban attributes and the three water transfer processes in Hyderabad, Coimbatore, and Kaifeng, two typologies of water transfers are developed. The first assesses the formality of water transfers and the second assesses the level of indirect water transfer. Together these typologies indicate likely water transfer scenarios for cities and towns on the basis of information related to urban attributes.

5.1.1 Contribution to Main Thesis

This chapter contributes to the main thesis in three ways. Firstly, it supports the central contention that greater emphasis should be placed on the influence of 'the urban' in agricultural-to-urban water transfer analysis. This is achieved by supplementing conventional analysis, which often limits itself to the study of institutional mechanisms of water allocation and politics, rather than replacing it. Secondly, the chapter advances theory by developing a typology to indicate how cities obtain water from agriculture in different contexts. And thirdly, it demonstrates the notable differences in transfer regimes (the combination of formal, informal, and indirect transfer processes) between the cases studies, particularly with respect to the Kaifeng versus Hyderabad and Coimbatore. This difference between the case studies, reveals the context specificity of transfers, and cautions against generalising agricultural-to-urban water transfers on the basis of institutional mechanisms alone.

Moreover, the arguments developed in this chapter have implications for policy. Firstly the chapter shows that informal and indirect water transfers from agriculture are a systemic and volumetrically significant element of urban water use in certain urban contexts. Hence, overlooking informal and indirect transfers leads to an underestimation of the wider hydrological impacts of urbanisation. Secondly, where informal and indirect transfers are significant, meeting basin planning allocation objectives is difficult. This is because of the problems that arise trying to control and regulate decentralised informal processes that involve many actors (Srinivasan et al., 2013). Furthermore, indirect transfers are inextricably linked to land-use rather than water policy, thus controlling sectoral water budgets requires close integration with land use planning (a cross-sectoral policy objective often stated in the water resources management literature, but rarely achieved, see for example, Mitchell (2005)).

5.1.2 Chapter Structure

The chapter begins by setting out a conceptual framework linking types of water transfer process and urban attributes. Section 5.3 builds on the conceptual framework to develop two typologies of different aspects of the urban attribute-water transfer relationship. The remainder of the chapter examines the causal relationships proposed in the two typologies, supported by evidence and observation from the case study cities. Thus, section 5.4 situates the analysis by providing a summary of observed water transfer processes to Hyderabad, Coimbatore, and Kaifeng. Section 5.5 focuses on the relationship between urban attributes and informal water transfers. Section 5.6 addresses the relationship between urban attributes and indirect water transfers. Section 5.7 explores the implications for transfer theory. Finally, section 5.8 concludes the chapter and synthesises the findings.

5.2 A Conceptual Framework for Formal, Informal, and Indirect Transfer Processes

The section begins by defining what is meant by the 'urban', and presenting the urban attributes that have been identified in this thesis as being important determinants of different water transfer types. The conceptual framework then moves to an explication of the transfer framework, which addresses each type of transfer in turn. For each transfer type – formal, informal, and indirect – the literature between 'urban' and the type of transfer is reviewed and the gaps that this thesis addresses are highlighted.

5.2.1 Urban Attributes and 'The Urban'

Definitions of 'the urban' and the attributes that define an urban area are highly discipline specific. For example at one extreme, 'the urban' can be viewed as an entirely apolitical amalgam of infrastructure, including the roads, pipes, buildings and various other physical features, that make up urban spaces. This apolitical representation can be understood in terms of physical attributes and indicators including density, network connectivity, and spatial extent. By contrast, 'the urban' can also be understood in terms of civil society, the market, the state and urban institutions by urban governance scholars, or in terms of urban processes, resource flows and socio-ecological processes by urban political ecologists (Monstadt, 2009).

This thesis does not attempt to define what constitutes ‘the urban’ given the large and varied literature devoted to this question, and the differences in epistemology these different bodies of research imply (see for example, Heynen et al. 2006, and Monstadt, 2009 as introductions to the different fields). Instead, the thesis builds on the existing literature linking attributes of urban areas and water resource use. This results in the development of a non-exhaustive list of attributes of the urban environment and processes of urbanisation that appear to influence how cities gain water share. Thus the attributes examined in this chapter span the apolitical, urban governance and urban political ecology spectrum of what it is to be ‘urban’.

Relationships between different types of urban area, their style of growth, and the resulting impacts water resources, have previously been highlighted by researchers from different disciplines. For example, in the urban studies literature, Seto et al. (2010) note that urban form and modes of urbanisation determine the interaction between urban areas and their environments[16]. This view is echoed in the water resources literature by Feldman (2009) who argues that further research is needed on how ‘cities’ contending patterns of growth and development produced distinctive typologies of human impacts on the water environment’.

Recently, researchers have begun to classify explicitly the links between different types of urban area and water-use using formalised typologies. For example, in Spain, urban typologies have been developed linking different types of urban sprawl with different levels of water demand (Morote and Hernández, 2016). And in India, research on urban water management in cities by IRAP (2010) argues that the physical attributes of urban areas predict likely urban water supply strategies. IRAP’s typology, however, is limited to physical and environmental attributes such as precipitation, evaporation, and hydrogeology. This thesis builds on IRAP’s typology by considering several additional attributes that influence how cities gain water from the agricultural sector. It does so,

[16] Seto et al. (2010) implicitly separate notions of the urban from the environment. This view contrasts with the urban political ecology literature that focuses in part on the production of cities and urban environments by focusing on the ‘web of socio-ecological relations’ (Heynen et al., 2006, p.3) that produce urban natures. This perspective instead sees ‘the urban condition as fundamentally a socio-environmental process’ (Heynen et al., 2006, p.2). Thus political ecology moves away from the clear distinction between the ‘urban’ and ‘the environment’.

by comparing features of the case study cities observed during with fieldwork, and highlighting links to water transfer processes.

The resulting list of attributes examined in this chapter are thus derived from case observation and existing typologies such as the IRAP model. They include: groundwater availability; strength of groundwater regulation; urban planning regulation; level of water service; strength of urban water governance; spatial expansion patterns; and rates of urbanisation. In addition, the chapter also examines two characteristics of local agriculture policy: whether land lost to urbanisation is systematically replaced; and whether agricultural intensification policies are enacted in response to losing land to growing cities.

The following sections expand on the conceptual links between towns and cities, and water transfers. Together, sections 5.2.2, 5.2.3, and 5.2.4 set out the literature on different types of water transfers and the 'the urban', defined in the broadest sense.

5.2.2 Formal Water Transfers and the Influence of Cities

'Formal water transfers' refer to institutional mechanisms that allocate water. The implementation of these transfers, often piped bulk surface water schemes, is argued to be a product of both water policy and the political influence of cities. This subject has mainly been studied by geographers and political ecologists who have developed concepts to understand the relationship between cities and this form of transfer (Celio et al., 2010). Often, the objective of research of this type is to understand the malleability of institutional mechanisms in response to political and economic interests operating at different levels. Influenced by Swyngedouw's (2004) work on urbanisation, water, and power, and by the legacy of early accounts of the violent struggle for water at Owens Valley (see Libecap (2009)), various concepts have been proposed.

These include: urban water capture; hydraulic reach; appropriation; and the influence of urban-centric ideologies. See for example Celio et al.'s (2010) exposition of Hyderabad's 'appropriation' of water. Or, Scott and Pablos' (2011) use of 'policy regionalism' to understand the expansion of Monterrey's hydraulic reach through negotiations that circumvent established power relations. And in the United States, Feldman (2009) highlights the role of charismatic leadership and the 'ideology of destiny' to explain how the cities of Los Angeles and Atlanta win water resource conflicts. What unites these analyses is the implicit sense of urban control over water resources through their influence over allocating institutions.

The application of political ecology approaches to understand the relationship between urban areas and institutional mechanisms supplements an otherwise technical and descriptive agricultural-to-urban water transfer literature as shown in Chapter 2. Nevertheless, the political ecology approach limits itself to the politicisation of institutional mechanisms and rarely examines the additional ways that urban areas influence water flows. For example through informal water supply arrangements[17] or the effects of land-use change on sectoral water budgets. The following section addresses this gap by examining recent research on the relationship between cities and processes of informal water transfer.

5.2.3 Urbanisation and Informal Water Transfers

Informal[18] water transfers take many different physical forms including: domestic groundwater abstraction; water tanker markets; or illegal abstraction from surface water sources. The transfers are brought about by the aggregate effect of numerous, decentralised modes of informal water supply that bring water from predominantly agricultural and peri-urban areas to the city. While widely acknowledged in the literature, informal transfers are rarely the main focus of research and remain difficult to volumetrically quantify[19]. Rather, transfers of this sort are categorised as ad-hoc and secondary processes and given various different labels including: implicit; illegal; informal; and stealth forms of transfer (Meinzen-Dick and Ringler, 2008, Rosegrant and Ringler, 2000, Molle and Berkoff, 2009). By contrast, this chapter conceptualises informal transfers as a function of particular urban contexts. Informal transfers to the urban sector, therefore, are viewed as systemic, and under certain urban conditions, cause the movement of significant volumes of water.

The drivers of informal water transfers have recently been studied by Srinivasan et al. (2013). Their research shows how domestic groundwater pumping gives rise to an informal transfer process when considered in aggregate terms across a growing city.

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[17] Swyngedouw makes reference to the significance of the tanker trade in his case study city, Guayaquil, but stops short of making explicit connections with this and intersectoral water transfer theory (Swyngedouw, 2004).

[18] The definition of 'informality' and the 'informal' is fluid and subject to debate beyond the scope of this thesis. Ahlers et al. (2014) define a policy oriented literature and a critical literature which approaches the concept from different perspectives. This chapter defines 'informal' water supply and informal use to mean any process of supply, provision or coproduction that occurs outside of the authority and remit of the urban water utility or municipal administration.

[19] Exceptions include a study of how factories gain water in Indonesia by Kurnia et al. (2000) and research on Chennai's informal water tanker markets (Ruet et al., 2007, Packialakshmi et al., 2011) and more recently studies of the water tanker trade in Bangalore (Ranganathan, 2014).

The authors demonstrate this using a model of the Indian city of Chennai. They situate their findings – that Chennai gets significant amounts of water from informal processes – in the field of water allocation and transfer research. The explanation proposed by Srinivasan et al. (2013) for Chennai's levels of informal water use is relevant to many cities in the Global South. In these rapidly urbanising cities, informal means of accessing water are commonplace because universal water services are either absent or unreliable. Instead, these cities host multiple water service delivery models, many of which depend on a diverse range of informal providers sourcing water outside centralised piped networks (Ahlers et al., 2014). These include water tankers, private domestic wells, water kiosks, and various types of vendors selling small volumes of water. Much of this water is sourced from peri-urban, agricultural areas and therefore represents a de facto agricultural-to-urban water transfer. Given the decentralised nature of these processes, conventional frameworks to understand water often overlook the significant flows of water derived from these informal urban water supply options.

One factor commonly invoked to explain poor, unreliable levels of water service and consequent high levels of informal water use, is the rate of urbanisation. For example, in the Chennai study, the authors distinguish between fast and slow urbanisation processes, citing fast urbanisation as the main driver of informal, decentralised water transfers (Srinivasan et al. 2013). While urbanisation rates may indeed be influential, an extensive literature on urban water governance and 'informality' points to several additional drivers of informal water use (see, Gandy, 2008, Ahlers et al., 2014, Ranganathan, 2014). Example drivers include governance, political setting, and the impact of haphazard urban planning on infrastructure. In short, it is not just the rate of urbanisation that results in high levels of informal water use but a whole range of bio-geophysical and institutional factors that together form a loose set of urban attributes. This insight is an important finding for the development of the typologies linking urban attributes and informal transfers developed in section 5.3.

5.2.4 Urbanisation and Indirect Transfers

Indirect transfers are caused by the expansion of urban areas across formerly cultivated agricultural land. Hence urbanisation supresses local agricultural water demand because it reduces the area under cultivation. This type of transfer is considered separately from formal-informal transfers because, instead of examining how cities take water from the agricultural sector, the focus is on how cities supress agricultural water demand thereby altering relative sectoral water share.

An early article elucidating the relationship between urbanisation, land, and water transfer argues that urbanisation reduces intersectoral water conflict when land is converted from agricultural to urban uses (Kendy et al., 2007). Using an example from the Chinese city of Shijiazhuang, Kendy et al. show that urban water-uses tend to be less consumptive, with proportionally higher return flows, than agricultural uses. Therefore the expansion of urban footprints across agricultural land releases water to the wider basin. Kendy et al.'s study clearly connects urbanisation and water transfers through land-use change, a contention now seen more frequently in the water transfer literature, see for example Yan et al. (2015).

Despite the clear link between land-use and water, the consequences for sectoral water budgets are highly context specific. This is because of the dependence on the density of urban expansion (high density urban growth has a lower impact on indirect water transfer because the rate of spatial urban expansion is lower) and local agricultural land-use policies. This contention is developed further in section 5.5.

5.3 Typologies of Urban Attributes and Water Transfers

This section presents typologies derived from the empirical case research in Hyderabad, Coimbatore, and Kaifeng. The typologies link urban attributes to the three types of water transfer process described in the conceptual framework above.

5.3.1 Typology Construction

Typologies are classification schemes based on conceptual distinctions (Bailey, 1994) and they differ from the water transfer classifications presented elsewhere in the literature, because they enable rudimentary prediction. Existing classification systems include: classifications of transfer based on the presence or absence of compensation (Levine et al., 2007); the type of mechanism (Molle and Berkoff, 2009); and classification to document different transfers observed within geographic regions, see for example the exhaustive description of the different reallocating processes observed in western United States by Schupe et al. (1989). While these classifications provide an organising logic to the various permutations and combinations of different transfer types, they do not allow the prediction of likely transfer types given urban conditions.

The typologies developed in this chapter, arise from the application of the stepwise comparative method. By adding new case studies to Levi Faur's comparative framework, and comparing similarities and differences across the cases with respect to urban attributes and the transfer processes observed, a typology of 'types' of cases emerges. The typologies developed from analysis of urban attributes and water transfers in Hyderabad, Coimbatore, and Kaifeng are presented in Table 17 and Table 18 below. The first typology addresses how urban attributes influence the levels of formal versus informal water transfers and the second addresses indirect water transfer. The typologies are populated with data from the case cities. For illustrative purposes, an additional city (Los Angeles) is also presented in Table 17 to show the range of urban attributes and how these influence the different types of water transfer processes.

The typologies comprise two parts: information on water transfers and information on urban attributes. The left-hand column relates to the water transfer scenario according to a scale indicating the formality of the water transfer regime in Table 17 and in Table 18, the relative level of indirect water transfers. In Table 17, the scale depicts a relative assessment of the level of formality compared to other urbanising areas. So for example, Hyderabad's water transfer regime has a large contribution of water from informal transfers and is therefore low on the formality scale.

The right-hand portion of the table shows the various urban attributes contended to influence water transfer processes. Each attribute is assigned a relative 'score' using chevrons to reflect its magnitude, as described in the key below each typology. Transfer processes can thus be inferred by collecting information on the various attributes and determining the general trends towards formality or informality using the direction of the chevrons as a guide.

Table 17. A typology of urban attributes indicating levels of formal water transfers.

	Groundwater Availability	Groundwater Regulation	Urban Planning	Water Service	Urban Water Gov.	Spatial Expansion	Rate of Urbanisation
Hyderabad Very informal	Yes	«	«	«	«	«	«
Coimbatore Informal	Yes	«	‹	«	‹	«	‹
Kaifeng Mostly formal	Yes	‹	›	»	‹	›	‹
Los Angeles Formal	Yes	»	»	»	»	‹	-

« ‹	**Key**	› »
Weak or very weak lead to informal	*Groundwater Reg.*	*Strong or very strong lead to formal*
Weak or very weak lead to informal	*Urban Planning*	*Strong or very strong lead to formal*
Intermittent leads to informal	*Water Service*	*Continuous service leads to formal*
Poor water governance leads to informal	*Urban Water Gov.*	*Good water governance to formal*
Horizontal / low density leads to informal	*Spatial Expansion*	*Vertical / high density leads to formal*
High demographic growth leads to informal	*Rate of Urban.*	*Low demographic growth leads to formal*

Table 18. A typology of urban attributes indicating levels of indirect transfer.

	Spatial Expansion	Replacement of Agricultural Land	Agricultural Intensification
Hyderabad High	»	›	NA
Coimbatore High	»	›	›
Kaifeng Low	‹	‹	›

« ‹	**Key**	› »
Vertical / high density minimises indirect	*Spatial Expansion*	*Horizontal / low density leads to indirect*
Replacement minimises indirect	*Replacement*	*None or low lead to indirect*
Intensification minimises indirect	*Intensification*	*None or low lead to indirect*

5.3.2 Typology Limitations

Although the typologies, presented in Table 17 and Table 18, allow inferences to be drawn about likely transfer regimes, there are limitations of using this approach to analyse water transfers. The first limitation relates to the interdependence between urban attributes. This means that, on the basis of the evidence collected during field research, no individual attribute is diagnostic of how the urban area affects water transfer processes. Furthermore, it is difficult to distinguish, for example, between elements of urban planning and urban water governance as the planning regime has a direct effect on the ability of the city to provide and manage water distribution. The implication is that the ways that cities obtain water is a product of the complex urban environment, mainstream institutional mechanisms for transfer, and local agricultural land policies. Hence transfer processes are entirely symptomatic of their context. A second limitation is that the approach does not provide a great deal of resolution and does not enable detailed analysis of which type of formal or informal mechanisms are more likely (note however that the hydrogeological environment does influence the likely form of informal transfer, which will be described in section 5.5.1.1).

The typologies, presented in Table 17 and Table 18, are based on proposed causal relationships between urban attributes and transfer processes. To support these claims, the following sections use evidence from the three cases of water transfers to Hyderabad, Coimbatore, and Kaifeng. The aim is to address each attribute in turn and show its effects on water transfer processes. The analysis begins by summarising the main types of transfer observed at the case studies.

5.4 Case Study Transfer Summaries

To contextualise the upcoming analysis of the relationship between urban attributes and transfers implicit in the typologies, this section recaps the water transfer scenario observed in each case city (outlined in more detail in Chapter 4). This is summarised in Table 19, which presents an overview of the different types of water transfer process observed in each city. Evidence shows that while formal transfers (bulk surface water schemes) are important for all three case studies, in Hyderabad and Coimbatore, various informal transfer processes are also highly significant. However, in Hyderabad, the informal water tanker market plays a more prominent role than it does in Coimbatore.

Table 19. Summary of transfer processes observed at case studies.

Transfer Processes	Hyderabad	Coimbatore	Kaifeng
Bulk Surface Water Transfers	•	•	•
State operated standpipes	◦	◦	-
Private groundwater pumping	•	•	◦
Informal water tanker market	•	◦	-
Industrial abstraction from rivers	-	◦	◦
Community-managed groundwater schemes	◦	-	◦
Private water kiosks in peri-urban areas	◦	-	-
Abstraction from urban tanks	-	◦	-

• *Major transfer process* ◦ *Minor transfer process*

Building on Table 19, the remainder of this section addresses each case in turn, summarising the findings from Chapter 4 as to how they receive water and linking this to the typologies.

5.4.1 Hyderabad's Informal Water Transfer Scenario

The typology in Table 17 categorises water transfers to Hyderabad as being low on the scale of formality, or 'very informal'. This is because, the available evidence on groundwater abstraction suggests that the city receives large volumes of water through informal water transfer processes. Much of this water reaches residents via 5,000- and 10,000-litre tankers abstracting water from privately owned borewells in peri-urban areas, through domestic groundwater pumps, and also through the increasing numbers of water kiosk businesses in Hyderabad's peripheral communities. These informal processes supplement the more visible bulk surface water transfers that reach Hyderabad's water board from several large reservoirs.

The spatial expansion of Hyderabad also leads to indirect water transfers as agricultural land is lost to low-density urban development. This observation is examined in more detail in section 5.6.

5.4.2 Coimbatore's Informal Water Transfer Scenario

Coimbatore's water transfer regime is also characterised by informality. However, while significant levels of supply are derived from groundwater, Coimbatore differs from Hyderabad in that its tanker network is smaller and less extensive. Coimbatore's growth is also giving rise to indirect water transfers as formerly agricultural land (a significant proportion of which was rainfed) is converted to urban uses. For example, through the proliferation of cloth processing factories on the outskirts of the city and ribbon development along the Noyyal River (see section 5.6).

5.4.3 Kaifeng's Formal Water Transfer Scenario

Kaifeng differs from its Indian case study counterparts because rising urban water demand is met predominantly through formal transfer processes, resulting in periodic increases to urban water withdrawals from the Yellow River. This is represented in the typology as a transfer regime of high formality, and supported by the observation that the city does not obtain significant volumes of water through informal water transfer processes (Table 19). Moreover, indirect transfers to Kaifeng are also lower because of the higher density expansion of Kaifeng's urban growth, and also policies directed at replacing agricultural land lost to urban expansion (see section 5.6).

5.5 Urban Attributes Influence the Contribution of Formal-Informal Transfers

This section addresses the causal relationships that link urban attributes and levels of informal versus formal water transfer. The analysis is predicated on the contention that in the absence of a reliable water supply from the municipal water utility – a universal water service – informal water transfer processes flourish as residents find alternative sources of water (Srinivasan et al., 2013). Thus, the contribution from formal transfers delivered through the municipal supply network is reduced. Many of these informal modes of water access represent de facto transfers from the agricultural sector because in closed river basins, the interconnectivity of users implies that as one sector withdraws more water, another withdraws less.

Several urban attributes contribute to poor universal water services and create conditions in which levels of informal water transfer are likely to be high. Here, the following urban attributes are analysed: groundwater; rates of urbanisation; rate of spatial expansions; urban planning; and various urban water governance indicators.

5.5.1 Groundwater and Hydrogeology

The availability of groundwater is a necessary condition for many informal water transfer processes. However, informal transfers based on groundwater abstraction also require weak, or poorly enforced groundwater regulation. This is the scenario in Hyderabad, Coimbatore, and Kaifeng. Therefore a condition for many informal transfers is the combination of both available groundwater and weak groundwater regulation. Additionally, in the local hydrogeological environment also influences which informal transfer processes are likely to dominate, and thus contributes to shaping how particular cities increase their share of water resources.

5.5.1.1 Hydrogeological conditions influence informal water transfers

The relationship between geology, groundwater, and informal water transfers is best explored using the example of Hyderabad. Here, Hyderabad's hydrogeology (a volumetrically limited, shallow groundwater reservoir, underlain by fractured, crystalline rocks with limited water storage as described in Chapter 4) has three implications shaping how residents and businesses obtain water through informal water transfer processes.

Firstly, given the relatively small size of Hyderabad's shallow aquifer (see section 4.4.6 in the previous chapter, for a more detailed description of Hyderabad's hydrogeology), increased groundwater abstraction requires expanding the area over which water is abstracted. This is because in most parts of the city, it is not possible to increase the depth of pumping. Consequently, the physical extent of the city's water footprint (also known as its urban waterscape (Díaz-Caravantes, 2012)) expands as groundwater demand rises. This partially explains the increasing distances that water tanker drivers travel to meet growing demand (Interview, Water Tanker Driver, 2013). This therefore modifies the impact that urbanisation in Hyderabad has on adjacent agriculture.

Secondly, the narrative of groundwater tables that plunge to ever-increasing depths, does not readily apply to Hyderabad because the shallow aquifer is the main source of water. When this shallow aquifer runs dry during the summer months (an annual occurrence), families previously reliant on private borewells turn to water tankers instead. This increases the market for the tanker trade on a seasonal basis and changes the nature of informal water transfer processes from the decentralised household level (private borewells) to the informal tanker trade.

Thirdly, well yields vary dramatically depending on which aquifer is tapped (shallow or deep), the density of borewells and location (given the heterogeneous geology underlying the city). This means that residents in different parts of the city are reliant on different types of informal water supply process. It also means that as more borewells are drilled, local well yields change and residents once able to pump water in their homes, increasingly have look to alternative sources. The consequence is that water supply options available to urban residents are constantly changing and that there is a great deal of dynamism within the subset of informal water transfers.

This section has shown that groundwater and its availability determines whether informal water transfers are possible, furthermore it has indicated that the hydrological environment influences the type of informal water use. In Coimbatore and Kaifeng by contrast, high water tables (Interviews with the Public Works Department and Hydrographic Information Office respectively, 2013) and less impervious underlying geologies mean that the urban waterscape – the distance over which informal processes operate – is smaller. This is because domestic borewells rarely run dry and the market necessity for tankers to encroach into rural areas is reduced.

5.5.2 Rates of Urbanisation

Rates of urbanisation have previously been invoked as an explanation for why cities rely on informal water service provision and thus informal water transfers. Researchers have proposed both the rate of demographic growth and the rate of urban spatial expansion as factors explaining the lag between urbanisation and the provision of universal urban water services (Srinivasan et al., 2013). However, observations from the three case studies suggest that high rates of demographic and spatial growth exert different effects on informal water transfers. Furthermore, evidence from the case studies suggests that neither of these attributes fully explain observed water transfer scenarios. The influence of demographic growth on informal water use is considered first, followed by an overview of the effects of spatial expansion.

5.5.2.1 Demographic Growth Increases Urban Water Demand

Demographic growth increases total water urban demand because more water is needed for larger populations. When demographic growth occurs quickly, it poses engineering challenges given the need to expand distribution networks and find new sources of water. Where network expansion does not keep up with demographic growth, informal water use is thought to rise. However, the effect of demographic growth on water transfers is shaped not only by the speed of increase, but also by the form of growth.

As described in Chapter 1, three main processes result in increasing urban populations: natural population growth, the absorption of formerly rural areas into the city footprint and, most significantly, rural-to-urban migration (McGranahan and Satterthwaite, 2014). Contributions from these different types of demographic growth affect levels of informal water use differently because they influence where and how new settlements arise within the urban area. For example, unchecked rural-to-urban migration – the main contributor to rising population growth – often results in slum and temporary settlements which are unlikely to be connected to centralised water supply systems (Tamil Nadu Slum Clearance Board, 2011). Therefore, the ability to control and predict population flows to cities is important for managing urban water demand and effective urban planning of water supply infrastructure. This is an example of the interdependence between growth rate, its form, urban planning, and urban water governance attributes.

The effects of different forms of urban growth therefore offer an explanation of why rates of urbanisation are not powerful determinants of informal water transfer. For example, comparison of rates of urban growth between the case studies show there are other, arguably more significant, urban attributes influencing levels of informal water use. Table 20 shows that Kaifeng, with its population growth rate of 1.6%, is growing at a similar rate to Coimbatore, yet levels of informal water use are lower and service levels for the distribution network are better. This challenges Srinivasan et al.'s (2013) contention that it is the temporal aspect of 'rate' that explains levels of informal water transfers. Instead, rival explanations from the spheres of politics, governance, and urban water management may offer greater insights as to why informal water transfers appear to contribute more significantly to rising water demand in the Indian case study cities.

Table 20. Comparison of urban growth rates across the case study cities.

City	Annual Population Growth Rate (%)	Contribution From Informal Transfers
Hyderabad	3.3% (2014)	High
Coimbatore	1.4% (2011)	High
Kaifeng	1.6% (2012)	Low

Sources: Hyderabad: (Yellapantula, 2014); Coimbatore: (Urban-LEDS, 2015): Kaifeng: (Interview, Design Institute for City Planning Bureau, 2013).

5.5.2.2 Spatial Expansion

Rapid spatial expansion of towns and cities also affects the ability of water boards to provide services to the urban population. This is because supplying water across larger areas requires the extension of distribution networks and maintaining network pressure across larger areas. This in turn requires additional pumping, storage and distribution infrastructure, which is expensive and takes time to plan and construct (IRAP, 2012). Therefore the rate of spatial expansion affects a water utility's ability to extend the piped network efficiently. This is an important consideration because urban spatial expansion does not necessarily mirror demographic growth.

Indeed, increases to urban footprints commonly happen more quickly than population growth, giving rise to horizontal, low-density urban areas. This is seen at the global level where urban land cover is thought to have increased at approximately twice the rate of population between 1990 and 2000 (Angel et al., 2011). And this trend is echoed in Hyderabad (see, Hussain and Hanisch (2013)) and Coimbatore (Government of Tamil Nadu, 2006). By contrast, planning regulations in Kaifeng mean that density at the urban boundary does not tail off in quite the same way (Interview, Design Institute of City Planning Bureau, Kaifeng, 2013). The implication is that the rate of spatial expansion compared to the rate of demographic growth gives an indication of the challenges faced urban water infrastructure planners and designers. Where the urban area expands with low population density, it is more likely the informal water use will take place (although in isolation this is not a powerful explanatory variable as low density expansion and sprawl is commonplace in many cities with universal water services, particularly in developed country contexts). Where spatial expansion is linked to vertical, high-density growth, it is easier for utilities to maintain water services through centralised distribution networks.

5.5.3 Urban Planning

This section examines the relationship between urban planning and levels of informal water transfer. It argues that this is an important determinant of transfer processes because of the significant technical, social, and economic challenges of providing universal water supplies to cities that grow haphazardly. Furthermore, the distinction between planned urban environments and chaotic urban sprawl is one of the most significant differences between Kaifeng and the two Indian case studies. This is exemplified most clearly perhaps by the presence of slum areas in Hyderabad (Kit et al., 2012) and Coimbatore (Tamil Nadu Slum Clearance Board, 2011), which have limited access to centralised water provision (Eshcol et al., 2009), versus the notable absence of slums observed in Kaifeng.

The differences in planning regimes and the ability of local government to implement planning laws are manifold, and stem from the different cultural, legal, and political systems. For example, urban planning in India is described by Roy (2009, p80) as ‘the management of resources, particularly land, through dynamic processes of informality’. The ad-hoc planning process this engenders explains much of the observed chaotic urban growth and idiosyncratic infrastructure development decisions seen in cities like Hyderabad and Coimbatore. These projects are often delayed and beset by financial irregularities, see for example Bachan and Singh (2014), Express News Service (2015), and Jafri. S. A. (2012).

This is in stark contrast to urban planning implementation in Kaifeng, where infrastructure of various types is often completed before populations are moved to new areas of cities (a function of the local political economy and the incentives for urban development driven by the means available for urban areas to increase funds (Miller, 2010)). A complete comparative exposition of urban planning in India and China is beyond the scope of this thesis. Nevertheless, differences in the style of planning between them (and therefore Hyderabad, Coimbatore and Kaifeng) have a bearing on the ability of these cities to provide infrastructure. Where infrastructure provision is constrained, levels of informal water use are likely to be higher. This is borne out by the differences in the level of formality and informality of water transfer scenarios between the three case studies.

5.5.4 Urban Water Governance

Alongside urban planning regimes, urban water governance influences the levels of informal water transfer by determining whether urban water utilities can provide a good level of water service and expand water networks in line with growing populations. Urban water governance is defined as the 'institutions, organizations, policies, and practices, which shape and manage water resources, including the delivery of water services for diverse populations and industries' (Olsson and Head, 2015). Influence is exerted through factors including: the managerial and economic capacity of water utilities and water administrators; conditions for cost recovery and water tariffs; but, most importantly perhaps, by the political relationships between the water administration and informal water providers (rent seeking), see for example Lovei and Whittington (1993). For Hyderabad in particular, rent seeking is an important driver for the expansion of the water tanker network, which maintains the status quo of high levels of informal transfer (see Chapter 4 for a description of Hyderabad's water tanker network).

Urban water governance and its interrelationship with local politics influences informal transfer processes in a variety of other ways. For example, the provision of infrastructure acts to legitimise claims to land in slum areas in peri-urban areas. Therefore, extending the centralised water network may be politically impracticable even where there is the technical and financial capacity to extend networks (Ranganathan, 2014). This political, governance constraint therefore drives up informal water use at the urban periphery. A second example is that network expansion in low-density or poor areas may be economically difficult to justify because it poses risks for cost recovery. Together, these factors highlight the importance of considering urban governance when analysing levels of informal versus formal water transfer.

5.5.5 Summarising the Relationship between Urban Attributes and Informal Water Use

The preceding section reviewed each of the urban attributes given in the first typology with respect to their influence on informal water use in Hyderabad, Coimbatore, and Kaifeng. This shows that a wide variety of factors shape the ability of the water utilities to provide universal water services and, therefore, whether informal water use is prevalent. The analysis of different urban attributes suggests that groundwater is a necessary condition for many informal processes, but does not lead to informal water transfers unless accompanied by weak urban planning and poor water governance. Rates of urbanisation were not able to fully explain the differences in levels of informal water use between the three case studies.

5.6 Urban Attributes and Indirect Water Transfers

This section examines how urban attributes combined with local agricultural policies influence indirect transfer processes. Indirect transfers arise as urban areas expand and subsume formerly agricultural land into their footprints. The effect of this is to suppress local agricultural water demand. Land-use change, therefore, can be conceptualised as an indirect water transfer process that changes sectoral water budgets. The magnitude of indirect transfers is determined by how much land is converted, which itself is a function of the rate of spatial urban expansion compared to urban demographic growth (an urban attribute presented in Table 18) and also by the mitigating effects of local agricultural policy. In addition to the indirect transfer effect, the conversion of agricultural land may also result in more water being available to the wider river basin. This is because urban uses of water tend to be less consumptive than their agricultural counterparts and give rise to proportionally higher return flows.

To demonstrate the potential impacts of indirect transfers for the case study cities, Table 21 presents a high-level, illustrative estimate of the effect converting agricultural land to residential use. The calculation assumes that prior to conversion, the agricultural land supported one annual irrigated lowland rice crop. This land is converted to residential use with an average population density relevant to each case city. The calculation assumes that urban return flows are 80% of total water supply per capita and agricultural return flows are 40% of the crop water demand. The results from Table 21 show that where population density is high, total urban and agricultural water demands are similar. Yet, the proportion of the return flow from residential land uses is much higher. Note that for Kaifeng and Coimbatore, the total volume of return flow from agricultural versus urban water uses are similar. Hence while agriculture demands more water, the overall return flow will be unchanged. Thus land use change surrounding Coimbatore and Kaifeng may not result in appreciable differences in downstream return flows.

Table 21. The effects of land-use change on water availability for the urban and agricultural sectors in the case study cities.

	Hyderabad	Coimbatore	Kaifeng
Rate of Land-use conversion from agriculture to urban (low or high density) (ha/year)	2,000[20]	112[21]	670
% Annual Rate of Population Growth	3.3[22]	1.4	1.6
Average Urban Density (capita/hectare)	589	115	107
Water Demand per capita per year (litres/day)	96	135	112
Municipal Water Demand (m^3/ha)	20,639	5,667	4,374
Agricultural Water Demand per Hectare of Rice[23]	16,500	16,500	16,500
Return Flow from Urban Use (m^3): 80%	16,511	4,533	3,499
Return Flow From Agricultural Use (m^3): 40%	6,600	6,600	6,600

Despite the potential local significance of land-use change on local water budgets, indirect transfers must be seen in the context of the relatively small amount of agricultural land lost to urbanisation. For example, in India between 2001 and 2010 only 1% of agricultural land has been lost to urbanisation. Nevertheless, the rate at which the land conversion takes place is increasing (Pandey and Seto, 2014). Analysis of indirect transfers is further complicated by the observation that transitions from ‘agricultural’ to ‘urban’ uses of land are rarely linear. For example, land-use change often

[20] Source: (Wakode et al., 2013).

[21] Source: (Sujatha and Bhuvaneswari, 2014).

[22] Source: (Yellapantula, 2014).

[23] Assumes one crop per season and 1,650mm/ha average crop water requirement for lowland irrigated rice cultivation (Tuong and Bouman, 2003).

involves interim stages (Wakode et al., 2013). This occurs when agricultural land is fallowed, for example when farmers turn to more profitable activities such as supplying water tankers, before it is later converted to urban uses.

Furthermore, the effects of land-use change on sectoral water budgets are modified by three factors. The first is the implementation of agricultural intensification policies. The second is the replacement of lost agricultural land from other sectors such as the environment. The third relates to the rate of spatial expansion with respect to demographic growth. Thus, the density and style of urbanisation – whether horizontal or vertical – influences the amount of agricultural land lost per capita additional urban population growth. Given that the effects of spatial expansion were considered in section 4.5.2.2, they are not considered further here. Instead, the following sections explore firstly, the replacement of lost agricultural land, and then the effects of agricultural land-use intensification in response to urbanisation.

5.6.1.1 Replacing Lost Agricultural Land

The loss of agricultural land due to urbanisation causes an indirect sectoral transfer only when lost cultivated land is not replaced elsewhere. For example, in China, the central government stipulates a national 'red line' minimum level of agricultural land of 120 million hectares (Huang et al., 2014). Designed to ensure food security, this policy requires each province to maintain a minimum cultivated area. Therefore, urban planners are obliged to replace agricultural land lost to urban development. The extent to which this policy is implemented, however, is uncertain. This view is supported by the downward trend in cultivated land area in the area surrounding Kaifeng (China Statistics Press, 2011). Moreover, interviews with Kaifeng's urban planners suggests that that there are practical and political difficulties with respect to finding 'replacement' agricultural land to balance the growth of the main city and its suburb of Kaifeng Xian. Thus, the level of agricultural land replacement in the region is low, and any indirect transfers resulting from Kaifeng's expansion across agricultural land are not mitigated.

For Coimbatore, interviews with the Department for Agriculture revealed that the area of land under cultivation is declining in the Noyyal Basin and that land availability is a constraint on the expansion of agriculture. And in Hyderabad, the extent to which lost agricultural land is replaced is unclear. On the one hand, rising land prices and speculation by developers results in the urbanisation of agricultural land (Hussain and

Hanisch, 2013). On the other hand, the availability of wastewater downstream of Hyderabad may encourage the extension of wastewater-irrigated cultivation. The results from the case studies therefore suggest that agricultural land lost to urbanisation is unlikely to be replaced elsewhere and that the suppression local agricultural water demand is unlikely to be mitigated.

5.6.1.2 Agricultural Intensification

Intensification of cultivation on residual agricultural land can minimise the indirect transfer effect of urbanisation. This is because intensification increases agricultural water demand, thereby cancelling out the effects of land-use change and indirect transfers. The relationship between urbanisation and the intensification of agricultural is documented in a recent study in China. Jiang et al. (2013) showed urbanisation to be negatively correlated with agricultural intensification, due to off-farm employment opportunities provided by the city. This suggests that land-use conversion from agriculture to urban may result in a permanent indirect water transfer and one that is actually increased due to the wider effects of urbanisation on agricultural labour availability and therefore production (see Chapter 6 for more discussion on this effect). Limited evidence was available from Coimbatore and Hyderabad with respect to agricultural intensification.

The brief reflections on intensification and replacement of agricultural land given above, and the available evidence, suggests that neither process mitigates indirect transfers in the case areas. However, the balance of these competing factors – urbanisation, replacement of land, intensification and the form of urban expansion, is likely to be highly location-specific. This emphasises the need to consider the case study environment context in order to understand water transfer processes and their potential impacts.

5.7 Implications for Transfer Theory

Three immediate implications arise from the arguments and typology presented in this chapter. The first is that typologies can be used to guide researchers and decision-makers as to the appropriate analytical frameworks to understand transfer processes in different urban contexts. The second implication relates to the effects of informal and indirect transfers on the planning of river basin allocation due to water control and land-use change. Finally, the third implication relates to the evolving nature of water transfers, as institutions catch-up to the wider process changes taking place around them.

5.7.1 Choosing Appropriate Analytical Frameworks

The typologies enable a quick assessment of the levels of the three broad water transfer processes proposed in this chapter. Combining data on different urban attributes, the typologies indicate whether transfer processes will be largely formal or informal and whether urban growth results in high levels of indirect transfer. This information can guide analysts to the most suitable framework to understand water transfers and their impacts. For example, in cities where informal water transfers are insignificant, existing conventional assessments of sectoral water use based on water policy are appropriate. This applies, for example, to growing cities in the western United States. Whereas, for cities where informal and indirect forms are transfer are posited as high, greater attention should be directed to peri-urban areas and understanding the impacts of urbanisation on the local agricultural sector. This would apply to cities similar to Hyderabad, Chennai, and Coimbatore where significant volumes of water are transferred through the aggregate effects of informal water use in the urban and peri-urban areas.

5.7.2 Implications for River Basin Planning

High levels of informal and indirect transfer have two implications for river basin planning and allocation. The first is that most informal transfer processes are decentralised and involve numerous actors, thereby raising management challenges. The second relates to the interlinked nature of land-use change and water transfers. These are discussed in the following section.

5.7.2.1 Decentralised Processes and Controlling Intersectoral Transfers

Informal water transfer processes are often decentralised, for example domestic groundwater pumping. This means that aggregate water transfer effects are caused by numerous actors, thereby raising problems for the control and oversight of transfer processes (Srinivasan et al., 2013). Furthermore, few of these actors are engaging in purposive forms of transfer. Therefore, the level to which transfers can be controlled is questionable, a problem exacerbated, or indeed caused, by the relative lack of groundwater regulation (or its enforcement) in India and China. Thus attempts at basin planning as cities grow should take in to account, firstly, the often significant volumes of water moving through informal processes, and, secondly, recognise that this is unlikely to be reduced unless centralised water services are improved, or groundwater regulation enhanced. For example, India and China are both engaging in reform of their groundwater management policies (Cullet, 2014) and it remains to be seen what effect this may have on agricultural-to-urban water transfers.

5.7.2.2 Land-Use Change, Water Transfer Theory, and Zero-Sum Games

The second implication of the analysis of different transfer processes is the recognition that sectoral water use is inextricably linked to land allocation through indirect water transfers. When urban areas grow across agricultural land, sectoral water budgets are altered. This has implications for the 'zero-sum game' analogy applied to many closed river basins (see for example Falkenmark and Molden (2008)). Instead, the evidence in this chapter suggests that urbanisation leads to a local reopening of the basin. This occurs because local agricultural water demand is reduced and replaced by urban uses with higher return flows. Nevertheless, whether a river basin remains closed as urbanisation subsumes agricultural land, is dependent on local conditions. For example, whether agricultural land replacement or intensification policies are implemented. This insight suggests that water allocation planning requires the explicit consideration of land use and how changes might affect water budgets.

5.7.3 Allocating Institutions 'Playing Catch-up'

> *India is shifting away from being an agricultural economy … water taken by the agricultural sector has fallen from somewhere near 93% to about 86%. The problem is that the rules of the game of this transition are not written*. (Former member of Department for Irrigation and CAD, Andhra Pradesh, 2012)

The final implication arising from the analysis in this chapter is captured in the above quote. The statement from a former irrigation official conveys the sense of inevitability regarding transfers in urbanising and industrialising economies, and describes how the change is happening faster than institutions are able to evolve their regulation of the movement of water between sectors. This suggests that water institutions are playing a form of 'catch-up' as powerful processes, such as urbanisation, shape water use in evolving river basins. In the short to medium term, this means there is likely to be a lag between formal, institutional mechanisms for allocation and de facto water use. However, as urbanisation rates stabilise and universal water services become the norm (see for example, Coimbatore's efforts at implementing a continuous water supply service), formal transfer processes may replace many of the informal processes and the application of basin planning approaches may become more appropriate. Hence, the relationship between urban attributes and water transfer processes are likely to evolve over time.

5.8 Conclusions

This chapter set out to understand the role of urban attributes in shaping water transfer processes. Building largely on the work of Kendy et al. (2007) and Srinivasan et al. (2013), the chapter showed that in certain urban contexts, informal and indirect water transfer processes operate alongside formal water transfer processes to make significant contributions to urban water budgets. Based on a comparison of evidence from the case studies, two typologies were presented showing how urban attributes can be used to infer likely levels of informal water versus formal water transfer, and likewise, the significance of indirect transfers.

The broad causal relationships between urban attributes and transfer processes proposed in the typology were supported by data from the three case studies of Hyderabad, Coimbatore, and Kaifeng. The data indicated that modes of water governance and urban planning influenced levels of informality in water transfers more than the speed of urban growth (rates of urbanisation). Indirect transfers were shown to be a function of local agricultural land use policies and the density of urban expansion. These claims, however, are based on only three case studies, and therefore additional research to add more case studies to the typology would enable more robust conclusions.

Moreover, the findings from the chapter support the main thesis contention regarding the importance of addressing 'the urban' in agricultural-to-urban water transfer research. The main argument is that agricultural-to-urban water transfer research requires not only an analysis of institutional mechanisms of allocation (formal transfers), the political context, but also an in-depth evaluation of the attributes of the city receiving additional water supplies. In this context, the chapter therefore advocates greater engagement with the urbanisation and urban water governance literatures to understand potential implications for informal and indirect transfer processes.

Finally, understanding the relative significance of different types of water transfer processes enables a better appreciation of the location of likely water transfer impacts – whether water is donated from peri-urban agriculture or from distant agricultural command areas – and to whom impacts accrue. The issue of impact estimation in the context of rapid urbanisation is developed further in Chapter 6. Its main argument points to the importance of considering the wider impacts of urbanisation on river basins when estimating the impacts of agricultural-to-urban water transfers.

6 Estimating Water Transfer Impacts

Summary

The application of economic modelling methods such as the residual imputation approach, to transfer impact estimation in the dynamic environments of the Krishna, Cauvery, and Yellow river basins, results in high levels of uncertainty. This chapter examines this problem from three perspectives. The first considers effect attribution arising from the contemporaneous effects that urbanisation and agricultural modernisation have on agricultural production in water-donating regions. The second focuses on whether economic frameworks based on the idea of sectors can usefully be applied to understand impacts in peri-urban areas – the source of significant water for cities similar to Hyderabad – given sectoral interaction across rural and urban boundaries (Tacoli, 1998). The third is how inter-annual climate variability obscures the relationship between water transfers and impacts, thereby adding additional complexity for which these methods cannot account. Building on the insights generated from this analysis, the chapter advocates the use of research designs, which take account of local contexts, and how these are likely to affect transfer impacts.

6.1 Introduction

The impact of agricultural-to-urban water transfers on agricultural production, livelihoods, and rural economies is the reason that water allocation decisions are controversial. Identifying and quantifying impacts, therefore, informs allocation decision-making, the setting of compensation (where appropriate) and interventions to mitigate impacts in water-donating areas. Hence the modelling and estimation of water transfer impacts, particularly in the context of dynamic river basin systems, is an integral requirement of water transfer research. Yet, despite the need to make water transfer impacts explicit, relatively little research on transfer impacts has been undertaken outside of the United States and China. Moreover, where impact estimation has been conducted in river basins similar to the Yellow, Krishna, and Cauvery, mainstream economic frameworks, arguably more suited to the more stable contexts of the United States, have been applied. This chapter argues that there is a disparity between the assumptions underpinning mainstream, conventional approaches to impact estimation and the environments of river basins experiencing rapid urbanisation and agricultural modernisation. This raises questions as to the feasibility of using these approaches in river basins similar to the case studies.

To develop this argument, this exploratory chapter is structured around three interlinked research contentions. The first contention examines the difficulty of distinguishing water transfer impacts on agricultural production from the impacts caused by urbanisation and agricultural modernisation[24]. The second contention argues that the economic notation of sectors to distinguish water donors from recipients is problematic where peri-urban zones – often the source of significant volumes of water to cities – blur the sectoral boundaries of 'agriculture' and 'urban'. Finally, the third contention notes the role of inter-annual climate variability as a complicating factor in water transfer impact modelling.

6.1.1 Contribution to Main Thesis

Moving from Chapter 5's focus on processes of transfer, this chapter examines the impacts of agricultural-to-urban water transfers in rapidly urbanising river basins. This contributes to the main thesis contention regarding the inclusion of 'the urban' in transfer analysis by illustrating how impacts and approaches to impact estimation are shaped by urban considerations. The main chapter premise is that urbanisation not only draws water from agriculture, but also draws people from agriculture and exerts wider impacts on the socioeconomic environment. This chapter also emphasises the importance of considering water transfers in the context of their river basin systems rather than, as is commonly observed in the literature, the tendency to analyse transfers in isolation.

6.1.2 Chapter Structure

The chapter proceeds as follows: section 6.2 reviews water transfer impact research to highlight the types of impact analysed in the literature, where research has been conducted, and the methods used to estimate impacts. Section 6.3 defines the research contentions in more detail. Section 6.4 explores the first research contention, which uses the concept of effect attribution to examine the difficulties of isolating water transfer impacts from those of urbanisation and agricultural modernisation. Section 6.5 examines the second research contention, which shows how peri-urban areas resist the standard 'sectoral' frameworks of water transfer and their impacts. Section 6.6 addresses the third research contention on inter-annual climate variability and the

[24] Agricultural modernisation is defined as the transformation of the agricultural sector resulting from interventions that raise land and labour productivity (Briones and Felipe, 2013). For example, technological advances such as the use of higher yielding, more resilient crops, mechanisation, land consolidation, and, of particular relevance for this chapter, interventions to raise agricultural water use efficiency.

additional challenges this poses to the estimation of water transfer impacts. Section 6.7 draws together the implications for agricultural-to-urban water transfer theory and finally, section 6.8 concludes the chapter.

6.2 Agriculture-to-Urban Water Transfer Impact Literature

This section reviews the agricultural-to-urban water transfer impact literature. The review is divided into three parts. The first examines the different types of water transfer impacts addressed in the literature. The second outlines the various methodological approaches to estimating the magnitude of impacts. The third part reviews research on impacts conducted outside of the United States.

6.2.1 Types of Water Transfer Impact

Water transfer impacts fall broadly into economic, cultural, and environmental categories, which are felt at scales from the farm to the wider economy. The main impacts accrue to agricultural producers whose irrigation supplies are reduced. Hence, most impact research aims to understand losses to these producers in terms of forgone direct economic benefits, which requires determining the value of forgone irrigation supply. Moreover, the estimation of forgone direct benefits is also integral to the process of calculating the overall economic feasibility of water transfers (Taylor and Young, 1995). Feasibility assessments are used by decision-makers to evaluate water transfers. They seek to show that the benefits of transfers to the receiving sector (cities) outweigh the forgone benefits to the donor sector (agriculture) once scheme costs have been accounted for. Therefore there is considerable interest in the estimation of forgone benefits from both researchers, attempting to understand the impacts of transfers on farmers, and also decision-makers seeking to evaluate transfer schemes.

Third party effects are another important type of transfer impact. These, often unintended impacts, arise because water transfers change water flow pathways and alter the fate of return flows. Therefore, third parties relying on agricultural return flows can be affected if they are not properly accounted for in water transfer analysis, see for example Merrett (2003). In addition to the economic impacts to producers and third parties, there are known cultural impacts of water transfers. For example, in the scenario where rural communities (possibly already in decline) struggle to cope with the loss of their symbolic water resource (Solís, 2005). Moreover, transfers can also affect the environment by changing water quality and flow regimes in source areas (Arkansas Basin Roundtable Water Transfer Guidelines Committee, 2008). The nature of these impacts varies according to different scheme characteristics. For example, the size of the transfer compared to the available resource, or the location of the diversion point with respect to the configuration of farms receiving irrigation water (ibid.).

Impacts to individual farmers can accumulate at regional scales due to secondary linkages. For example, secondary impacts to the agricultural economy in the water-donating region occur because of links between reduced agricultural production, the effect on local agribusinesses, and the consequent reduction in the tax base (Gardner, 1990). Furthermore, water transfers are also observed to have cumulative and future impacts, particularly if one transfer scheme paves the way for additional, later transfers from the same region (Arkansas Basin Roundtable Water Transfer Guidelines Committee, 2008).

6.2.2 Methods to Estimate Water Transfer Impacts

This section reviews the mainstream methods used to estimate water transfer impacts. It begins by explaining why impact estimation is challenging, and describes the modelling methods commonly used to circumvent these difficulties. Note that the techniques described in this section are also used to estimate impacts from different forms of transfer, particularly intra-sectoral agricultural water transfers, and to studies attempting to show the benefits of increases to available irrigation water (as compared to the reductions in irrigation supply considered here). Nevertheless, this review limits itself to research related to water transfers from agriculture to growing urban areas.

Estimating the magnitude of transfer impacts, economically or otherwise, is challenging because the consequences of reduced irrigation supply often cannot be directly observed in the field. For example, impacts may be distributed across command areas and between large numbers of farmers. Compare, for example, the difference between one farm selling its water and fallowing land, where impacts are tangible, to the situation where a large multi-use reservoir transfers a small proportion of agricultural water to urban uses. Impacts in the latter example are spread across the command area (not necessarily uniformly) and therefore are difficult to observe directly. Furthermore, difficulty of impact estimation in the latter example is exacerbated by the piecemeal approach to water flow monitoring and evaporation measurement in many irrigation systems (Lankford, 2013). This means it is difficult to know how much water is delivered, consumed, and returned in many agricultural systems, thereby contributing to impact estimation challenges.

To circumvent these challenges, impacts are often estimated. This is done by modelling the nonmarket value of irrigation water in the estimation of forgone direct benefit to agricultural producers. Modelling is necessary because irrigation water is rarely priced and its relationship to agricultural production with respect to other inputs is rarely simple. Therefore, nonmarket valuation techniques and models are required, many of which have been applied to understand the impacts of transfers on water-donating farms in the United States. Recent reviews of the economic water reallocation literature and the agricultural water productivity literature by the World Bank (Scheierling et al., 2014, Scheierling, 2011) shows the range of different approaches to modelling the value of irrigation water and estimating forgone direct benefits. The review finds, however, that these different methods generate wide-ranging estimates of the potential impacts of water transfers. This variation is thought to result from differences in model parameters and the existence of several conceptual gaps linked to the treatment of agricultural inputs and the choice of water measurement (withdrawn, delivered or consumed) (ibid.).

Models used to estimate forgone benefits include input-output models, for example Howe and Goemans (2003), computable general equilibrium models and, most commonly, residual imputation methods. The residual imputation method is discussed in depth in section 6.4.1, as it is the most widely applied to the assessment of agricultural-to-urban water transfer impacts. Despite various differences in the methods employed by these models to the estimation of forgone benefits, they all fail to fully embrace the complexity of modelling the contribution of water to agricultural production. Scheierling (2011) lists the following issues: specifying production functions; omission of variables; and correctly assigning prices to non-water inputs particularly owned inputs including household labour, land, and managerial skills (all of which are highly sensitive to agricultural modernisation and the effects of urbanisation). In short, even when applied in the relatively stable context of the United States, these different models give rise to a range of impact estimates for the above reasons. Hence, levels of uncertainty are likely to increase significantly if applied in highly dynamic river basins similar to those of the case studies of Hyderabad, Coimbatore, and Kaifeng.

6.2.3 Impact Analysis outside the United States

The systematic map in Chapter 2 shows that only a small number of studies have been conducted on the estimation of agricultural-to-urban water transfer impacts in river basins outside of the United States. This section examines this limited pool of research to review its approaches to impact estimation, to document the methods used, and to ascertain whether these take account the dynamic river basin environments in which these transfers take place. For example, through the use of baselines, counterfactuals, and triangulation.

The largest source of water transfer impact research outside the United States is China. Four impact studies were identified by the systematic map, each of which is based on primary data analysis. These studies illustrate the importance of considering the wider basin context in which water transfers occur and how this might modify the estimation of potential impacts. For example, two papers from the Zhanghe command area in central China show water efficiency improvements in irrigated agriculture offset the impact of reduced irrigation supplies caused by water transfers. In these studies, agricultural productivity was improved by changing to alternate wet and dry irrigation technologies. This allowed yields to be kept constant despite water transfers to urban and industrial sectors (Loeve et al., 2007, Loeve et al., 2004).

Additionally, two studies from the Chaobai basin analysing the household economic impact of water reallocation policies on farmers demonstrate why transfer research should assess wider processes changing river basins and use research designs that reflect the resultant additional complexity. For example, Zhou et al. (2009) include no baseline against which to compare estimates of water transfer impacts. Therefore, it is difficult to assess whether changes to farmer income are caused by reallocation or other factors. Secondly, the farmers in the study engage in high levels of off-farm employment, so that only 25% of their income derives from cropped agriculture. This diverse income strategy changes the context in which water transfer impacts are interpreted.

There is also a limited selection of studies from India, Nepal, and Taiwan. In India, Davidson et al. (2010) use the residual imputation approach to value water in a social cost-benefit analysis of allocation in the Musi catchment. The authors of this study note the 'heroic' assumptions required to use a residual valuation approach in this context. And in Nepal, a wide-reaching assessment of the Melamchi Water Supply Scheme to Kathmandu considers the likely impact of the proposed scheme on the donor basin (Bhattarai et al., 2005). However this study is undertaken *a prioiri* and therefore it is difficult to gauge how effectively the impacts are estimated. In Taiwan, a recent study used a computational partial equilibrium model to assess the impact of water transfers on rice production (Huang et al., 2007). This used a structured model that considers the rice sector in isolation and focuses on water reductions arising from policy. It therefore does not explicitly account for urbanisation or agricultural modernisation.

Finally, there are a handful of papers looking at different types of impacts, for example Díaz-Caravantes (2012), Díaz-Caravantes and Sánchez-Flores (2011) look at the impacts on livelihoods and land-use change, respectively, of water transfers to a city in Mexico. This research triangulates interview data, hydrological data, and land-use data from remote sensing to reach conclusions about the impacts of water transfers for one city. The use of multiple methods allows transfers to be understood in broad terms and their impacts assessed according to local contexts.

This review of research on water transfer impact estimates in the agricultural-to-urban water transfer literature has shown that most studies have focused on water transfers and their impacts in the United States – a context where levels of urbanisation (and rates of agricultural modernisation) are demonstrably lower than in the river basins hosting the case study water transfer examples (see Chapter 1 for a comparison of urbanisation in India, China, and the United States). Additionally, the review examined several studies from outside the United States. These have applied different approaches to impact estimation with varying degrees of success and the findings of this research alludes to the importance of considering the context in which transfers and their impacts occur. For example, changes to agricultural water productivity in China mitigate transfer impacts and rising off-farm incomes for farmers means that relative losses from transfers are minimised. However, it is apparent that further conceptual and methodological development is required to design studies able to accommodate the rapidly changing contexts in which agricultural-to-urban water transfers occur.

6.3 Research Contentions

The aim of the chapter is to outline the challenges of applying conventional economic approaches to estimating the impacts of agricultural-to-urban water transfers in the highly dynamic, urbanising environments of the case study river basins. The chapter is structured around the three research contentions. These contentions have emerged from field observations and the iterative process of data analysis, and thus can be interpreted as research findings. The contentions are used to provide an organising framework for the arguments developed in this chapter.

RC1. Urbanisation and agricultural modernisation modify the causal links between water transfers and agricultural production.

The first research contention focuses on the problem of tracing causal relationships between water transfers and their impacts on agricultural producers. The difficulty arises because of the contemporaneous impacts of urbanisation and agricultural modernisation on agricultural production. These non-water processes affect agricultural production through their influence on labour, access to markets, and land productivity. Agricultural production can therefore be understood as being dependent upon a web of interrelated inputs, the availability and price of which are affected by the dynamics of rapidly urbanising and modernising river basins. This not only modifies the relationship between water transfers and their impacts on the ground, but it also creates problems of endogeneity and effect attribution for many of the approaches typically used to estimate the impacts of water transfers. This contention is addressed in section 5.4.

RC2. Sectoral definitions do not reflect the mixed uses of water and dynamic agricultural-urban interactions in peri-urban areas.

The second research contention examines the applicability of conventional economic frameworks that distinguish between water uses in terms of 'sectors'. Such analysis is often used to determine the feasibility of water transfers or to quantify impacts accruing to a particular sector. A sector typically refers to the productive use to which water is put. This simple notation readily allows the identification of winners and losers, recipients and donors, as water and water rights move from agriculture to urban areas. However, a growing body of literature suggests that the distinction between the rural-agricultural and urban is increasingly tenuous (Satterthwaite et al., 2010, Tacoli, 1998). This tenuous distinction is exemplified in peri-urban areas surrounding many of the Global South's growing cities. Furthermore, these areas are also increasingly understood to be important sources of water for agricultural-to-urban water transfers (see Chapters 4 and 5). In these environments, the static economic notation of sectors does not capture the mixed uses of water occurring in dynamic peri-urban zones and therefore many informal forms of water transfer cannot easily be represented using this mainstream economic notation. This problem is addressed in section 6.5.

RC3. Inter-annual climatic variability obscures the impacts of urban water transfers.

The third contention highlights the additional complexity brought to the modelling of water transfer impacts by climate variability. It notes how inter-annual climate variability obscures the signal of water transfers and influences production functions, thereby exacerbating the issue of impact identification and quantification.

Together, the three research contentions described above aim to show the difficulty inherent in the application of conventional economic frameworks to understanding water transfer impacts in river basins similar to the Krishna, Cauvery, and Yellow.

6.4 Urbanisation and Modernisation Modify Transfer Impacts

This section examines the first research contention. It argues that urbanisation and agricultural modernisation modify both the impacts of water transfers and also undermine many of the assumptions required to model these impacts. This introduces high levels of uncertainty to estimates made using conventional economic methods such as the residual imputation (RI) approach (see for example, Chang and Griffin (1992)). The analysis supporting this contention begins by presenting four observations that point to the comingling interrelationships between water, agricultural production, urbanisation, and agricultural modernisation:

1. Water transfers affect agricultural production by reducing irrigation supplies.
2. Agricultural production relies on many inputs of which water is only one.
3. Conventional impact estimation models rely on production functions of inputs.
4. Urbanisation and agricultural modernisation also affect the inputs to agricultural production functions.

Together, these observations create a circular effect attribution problem for water transfer analysts attempting to isolate impacts. Effect attribution in this context refers to the extent to which 'changes in outcomes of interest can be attributed to a particular intervention' (Leeuw and Vaessen, 2009). Here, the *intervention* is the water transfer and *outcomes* are forgone direct benefits to agricultural producers. Building on the concept of effect attribution, this section shows that urbanisation and agricultural modernisation in the case study regions modify the relationship between the intervention (transfer) and outcome (impact on agricultural production). Consequently, this undermines the modelling approaches to estimating impacts such as the RI approach. This section develops this argument by firstly describing the RI approach and its assumptions. The final part of this section describes the effects of urbanisation and agricultural modernisation for transfers to Hyderabad, Coimbatore, and Kaifeng.

6.4.1 Residual Imputation Approach

The residual imputation (RI) approach, based on Young (2005), is a widely used nonmarket valuation method to estimate water transfer impacts in terms of forgone direct benefits to agricultural producers (Scheierling, 2011). In essence, the RI approach is a budget analysis, which estimates the returns from agricultural production that are attributable to water. In other words, the RI approach calculates a water rent. This is achieved by firstly assigning the value of agricultural products amongst agricultural inputs (excluding water). Secondly, the remaining or *residual* value is assumed to represent the value of irrigation water, and hence the losses incurred when the water input is reduced. Note that the residual term also captures the errors and uncertainty from all the other terms in the equation (Turner et al., 2004). Therefore the use of the RI approach is more likely to overstate the value of water rather than underestimate it, and, as this chapter argues, is likely to have high levels of uncertainty if applied in river basins experiencing rapid change outside the water sector.

The approach can summarised by two equations, following Scheierling (2011). Equation 1 is the agricultural production function, which represents the complex relationship between agricultural inputs and outputs. Once Y (the quantity of agricultural output) is known, Equation 2 is then used to derive the rent from irrigation water.

Equation 1. Agricultural Production Function.

$$Y = f(X_{M,} X_{H,} X_{K,} X_{L,} X_{C,}\ X_W, E)$$

where:

Y = the quantity of an output
X = the quantity of an input
M = material, energy and equipment inputs
H = labour inputs
K = (borrowed) capital
L = land (unimproved or rainfed)
C = equity
W = water
E = the opportunity costs of owned skills, management and technical knowledge

Equation 2. Rent Function (at site).

$$\boldsymbol{R^W} = [\boldsymbol{Y} \times \boldsymbol{P_Y}] - [(\boldsymbol{P_M} \times \boldsymbol{X_M}) + (\boldsymbol{P_H} \times \boldsymbol{X_H}) + (\boldsymbol{P_K} \times \boldsymbol{X_K}) + (\boldsymbol{P_L} \times \boldsymbol{X_L}) + \boldsymbol{C} + \boldsymbol{E}]$$

where:

R = rent
P = price

Dividing R^W by W gives the monetary value per volumetric unit of water transferred, for example $/m^3.

The important point to note from these equations is that the residual term is dependent on specifying not only the quantity of different types of agricultural inputs, but also their prices. Furthermore, despite the conceptual simplicity of the RI approach, estimation is complicated by the crop-water sub-model and farmer decision sub-model that underpin production functions. These sub-models evaluate the possible options available to farmers to maximise yields (given available inputs) and often are based on models of representative farms. Decisions include the timing of irrigation deliveries, the choice of land parcels to irrigate, fertiliser and pesticide regimes, and crop choices. These complexities require extensions to the RI approach, for example discrete stochastic programming, which are beyond the scope of analysis in this thesis.

The difficulties of using the RI approach in highly dynamic environments, for example river basins similar to the Krishna, Cauvery, and Yellow river, are twofold. The first is the practical issue of data availability, as large amounts of reliable information are required to populate the production and rent functions. Chapter 3 of this thesis has shown that data availability and reliability are key constraints to water transfer research in these regions. The second, and more conceptually fundamental, is the recognition that agricultural production, the availability of inputs, and their prices vary because of wider processes occurring in the river basin and beyond, the two of main interest here are urbanisation and agricultural modernisation. To better understand the extent to which water impact estimates might be influenced by these interdependencies, the following sections examine the impacts of, firstly, urbanisation and, secondly, agricultural modernisation on agricultural inputs and production using evidence from the three case studies.

6.4.2 Urbanisation Affects Agricultural Production

Urbanisation exerts competing effects on agricultural production. This dual effect is observed at the cases studies in relation to the impact of urbanisation on local agriculture – a potentially significant source of water for cities similar to Hyderabad and

Coimbatore. For example, while Coimbatore creates a 'nearby market for higher cost produce (vegetables)' at the same time urbanisation reduces local agricultural land availability and contributes to a shortage of agricultural labour (Interview, Department of Agriculture, 2013). Urbanisation, therefore, through its effects on inputs such as labour and markets, shapes farmer decision-making and agricultural production. This section develops this argument by showing how the competing effects of urbanisation influence the terms in Equation 1 and Equation 2 of the RI approach, thereby creating an effect attribution problem for the estimation of water transfer impacts.

6.4.2.1 Urbanisation as an Opportunity for Local Agriculture

Urbanisation creates opportunities for agriculture given its effects on markets and how producers access them. Table 22 summarises the opportunities for agriculture described by local farmers, water resource managers and the literature at the three case study cities. These benefits alter crop choices made by farmers and hence alter the assumptions underpinning the RI approach.

Table 22. Summary of opportunities for peri-urban agriculture caused by urbanisation in Hyderabad, Coimbatore, and Kaifeng.

Aspect of urbanisation	Hyderabad	Coimbatore	Kaifeng
Larger and more affluent market for cash crops	•	•	•
Improved transport links and access to urban markets	•	-	•
Access to wholesalers reduces risk of cut price/no sale	-	-	•

Source: Author's compilation from field interview data and literature.

6.4.2.2 Urbanisation Constrains Local Agriculture

Urbanisation constrains peri-urban and local agriculture due to its influence on labour and land availability. This section expands on these two factors in turn. First is the potential for urbanisation to affect labour availability and therefore the price of agricultural labour (term P_H in Equation 2). Agricultural labour availability is affected by rural-urban migration, changes to generational succession in which the young are less likely to take-on the agricultural lifestyles of their parents, and, in India, competition from schemes such as the National Rural Employment Guarantee scheme (Gibson, 2013, Hussain and Hanisch, 2013). Furthermore, the influence of urbanisation on labour is likely to be felt beyond the immediate urban and peri-urban vicinity. This is because the improved transport links that accompany urbanisation mean that the agricultural workforce can travel longer distances to find off-farm employment. Evidence for these trends at the case study cities is described below.

A recent study of peri-urban farms near Hyderabad found that farmers respond to the area's rising labour costs by choosing to sell land, fallow land, or switch to less labour intensive crops (Gibson, 2013). The changes to agricultural production in peri-urban Hyderabad brought about by these decisions are independent of water availability. In Coimbatore, the local Department for Agriculture stated that the lack of available labour was one reason for the reduction in area under cultivation adjacent to the city. And farmers in villages close to Kaifeng explained that the younger generation mainly worked in city, although they return to help with harvests or for short periods when they have young families (Farmer Interview, 2013). Nevertheless, the relationship between urbanisation and agricultural labour availability is highly context specific. For example, research by Díaz-Caravantes (2012) in the peri-urban regions of Hermosillo in Mexico found that urban employment opportunities were not available for farmers due to educational and skills barriers.

Urbanisation can also constrain agricultural production through increased land competition (thereby affecting the X_L and P_L terms in Equation 1 and Equation 2). This leads to higher land prices and rents. This effect is most significant in peri-urban areas where land-use change has the strongest influence. Nevertheless, improved transport links accompanying urbanisation mean that land prices begin to rise ever further from the central urbanising area, as speculators and developers start buy land and build industrial, commercial, or residential blocks. This effect is observed at all three case study cities. In Hyderabad for example, Hussain and Hanisch (2013) show that more sensitive farmers in peri-urban zones are likely to sell land as prices rise. And in the areas surrounding Kaifeng, land-use change is also accelerating, particularly towards to the west where Kaifeng grows towards the large city of Zhengzhou. This has resulted in local reductions in cultivated land areas. Recognising the effect of urbanisation on land prices matters for the estimation of water transfer impacts using nonmarket valuation methods because it can affect farmers' choices about how to optimise their income. In turn, this affects production functions and the estimation of water rents.

6.4.3 Agricultural Modernisation Affects Agricultural Production

Agricultural modernisation alters the characteristics of production functions represented by Equation 1. Therefore attempts to calculate the residual value of irrigation water in farms undergoing modernisation and transformation result in high levels of uncertainty. Modernisation refers to technologies and policies, which improve land and labour productivity. These productivity gains are achieved through intensification, land consolidation, mechanisation, and the adoption of new technologies and farming practices (Briones and Felipe, 2013). The rate and characteristics of modernisation differ between India and China, with China leading in terms of mechanisation and increases in agricultural outputs (Lele et al., 2011). Nevertheless, the consequences for the estimation of water transfer impacts are similar for river basins in both countries because modernisation modifies how water transfers affect agricultural output.

Of all the interventions to modernise and increase agricultural productivity, those that affect water use efficiency are most relevant to estimates of water transfer impacts. Moreover, water use efficiency is a central policy concern of agricultural water managers at all three cases given its political expediency and neutrality. This is exemplified by the description of efficiency policies as 'win-win' (stated in English) by YRCC water managers in Henan Province (Interview, YRCC, 2013). Here, a brief description of water efficiency interventions in irrigated areas linked to Hyderabad, Coimbatore, and Kaifeng is presented to show the causal links between transfers, efficiency measures, and impacts on agricultural production. Given that many policies to raise water efficiency arise from national directives, the following sections examine start from the national level before describing water use efficiency interventions at the case study areas.

6.4.3.1 Water Use Efficiency in India

In India, interventions to raise water efficiency are widely advocated given the context of perceived inefficient water use in the agricultural sector (Vaidyanathan, 2013). However, the effects of these policies on agricultural water use, and therefore their influence on water transfer impacts, are unclear. Consequently, the magnitude and fate of water volumes 'saved' by attempts at efficiency are highly uncertain. This section outlines the main water efficiency policies applied in India and introduces the reasons for ambiguity over their effects.

The National Water Mission, an initiative by the Ministry of Water Resources, aims to implement the central government target of improving water use efficiency in agriculture by 20% (Ministry of Water Resources, 2009). Examples of interventions to achieve this target include the Ministry of Agriculture's scheme to promote micro-irrigation through the use of subsidies of drip irrigation for farmers (Planning Commission, 2014). At the State level, the governments of Andhra Pradesh and Tamil Nadu have set their own policies for subsidising drip irrigation and are training farmers in water use efficiency methods through agricultural extension officers. Despite the clear objective of improving (classical) efficiency of water use by 20%, there is confusion as to fate of return flows generated by implementing these water saving technologies. For example, interviews with government representatives and academics in both Tamil Nadu and Andhra Pradesh revealed a disparate list of possible uses for water saved through raising efficiency. These included storing 'saved' water to reduce climatic risks during the growing season, expanding the area under irrigation, or transferring water to high-value uses.

Beyond the uncertainty linked to the fate of savings, the size of expected water savings from micro-irrigation interventions is extremely unclear. Reasons for uncertainty include the lack of baseline water data against which to compare the outcomes of efficiency schemes (Lankford, 2013, Lopez-Gunn et al., 2012) and also farmer choices once micro-irrigation is installed. The latter is exemplified by interviews with cash-crop farmers upstream of Coimbatore in the Noyyal Basin. Farmers stated that their (heavily subsidised) drip irrigation systems saved labour and space thereby allowing more rows of crops to be planted per field and total water use to rise (Interview, Farmer, Coimbatore District, 2012). In this context, while it is apparent that efforts to raise water use efficiency may mitigate some agricultural-to-urban water transfer impacts, the magnitude of these effects is unknown. For economic modelling techniques that rely on accurate specification of production functions to estimate water transfer impacts, the ambiguity of water efficiency interventions is problematic.

6.4.3.2 Water Use Efficiency in China

Recently, the Chinese Ministry of Water Resources has renewed its focus on improving efficiency targets in irrigated agriculture. This objective is echoed at the river basin level where managers at the Yellow River Basin Conservancy report raising water use efficiency as an important goal (Interview, YRCC, 2013). Similar to India, the main target is to save 20% of agricultural water through interventions such as canal lining and modern irrigation techniques. Therefore staff at the YRCC emphasise the strategic importance of modernising and rehabilitating irrigation infrastructure, and demonstrate a growing interest in the potential for 'win-win' water rights transfer schemes facilitated by efficiency measures. Analogous to the Indian efficiency scenario, the magnitude of likely efficiency savings is unclear and impacts on agricultural production uncertain.

6.4.4 Implications for the Use of Residual Imputation Methods in Dynamic River Basins

Together, rapid urbanisation and the water use efficiency elements of agricultural modernisation suggest there are significant challenges for water transfer impact estimation using the RI approach. Because processes of urbanisation and agricultural modernisation affect production functions and the prices of agricultural inputs, the resulting estimates of irrigation water value and the forgone benefits to producers are highly uncertain. To circumvent these problems, water models are required that reflect the range of contemporaneous processes that affect agricultural production in water donating agricultural areas. Building on this analysis, the following section explores the second research contention regarding the difficulty of accounting for the peri-urban – a significant source of water for cities similar to Hyderabad – in conventional economics frameworks based on the distinction between water 'sectors'.

6.5 Peri-Urban Areas and Water Transfer Impacts

This section addresses the second research contention regarding peri-urban areas and the use of the economic notation of sectors. Peri-urban areas, the source of a significant volume of water for growing cities similar to Hyderabad, defy sectoral definitions. In these dynamic zones, it is difficult to distinguish between agricultural and urban water users and uses and therefore to understand transfers in terms of donor and recipient sectors. The analysis in this section begins by defining what is meant by a 'sector' with respect to agriculture, on the one hand, and the urban, residential and industrial on the other. This sectoral definition is then compared to the concept of the peri-urban, which is the source of many informal water transfers. This discussion highlights the incompatibility of these two models. The remainder of the section supports this exploration using insights from the case study cities.

The term 'sector' denotes the use to which water is put by different economic activities engaged in production. Historically, the distinction between the agricultural and urban sectors also had a spatial connotation because agricultural activities occurred predominantly in rural areas whereas industrial and residential water uses were urban. Increasingly however, the 'urban-rural distinction is losing its salience' (McGranahan and Satterthwaite, 2014). One reason for this is the highly dynamic, heterogeneous nature of the peri-urban zone that exists between the rural and urban spheres, in which agricultural and urban uses of water coexist. Given the importance of peri-urban areas as a source of water for transfer in some urban contexts (Shrestha et al., 2015), the framing of water uses in sectoral terms becomes progressively redundant.

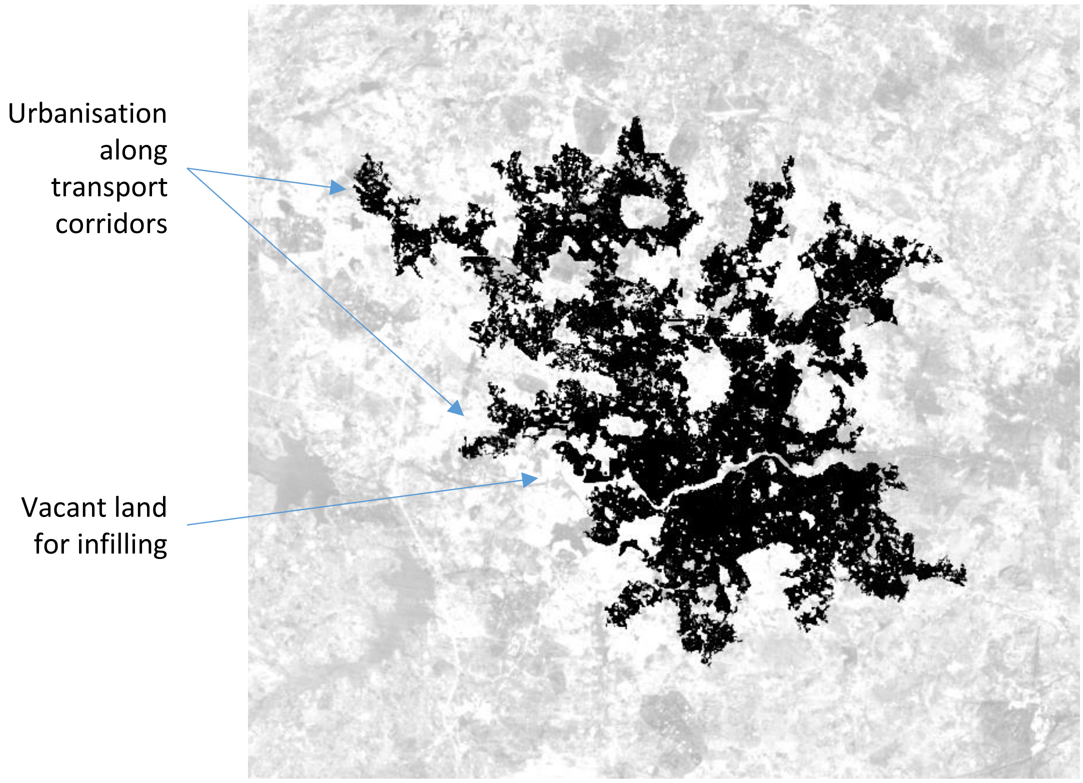
6.5.1 Defining the Peri-Urban

This section defines ‘peri-urban’ in the context of agricultural-to-urban water transfer analysis. There are many different definitions of what constitutes the peri-urban. These reflect both the different characteristics of peri-urban areas in culturally distinct settings but more fundamentally the conceptual distinction between the peri-urban as a place and as a process (see Adell (1999) and Marshall et al. (2009) for detailed theoretical reviews). This chapter uses a definition that incorporates elements of both placed-based and process-based assessments. Hence the peri-urban is understood to be an area or zone at the leading edge of towns and cities that has physical, spatial, and process properties. Physically, it can be delineated using metrics such as land-use or population density. Yet its defining feature is its transience. The location, extent, and composition of the peri-urban change as urbanisation progresses. Process-wise, definitions reflect the flows of capital, labour, goods, and services that cross the peri-urban space and undermine rigid distinctions between agricultural and urban.

There has been a recent upsurge of academic interest in peri-urban areas, definitions of urban-rural boundaries, and water transfers (see most recently (Prakash, 2014, Shrestha et al., 2014, Shrestha et al., 2015)). This builds on research showing that the distinction between the agricultural and the urban is not well defined with respect to understanding water transfers from peri-urban areas. One of the concepts applied, for instance, is the idea of the rural-urban gradient. See for example Díaz-Caravantes and Wilder (2014). However, the gradient model struggles to capture the ways that urbanisation affects the rural areas into which it encroaches and shapes water transfer impacts.

The gradient model is problematic for three reasons. The first is because of ‘sectoral interaction’, both within and across peri-urban areas, that causes an intermixing of urban and agricultural across space and livelihoods (Tacoli, 1998). This phenomenon is analysed in section 6.5.2. The second is that there is often no uniform gradient, instead urbanisation may occur as a result of infrastructure and follow non-uniform patterns. For example, Hyderabad is growing in a radial pattern with new urban land emerging along transport corridors. This pattern creates vacant land for ‘in-filling’ in a wedge pattern between more built-up areas (Iyer et al., 2007) and therefore leads to a patchy distribution of land used for urban versus agricultural purposes. This pattern is illustrated in Figure 15.

Figure 15. Hyderabad's urban growth pattern.



Description: Image of Hyderabad's urban area showing growth along transport routes and locations of likely urban infilling. Source: Author's own compilation.

The third reason that the gradient model is problematic is because urbanisation is increasingly understood to involve the development of polycentric hubs around mega-cities, rather than a transition from dense urban areas through to rural areas (McGranahan and Satterthwaite, 2014). Kaifeng is an example of this process as it grows towards the mega-city hub of the provincial capital of Zhengzhou. These three characteristics disrupt a 'gradient' view of the boundary between agricultural-rural and urban.

6.5.2 Sectoral Interaction

The theory of sectoral interaction partially explains the breakdown of conventional distinctions between the rural-agricultural and the urban sectors (Tacoli, 1998). There are two main forms, firstly interaction across space and secondly interaction across livelihoods. Place-based sectoral interaction refers to the rise of typically rural activities occurring in urban spaces and, likewise, industrial activities occurring in rural spaces. The ruralisation of industry due to lower land prices is exemplified by the newly-constructed cotton mills surrounding Coimbatore. Livelihood-based sectoral interaction occurs as a result of mobility and migration where improved transport links accompanying urbanisation enable households and individuals to adopt diverse livelihood strategies. Livelihood-based sectoral interaction therefore can mean that rural communities at increasing distances from urban places feel the effects of urbanisation on labour availability, as individuals commute for urban-industrial work. This chapter concentrates on the livelihood dimensions of sectoral interaction, as this has a greater bearing on water using sectors.

Sectoral interaction across livelihoods can be summarised by the observation that 'many families span the urban-rural divide' (Tacoli, 2006). This statement encapsulates the idea that families and individuals engage in diverse livelihood strategies encompassing agriculture and off-farm, urban employment. As a result, distinguishing between agricultural producers and the urban workforce becomes redundant because family units and individuals have multiple identities. This complicates the interpretation of agricultural-to-urban water transfer impacts because the benefits of urban water transfers and the forgone benefits caused by reductions to agricultural water availability may accrue to the same household, or indeed the same individual.

Many examples of sectoral interaction across livelihoods were observed at the case study cities. In the villages surrounding Kaifeng, for example, interviews with peri-urban farmers (often older women) revealed that the younger generation typically adopted diverse labour strategies. This observation was exemplified for example, by a key informant who worked as both a leisure centre manager in the city and as a farmer on his family land in Kaifeng's peri-urban area. Although the informant lived in Kaifeng, he returned regularly to the former family home, 7km from the city, to farm wheat and rice under the instruction of his parents. His experience of both agricultural and urban employment illustrates the fuzziness of the rural-urban divide. The notion of sectoral interaction with respect to livelihoods is also visible in peri-urban Hyderabad. For example, recent studies of peri-urban farm adaptation in Hyderabad found that farmers were increasingly engaging in off-farm employment (Gibson, 2013, Hussain and Hanisch, 2013).

For many growing cities in rapidly urbanising river basins, the peri-urban area is a critical source of water. The impacts of agricultural-to-urban water transfers on these regions are bound up with the regional transition from agriculture to urban. In these areas, from which significant volumes of water are sourced to meet urban demand, the intermingling of the urban with the rural and agricultural, in the form of sectoral interaction, poses conceptual challenges for the application of conventional economic frameworks. Understanding impacts for farmers in these areas requires a more-grounded approach that reflects the dynamic local context and the influence of wider change on peri-urban areas.

6.6 Climate Variability Complicates Impact Attribution

This section addresses the third research contention on the additional complexity introduced to water transfer impact models by climate variability. A full assessment of this issue is beyond the scope of this exploratory thesis, however this section highlights the two main challenges. The first is that water transfers, particularly those from multi-use reservoirs, may be volumetrically small compared to the size of the source. This means that the distributed impact may not be large enough to be traced through to agricultural production. For example, at all three case study sites – with the qualified exception of transfers to Hyderabad from the Manjira River affecting the Nizamsagar command area – bulk surface water transfers represent a only a small fraction of the volume of available sources. Furthermore, reductions in irrigation water supplies are distributed across a large number of users within the command areas served by these sources. This is particularly true for additional urban diversions from the Yellow River, where it is difficult to trace the impact on dispersed downstream users. The consequence is that analysis of the impact of reduced irrigation availability examines focuses on a small volumetric signal.

Inter-annual climate variability exacerbates the problem of tracing a small transfer impact signal. In some regions, inter-annual changes in precipitation may be more significant that agricultural-to-urban water transfers. In peninsular India and the middle reaches of the Yellow river basin, inter-annual fluctuations in average precipitation are typical of the climatic regime (Duncan et al., 2013, Ringler et al., 2010). For example, officials in Tamil Nadu plan on the basis of an approximate four-year average cycle, in which they would expect to see a flood year, a drought year and two approximately average years (Interview, Public Works Department, 2013). And the availability of irrigation water in the Liuyuankou Irrigation System (LIS) command area is directly linked to the flow of the Yellow River Basin, which changes depending on precipitation (Khan et al., 2008).

Acknowledging the role of inter-annual climatic variability on water transfer impacts is important for three reasons. Firstly, climate variability can dwarf the signal of water transfers, adding to the difficulty of estimating impacts on production. Secondly, transfers can exacerbate the impacts of climate variability because of the priority given to urban and industrial uses of water in times of low water availability (Gaur et al., 2008). Therefore, the issue of variability and transfer impacts are intertwined. Thirdly climate variability is yet another factor affecting farmer decision-making processes (Hertzler et al., 2015). Consequently, it also affects the assumptions underpinning production functions and the estimation of forgone benefits from transfers using models such as the residual imputation method.

6.7 Implications for Water Transfer Theory

Impacts are a critical element of water transfer research, and understanding their magnitude and significance serves to make explicit to decision-makers the trade-offs inherent in water allocation decisions. However, there remains considerable uncertainty as to how best to measure and model transfer impacts on agriculture in river basins similar to the Krishna, Cauvery, and Yellow. The analysis in this chapter raises two issues for theorisation and future research. The first is methodological and relates to the strategies required to estimate water transfer impacts in highly dynamic environments. The second is rather more policy oriented, and concerns how to contextualise water transfer impacts given the profound concomitant changes to river basins caused by urbanisation and the modernisation of the agricultural sector in India and China.

The mainstream approaches to agricultural-to-urban water transfer impact modelling are data intensive and rely on the economic framing of water use in terms of sectors. Modelling approaches rely on capturing the relationship between agricultural production and water supply in a production function. In the relatively stable contexts of the United States, these approaches provide a useful approximation of water transfer impacts, albeit one subject to uncertainty given the range of estimates available depending on the choice of model (Scheierling, 2011). This chapter argues that, in river basins similar to the case cities, the levels of uncertainty in transfer impact models will be much higher than in the United States. This is because, in addition to the standard problems of data availability in these river basins, the processes of urbanisation and agricultural modernisation systemically influence agricultural production in ways that are not yet widely acknowledged in the water transfer impact literature.

In light of these findings, this chapter recommends that impact modelling be undertaken using frameworks suited to local contexts. Therefore, 'stable' cities and agricultural areas where transfers occur through formal mechanisms can be analysed effectively using conventional economic approaches including the residual imputation method. For impacts estimation in dynamic environments, this chapter suggests approaches that account for alternative explanations of changes to agricultural production and recognise the uncertainties inherent in the methods applied. The use of baseline data (where available) would help to indicate alternative explanations. Furthermore, these approaches must also account for the inherent variability of river basin systems as seen for example through climate indicators.

A final observation related to methodology is that many models estimating water transfer impacts are applied at the level of the farm (Zhou et al., 2009, Hadjigeorgalis, 2008), whereas many of the explanations for changes in agricultural production are caused by processes operating at the river basin level. Therefore a greater focus on the links between the farm and the basin are required to understand how water transfers and their impacts are affected by processes such as urbanisation. This echoes a key theme of this thesis that agricultural-to-urban water transfers and their impacts cannot be effectively analysed in isolation from their river basin context.

Beyond the technical challenges of tracing cause and effect using modelling techniques, lies a wider debate about how to contextualise water transfer impacts given contemporaneous change across the urban and agricultural sectors. For example, what is the role of compensation in offsetting forgone transfer benefits in regions where subsidies for micro-irrigation are available? Or where farmers gain significant income from off-farm employment opportunities driven by urbanisation? Or indeed where water availability concerns are secondary to other limitations placed on agricultural production, such as the difficulty in securing agricultural labour? This latter point resonates with observations at all three case studies. Despite the administratively closed nature of the three case river basins, and the rising competition from urban and industrial water users, literature and interview data suggests that water is not the primary concern of farmers. See for example Hussain and Hanisch (2013) and their study of peri-urban Hyderabad where water scarcity is listed behind labour and costs as a constraint on agricultural production. This context of wider change means that attention is required not only to understand the type and magnitude of water transfer impacts, but also their relative importance in light of the conditions surrounding agricultural production.

6.8 Conclusions

This chapter set out to illustrate the disparity between mainstream economic approaches to water transfer impact estimation and the effects of urbanisation and agricultural modernisation in river basins. It began from the observation that in river basins experiencing rapid urbanisation and agricultural modernisation, conventional approaches to impact analysis are likely result in highly uncertain water transfer impact estimates. This uncertainty arises from three areas. Firstly urbanisation and agricultural modernisation cause effect attribution problems because they independently influence the inputs used in agricultural production functions. Secondly, the characteristics of peri-urban areas do not easily lend themselves to the sectoral model for distinguishing between agricultural and urban water uses. Therefore, in these environments, economic frameworks based on sectors struggle to convey the impact of water transfers on agricultural producers engaging in both urban and agricultural activities. Finally, inter-annual climate variability further compounds effect attribution challenges. Given these issues, this chapter calls for impact analysis that is grounded in local contexts and uses research designs that explicitly address concerns regarding complexity and effect attribution.

Building on the themes developed in this chapter, Chapter 7 also examines the question of agricultural-to-urban water transfer impacts by examining the role of urban return flows as a source of new water that can mitigates losses in agricultural production. The chapter considers this possibility by examining how the urban context and local agricultural sectors at the case cities shape the extent to which wastewater irrigation can readily be undertaken.

7 On the Potential for Urban Wastewater to Mitigate Agricultural-to-Urban Water Transfer Impacts

Summary

This chapter addresses the potential for urban return flows to mitigate agricultural-to-urban water transfer impacts through wastewater irrigation. Using insights from Hyderabad, Coimbatore, and Kaifeng, the chapter shows that the extent of wastewater irrigation downstream of cities is context specific and depends variously on the ability of cities to consolidate wastewater flows and conditions in the agricultural sectors in downstream areas. The results suggest that, while urban wastewater can mitigate net impacts on agricultural production and income, claims related to the widespread application of this effect should be treated cautiously. The chapter closes with reflections on evaluating allocation efficiency between sectors and the scope of water transfer research in light of the moderating effect of urban wastewater on transfer impacts when viewed from the basin level.

7.1 Introduction

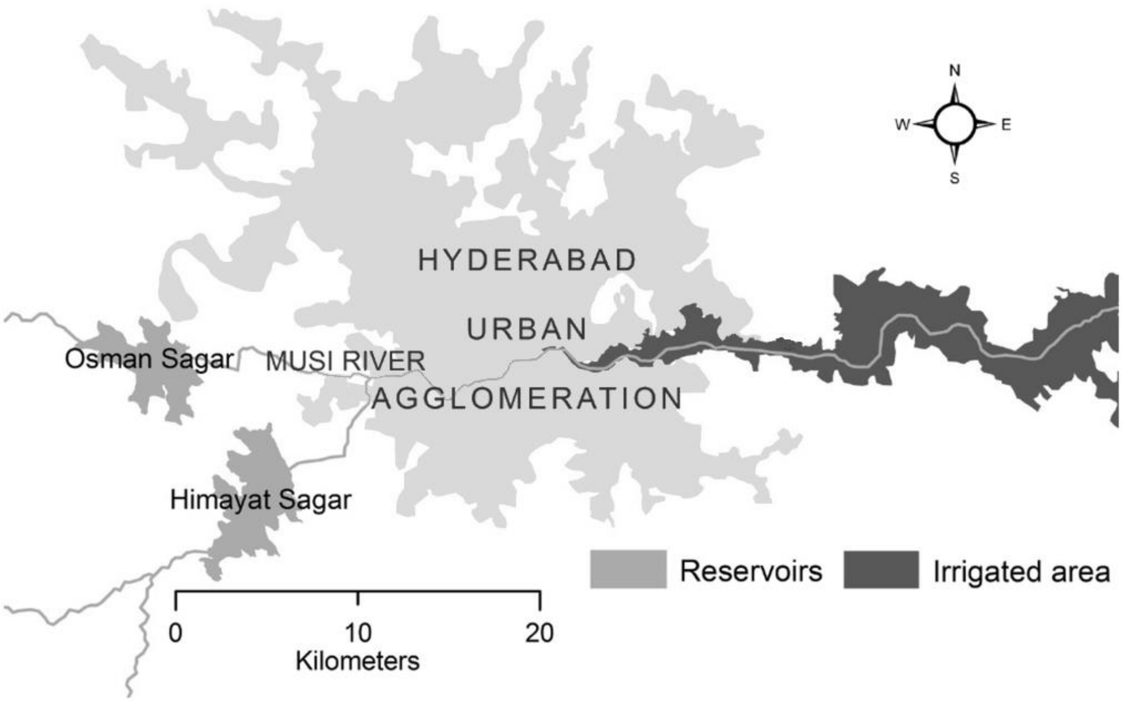
New research portrays towns and cities as sources of irrigation water (Bird, 2013, Van Rooijen et al., 2005, Amerasinghe et al., 2013, Kurian et al., 2013). From a mass balance perspective – water in versus water out – urbanisation, and the resultant upsurge in the generation of wastewater, is increasingly seen as an opportunity to expand cultivated areas under wastewater irrigation. This 'new' agriculture has the potential to mitigate upstream reductions to agricultural production caused by transfers from water-donating areas. For example, a recent report suggested that the cumulative wastewater produced by India's cities alone could irrigate 1.1 million hectares if released to waterways (Amerasinghe et al., 2013). This is therefore a volumetrically significant source of water. Moreover, using urban wastewater for irrigation is hypothesised to generate further benefits given its nutrient load, which reduces the need for inputs such as fertiliser and makes production more profitable (see Kurian et al. (2013)).

In light of the above, this chapter explores claims related to urban wastewater irrigation and the mitigation of transfer impacts on upstream agricultural production. The central questions surround the conditions required for the expansion of wastewater irrigated urban agriculture downstream of growing cities and the scale-dependence of impacts from local and river basin perspectives.

The starting point for analysis is Hyderabad and its downstream wastewater irrigation. Hyderabad features prominently in both the agricultural-to-urban water transfer and wastewater irrigation literatures (Celio et al., 2010, Gumma et al., 2011, Hussain and Hanisch, 2013, Van Rooijen et al., 2010, Van Rooijen et al., 2005, Starkl et al., 2015, Amerasinghe et al., 2009, Mahesh et al., 2015). Its dual role as both a receiver of transfer water and as a source of perennial wastewater for downstream agriculture usefully illustrates how cities pass water between upstream and downstream sectors. This city transfer effect arises because most urban water uses have low rates of consumption (evaporation) and therefore a large proportion of water entering a city is released downstream in the form of wastewater.

In Hyderabad, wastewater – only approximately 50% of which is treated (Starkl et al., 2015) – is released downstream through the Musi River. Water from the Musi is then used to irrigate vegetables, fodder (paragrass), and rice across a cultivated area estimated variously between 10,000-40,000 ha (ibid.). The location of wastewater irrigation with respect to the city and the Musi River is illustrated in Figure 16. Hyderabad, therefore, is an example of how water diverted from upstream agriculture is returned to the agricultural sector via the generation of urban wastewater.

Figure 16. Map of the location of wastewater irrigation downstream of Hyderabad.



Source: Adapted from Starkl et al. (2015).

The robustness of claims regarding the potential for wastewater irrigation to mitigate transfer impacts are dependent on whether Hyderabad (and a limited selection of other case studies) are representative of the majority of growing cities receiving water transfers, or whether Hyderabad is atypical. Preliminary observations from Coimbatore and Kaifeng suggest the latter. In Coimbatore, little wastewater irrigation was observed close to the city. This was primarily because of extremely poor water quality, competition for agricultural land and labour, and limited evidence of increasing downstream discharge of urban wastewater. And in Kaifeng, where extensive peri-urban cash crop agriculture takes place, most farmers used groundwater rather than wastewater for irrigation.

Moreover, despite its prominence in the literature and the attention focused on its characteristics (Gumma et al., 2011, Buechler and Devi, 2003, Starkl et al., 2015, Amerasinghe et al., 2009), there remains uncertainty as to the size and significance of wastewater irrigation downstream of Hyderabad. For example, it remains difficult to determine the extent of the wastewater irrigated area, the total volumes of water involved and rate of expansion of cultivated area (if any). The ambiguity arises because wastewater-irrigated urban agriculture is a heterogeneous practice operating in the dynamic peri-urban environment of a fast growing city. Therefore, even in the primary case study, the magnitude of the wastewater irrigation effect is not well established. The experiences of Hyderabad, Coimbatore, and Kaifeng with respect to wastewater generation and its use in agriculture form the basis for the remainder of this chapter.

7.1.1 Contribution to the Main Thesis

This chapter contributes to the main thesis by presenting a new perspective on the relationship between urban attributes and water transfer impacts. Thereby advancing the main thesis contention that greater attention should be given to analysis of 'the urban' in agricultural-to-urban water transfer research. Moreover, understanding the interrelationships between urbanisation, transfers, and wastewater, alters the lens through which the sectoral allocation and water transfer debate is viewed. In scenarios – and this chapter will identify which – where wastewater irrigation mitigates the agricultural production impacts of transfers, the nature of the water allocation and sectoral competition challenge changes. This is because the question of allocation and scarcity moves to one of effective sequencing of different water uses and strategies to manage return flows.

7.1.2 Chapter Structure

This chapter is organised as follows. Sections 7.2 and 7.3 situate the analysis by defining key terms and concepts. Section 7.2 defines wastewater irrigation and urban agriculture and section 7.3 describes the different ways that cities pass water from upstream to downstream agricultural sectors. Section 7.4 sets out the two main research contentions. Section 7.5 addresses the first research contention linked to the replacement of lost agricultural production downstream of cities. Section 7.6 addresses the second research contention, which examines how agricultural-to-urban water transfers can raise the economic productivity of agriculture. Section 7.7 draws three main implications for water transfers theory. Finally, section 78 presents the main conclusions.

7.2 Defining Wastewater Irrigation and Urban Agriculture

Wastewater irrigation is a widespread and long-established practice in developing and developed countries. It involves the application of wastewater – effluent from municipal, industrial, and commercial activities in its raw, partially treated, or treated form – in agricultural production (Mougeot, 2006). Its use in agriculture is stimulated by the ready availability of wastewater and because its nutrient load boosts production for certain crop types. However, the use of partially or untreated wastewater also brings with it concerns about the effect of pollutants on soils and crop yields as well as the wellbeing of farmers exposed to pollutants (Hanjra et al., 2012). In developed country contexts, particularly in arid or semiarid water mature economies such as Israel or the western United States, approximately two thirds of wastewater is already used in agricultural production (Friedler et al., 2006, WHO, 2006). Whereas, in developing countries, although wastewater irrigation is thought to be widespread, the lack of explicit regulation and policy means that its extent and significance is somewhat unclear.

Urban and peri-urban agriculture (UPA) is also a longstanding practice, defined as:

> *An industry located within or on the fringe of a town, a city or a metropolis, which grows or raises, processes and distributes, diversity of food and non food products, (re) using largely human and material resources, products and services found in and around the urban areas'* (Mougeot, 2006, p82.)

Until recently, the extent of urban agriculture was largely unknown, however a new global estimate suggests it comprises a significant proportion of total irrigated and rainfed cropland: 11% and 5%, respectively (Thebo et al. 2014). Urban agriculture also has a higher cropping intensity than the global cropland averages for both irrigated and rainfed crops (ibid.). The broad definition of urban agriculture means that it includes the production of a variety of different crops – fruits, flowers, vegetables, and cereal crops – at varying distances from the city (up to approximately 20km away from the urban area) and using different sources of water for irrigation.

For researchers interested in mitigating transfer impacts on agricultural production, only the subset of urban agriculture that uses wastewater irrigation is of interest, particularly any ‘new’ areas under cultivation. Yet identifying new or expanding urban agriculture is difficult for two reasons. The first challenge is distinguishing wastewater-irrigated agriculture from other forms of UPA. This is because farmers often adopt mixed irrigation practices, using both wastewater from canals, shallow groundwater, or freshwater from deeper borewells, for example as observed in Hyderabad’s peri-urban agricultural areas (Amerasinghe et al., 2009). The second challenge is to understand the drivers of expanding urban agriculture. For example, does urban agriculture occur because of opportunities provided by the availability of water, or is it a relic of formerly rural, agricultural land that has become urbanised as the urban boundary moves outwards? These difficulties contribute to the challenge of determining whether wastewater irrigation brings new land under cultivation.

7.3 Sponges, Swaps, and Water Exchanges

To situate the analysis of urban wastewater at the case study cities, this section sets out the literature linking urbanisation, transfers, and wastewater irrigation. This body of research has developed along two main themes. The first theme considers the relocation of agricultural production from upstream to downstream, when urban areas demonstrate ‘sponge like’ qualities as water passes through them. This best represents the flows of water through Hyderabad. The second theme considers the substitution of water between irrigators and urban users when swaps or exchanges occur.

The sponge analogy, as applied to Hyderabad by Van Rooijen et al. (2005) and now more generally to urbanising areas in receipt of additional water (see for example, Bird (2013)), describes how growing urban areas simultaneously absorb freshwater from upstream agriculture and release wastewater downstream for potential application in irrigated agriculture. The analogy implies that urban areas are passive transfer agents as water flows through their existing infrastructure to downstream sectors, often under gravity. Examples in the literature depicting this passive form of allocation include cities in India, Ghana, and Ethiopia (Van Rooijen et al., 2010).

As an alternative to relocating agricultural production, water quality exchanges or 'fresh water swaps' (Kurian et al., 2013) can also be used to mitigate the impacts of water transfers on agricultural production. Freshwater originally intended for agriculture is diverted to cities and the return flow is passed back for use in irrigation. Schemes of this sort, which involve the active engagement of urban administrators, yield potential benefits for both farming communities and towns and cities. For example, Heinz et al. (2011a) provides cost-benefit calculations for water exchange projects in Mexico and Spain. Farmers gain a reliable, nutrient-rich source of water and urban areas reduce their vulnerability to water shortages. Further examples of exchange schemes are described by Scott and Pablos (2011) for the city of Nogales in Mexico and by Murray and Ray (2010) for China.

When water flows through cities passively, wastewater availability for downstream users is not always guaranteed. Assumptions about the generation and fate of wastewater based on the simple mass balance assessment – that somewhere between 65-80% of urban water use is released as wastewater – may not materialise due to water's tendency to dissipate through multiple pathways and into different sinks within the complex urban environment (Lankford, 2013). Furthermore, even where wastewater flows are easy to access, its use in wastewater irrigation may not be possible because of constraints on land or agricultural labour availability. This observation sets the context for the research contentions presented in the next section.

7.4 Research Contentions

The objective of this chapter is to examine the potential for urban wastewater to mitigate the impacts of transfers on agricultural production in water donating regions. The argument is structured around two different types of mitigation. The first is the extent to which agricultural production can be replaced by expanding the area downstream of cities under wastewater irrigation. The second relates to the ways agricultural-to-urban water transfers can raise the economic productivity of agriculture. The research contentions arising from these considerations are presented here. In line with Chapter 6, the research contentions in this chapter have emerged from field observations and iterative analysis of the case study data. Thus, contentions can also be regarded as the findings of this research.

RC1. Urban attributes determine whether wastewater irrigated urban agriculture can replace lost upstream agricultural production.

The first research contention considers the conditions required for the expansion of wastewater irrigation. Based on the experiences of case studies similar to Hyderabad, the expansion of wastewater irrigation is linked to rising wastewater generation as the city grows. The Hyderabad wastewater irrigation scenario, however, is not replicated in Coimbatore and Kaifeng – two growing cities with commensurate increased water use. Field observation suggests the disparity is explained by two main factors. Firstly, how cities consolidate their wastewater flows so that they are readily accessible to downstream farmers. Secondly, whether there is local availability of land and agricultural labour. Furthermore, there are also a number of secondary factors including levels of pollution and the perception of wastewater as an irrigation supply source by peri-urban farmers. The chapter argues that the extent to which urban return flows can be used to mitigate upstream losses in agricultural production is therefore highly dependent on the local urban context.

RC2. Agricultural-to-urban water transfers raise the economic productivity of agriculture.

The second research contention examines how water transfers affect the economic water productivity of agriculture. Economic water productivity is defined as economic output per unit of water applied in agriculture (Molden et al., 2010). The contention relates to circumstances where water is transferred from low-value cultivation in water-donating regions and where urban return flows are used to irrigate cash crops. Hence the net transfer impact is to raise economic agricultural productivity. However, the magnitude of this productivity rise is context-dependent and, again, shaped by local urban factors. A final observation relates to the river basin level impact of expanding the area under wastewater irrigation and what this means for water availability downstream. This is considered in section 7.6.2.

7.5 Replacing Agricultural Production

The section addresses the first research contention regarding the scope for wastewater irrigation downstream of growing cities to replace upstream agricultural production lost because of water transfers. Its focus is the conditions required for the expansion of wastewater irrigation downstream of growing cities. The analysis is motivated by the disparity between the wastewater-irrigated areas observed downstream of Hyderabad versus the absence of wastewater irrigated urban agriculture in Coimbatore and Kaifeng. This difference indicates that, despite the volumetric reliability of wastewater generation, its use in irrigation is determined by local contexts. A useful framework to understand this apparent contradiction is Lankford's (2013) framework of the materiality of waste and the fate of losses and waste in resource systems.

Lankford distinguishes four fates of salvaged losses[25] within resource systems, of which three are relevant to the example of cities and wastewater generation. The first fate for wastewater generated by a city is that it remains within the 'proprietor' urban system. For example, if industries and water treatment plants enable municipal water reuse within the urban boundary, no water is available for downstream sectors. The second fate is when wastewater flows to a neighbouring sector such as downstream agriculture. The third fate for wastewater is the common pool, wider economy, or river basin (these are distinct destinations in Lankford's framework but merged here for simplicity). For example, wastewater may flow to aquifers used as a common pool resource. For wastewater irrigation downstream of cities to occur, wastewater must leave the urban system and reach the neighbouring sector. This is the second of Lankford's wastewater destinations.

Insights from the case comparison suggest that, in addition to the fate of wastewater flows, the second main determinant of the extent of wastewater irrigation is the presence of an enabling environment downstream of cities. Wastewater can only be used in agriculture if, for example, there are available land and labour. This factor is considered in section 6.5.4. Here, the analysis begins by examining the determinants for the fate of wastewater. This argument considers the reliability of wastewater generation, the consolidation of wastewater in urban systems, and the upstream-downstream positionality of the city. These are discussed in turn below.

7.5.1 Reliability of Wastewater Generation

This section explores how the volumetric reliability of wastewater generation lends itself to reuse in agriculture and encourages irrigation downstream of growing cities. At all three case studies, the reliability of wastewater is guaranteed because of the allocation priority given to drinking water in times of drought. This is exemplified by

[25] For the purpose of this analysis, losses, (in an urban system, losses constitute leaks from municipal water networks) and wastewater are considered to be synonymous. This is because they coexist within urban environments and due to the topography of urban areas and the influence of gravity, are likely to have similar destinations within an urban system.

the response to the severe water stress experienced in Tamil Nadu and Andhra Pradesh during the summer of 2012, when water for agriculture was stopped partway through the irrigation schedule to preserve supplies to cities (see for example Sundar (2012)). The prioritisation of urban water uses mean that, in times of high water stress, the most reliable water supply locations are likely to be downstream of cities. Nevertheless, the notional volumes of wastewater generated by urbanising areas are only useful if they flow in significant quantities to places where farmers can access it. This means that for wastewater to be easily applied in agriculture, discharges need to be consolidated into few release points and in suitable places for use by the agriculture sector.

7.5.2 Consolidation of Wastewater

The ability of the urban area to consolidate wastewater flows influences the likelihood of wastewater irrigation occurring downstream. Differences in urban infrastructure and wastewater management strategies in the case study cities were observed to affect the consolidation wastewater and therefore the fate of urban return flows. Differences in the management of wastewater at each case study are considered here.

7.5.2.1 Hyderabad Consolidates Wastewater Flows

Hyderabad receives water from many sources (see Chapter 4). These are consolidated into one main wastewater outflow in the Musi River[26]. Running west-to-east across the city, this is the natural sink for runoff across the urban agglomeration (Interview, Voyants Consulting, 2013). Therefore, wastewater discharged from the city's wastewater treatment plants and the untreated flows from urban drains are consolidated into this one channel, which is easily accessed by farmers downstream. As the urban area grows, wastewater flows in the Musi increase and the availability of water to support downstream irrigation increases. A recent measurement of dry season flows[27] indicates that approximately 1100MLD (Aarvee Associates, 2012, pers. comm.) is released by the city (a volume which will increase significantly when new transfers from Nagarjunasagar and the Godavari river come online in 2015).

The relatively large flows of wastewater in the Musi distinguish the Hyderabad wastewater irrigation scenario from Coimbatore and Kaifeng. Because Hyderabad is a

[26] A small proportion of urban water falls to a catchment to the northwest of the city, but these flows are negligible compared to those in the Musi.

[27] Dry season flows in the Musi represent the wastewater generated across the city. This is because there is no natural stream flow in the river due to a barrage upstream of the city. During the monsoon, wastewater is combined with storm water runoff.

large city, water from agricultural-urban transfers is combined with water from non-agricultural sources within Hyderabad's urban boundary. This results in a volumetrically significant source of water for downstream use. By consolidating water resources from many different sources, the proportion of waste available for any given transfer from upstream agriculture is much larger than the original input. This concentration effect is an important characteristic of the function of urban areas as agents of water transfer.

7.5.2.2 Coimbatore and Kaifeng Disperse Wastewater Flows

This section examines the fate of wastewater in Coimbatore and Kaifeng to understand why the discharge from these cities is proportionally less available for downstream agriculture than in Hyderabad. The section will show that wastewater outflows from Coimbatore and Kaifeng are dispersed across their urban area and therefore return to the common pool rather than being made available to downstream agriculture.

Coimbatore

In Coimbatore, interviews with the PWD, Department for Agriculture, and farmers adjacent to the Noyyal channel suggested that wastewater outflows from the city had not materially increased over time, despite rising urban water use caused by population growth. A second observation is that the groundwater table in the urban area is higher than the surrounding agricultural areas (Interview, Department for Agriculture, 2013). The absence of obvious increases to wastewater outflows and the simultaneous rise in groundwater levels can be explained by Coimbatore's domestic management of household effluent.

A critical feature of wastewater management in Coimbatore is households' separation of sullage (liquid effluent from kitchens and showers, for example) and sewage. Sullage is directed to soak pits in the gardens of houses and apartment blocks (Interview, Coimbatore Municipal Corporation, 2013). The fate of these sullage flows are unknown but presumably contribute to the high groundwater levels observed across Coimbatore's urban area. The result of this wastewater management approach is that large volumes of the wastewater generated by Coimbatore's residents and businesses are diffused across the urban area, reducing the proportion available for reuse by the neighbouring agricultural sector. The volumetrically smaller sewage flows from Coimbatore's houses are diverted to wastewater treatment plants or commonly discharged directly to open drains. These outflows eventually reach the Noyyal River but are not volumetrically significant enough to be used in local agriculture.

Kaifeng

According to the Hydrographic Information Office and peri-urban farmers adjacent to downstream drainage channels, the availability of urban wastewater for farmers downstream of Kaifeng has also reportedly remained constant. This is despite the fact that total wastewater generation is increasing given both urban growth and industrialisation. Again, this contradiction is likely to result from the diffusion of wastewater across the urban area. In Kaifeng, this is because there is no main sink for wastewater flows akin to the Musi in Hyderabad, instead water is discharged to a complex network of tanks and canals crossing the city. Furthermore, there are also high rates of evaporation from shallow groundwater tables, which may also account for some losses of wastewater (Loeve et al., 2004).

Comparing the evidence on wastewater outflows across the three case study sites suggests that the consolidation of flows, through infrastructure and wastewater management approaches, is an important condition for downstream wastewater irrigation. The consolidation of flows increases the 'neighbourliness' of urban areas as a source of water supplying downstream agriculture (Lankford, 2013). Hence, wastewater irrigation downstream of Hyderabad is more likely to arise because the local topography and approaches to wastewater management enable the city to pass wastewater to downstream farmers in a useable, volumetrically-significant form.

7.5.3 Upstream-Downstream Positionality

A final factor shaping whether cities can pass water to neighbouring sectors, is the upstream-downstream positionality of the urban area with respect to other users (Scott et al., 2014). City positionality matters in cases where wastewater flows to salt sinks (normally the sea). While positionality is not relevant to the current selection of case studies, it remains an important wider consideration given that many rapidly growing cities in water scarce river basins are coastal, for example Los Angeles.

7.5.4 Conditions for Wastewater Irrigation and Urban Agriculture

The second set of factors that determine whether wastewater irrigation expands downstream of growing cities is the downstream environment and whether it supports the expansion of agriculture. For example, the absence of obvious wastewater irrigation downstream of Coimbatore and Kaifeng is not just because it is difficult to access wastewater, but also because conditions for agricultural production are not met. Comparison across the three case studies indicates that land availability, labour availability, water quality, the perception of wastewater, and the existence of irrigation infrastructure are critical conditions for wastewater irrigation. Each of these factors is discussed in the following sections.

7.5.5 Land and Labour Availability

Competition for land and labour caused by urbanisation is one of the most critical constraints on the possible expansion of wastewater irrigation. This, above other factors, places practical limits on the extent to which agricultural production downstream of cities can mitigate reductions in upstream production caused by water transfers. This issue is discussed for each of the cases here.

Hyderabad

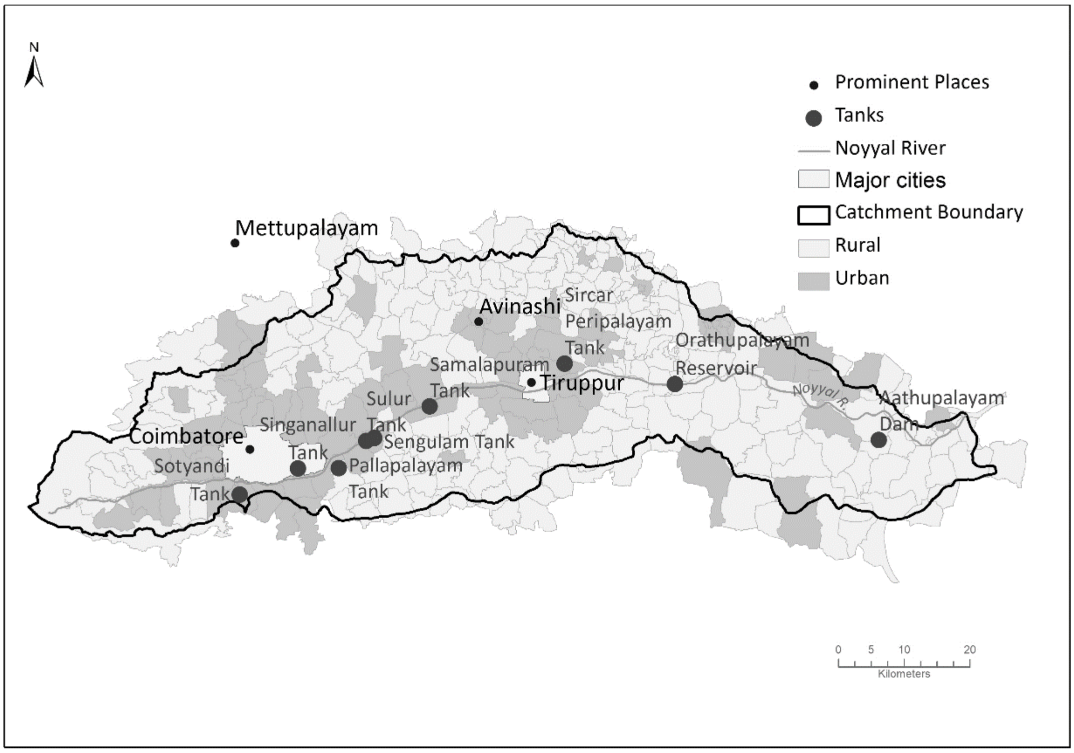
Wastewater irrigation downstream of Hyderabad is a longstanding practice (Gumma et al., 2011), however recent research on Hyderabad's peri-urban farms shows that many competing processes constrain the expansion of urban agriculture and wastewater irrigation. Of these, competition for land and labour cause the most significant changes to the structure of farming (Hussain and Hanisch, 2013). This research shows different farm types in peri-urban Hyderabad respond differently to these pressures. For example, when faced with rising land and labour costs, sensitive peri-urban farms close, whereas others intensify their use of resources to maximise profits (ibid.). These findings suggests that the prospects for expansion of wastewater irrigated area near Hyderabad and the longevity of cultivated land currently under wastewater irrigation are highly uncertain given the continued growth of the city and the rising price of land in peri-urban areas. This is despite the likely future increases in wastewater availability.

Coimbatore

In Coimbatore's Noyyal Basin, the potential use of urban wastewater for local irrigation is similarly limited by land and labour availability (Interview, Department of Agriculture, 2013). The availability of agricultural land downstream of Coimbatore is constrained not only because of urbanisation but also because of the 'ruralisation' of industry. For example, an increasing number of cotton processing plants are being built on formerly rainfed agricultural land close to the urban boundary. Furthermore, the regional style of urbanisation affects the availability of agricultural land adjacent to the

Noyyal channel – the location where wastewater irrigation would be most practicable. This is because Coimbatore is urbanising in a ribbon development along the banks of the Noyyal towards Tiruppur, a nearby, large industrial hub. This is shown in Figure 17, which illustrates the expansion of urban areas beside the Noyyal channel between the cities of Coimbatore (left) and Tiruppur (centre). Darker colours show the extent of the urbanised area, which now completely fills the gap between the two cities along the banks of the Noyyal where wastewater irrigated areas may have been expected.

Figure 17. Map of Noyyal Basin showing Coimbatore and urban land uses.



Note the ribbon development along the river channel towards Tiruppur. Source: Map prepared by EcoInformatics Lab, (ATREE, 2014).

Kaifeng

The potential for wastewater irrigation expansion downstream of Kaifeng is limited by the conversion of agricultural land to residential uses. This is despite the fact that peri-urban farming in the area surrounding Kaifeng supports fruits, leafy vegetable, and flower cultivation. Furthermore, interviews with farmers suggest that cash crops provide a reliable income and that markets for produce are good. However, the rapid growth of Kaifeng and its suburbs is encroaching on productive farmland. One farmer selling chillies at the edge of the city reported that his small farm (0.5 Mu or 330m^2) was the only remaining piece of cultivated land between four new apartment buildings that had been built in the last two years. Hence, field observations, farmer interviews, and discussions with Kaifeng's urban planners suggest that the competition for land is growing as the city grows. This is particularly relevant for agricultural land to the west of the city, as the merger between Kaifeng and the regional hub of Zhengzhou continues.

7.5.6 Water Quality

Water quality also contributes to whether wastewater irrigation is widely adopted downstream of cities. The quality of urban wastewater flows has varied effects on agricultural production. This issue is the subject of extensive research and therefore the discussion presented here limits itself to a summary of the main issues. For more detailed analysis, see for example (Mahesh et al., 2015, Hanjra et al., 2015). On the one hand, the nutrients in wastewater encourage its use because they reduce the requirement for agricultural inputs such as fertiliser. On the other hand, some components of wastewater negatively affect yields, for example where urban wastewater has a high salt concentration. Furthermore, where pollution is caused by industrial effluent and contains chemicals such as hydrocarbons and heavy metals, there are potential health implications of wastewater irrigation (Hanjra et al., 2012). Where water quality is very low, farmers may choose not to irrigate with wastewater. In this situation, farmers may instead choose to pump groundwater to irrigate their crops. This strategy was observed, for example, downstream of Kaifeng and Coimbatore. In situations where groundwater is used as an alternative to the direct application of wastewater, the impacts on water budgets are unclear because of the links between wastewater and groundwater recharge.

A second response to low quality wastewater observed in the field, particularly where wastewater is the only source of water, is to alter crop choices. Farmers choose varieties tolerant to the type of pollutant – for example, fodder (paragrass) is more tolerant to high salt levels than many varieties of rice. This encourages the cultivation of paragrass downstream of Hyderabad (McCartney et al., 2008). Crop substitution was also observed downstream of Kaifeng where peri-urban farmers situated close to channels draining urban effluent planted fruit trees, which have relatively high pollution tolerance. The substitution of crops in light of low water quality alters the characteristics of wastewater downstream and therefore influences the extent to which agricultural production downstream of urban areas can mitigate reductions to production in water-donating regions.

7.5.7 Perception of Wastewater Irrigation

How wastewater is perceived also affects its uptake as a source of irrigation water (Carr et al., 2011, Owusu et al., 2012). Perception applies both to the farmers using wastewater and the institutional environment in which wastewater irrigation occurs. Institutional ambivalence towards the use of wastewater irrigation and the suspicion of farming communities with respect to reuse – even in places where de facto reuse occurs – was noted at all three case studies. Water administrators in Hyderabad, Coimbatore, and Kaifeng reflected that wastewater reuse in agriculture was an underexploited resource but also expressed concern regarding its safety. In Hyderabad and Coimbatore, representatives from HWWSSB, the PWD, and the Department for Agriculture invariably invoked 'psychological' barriers to the use of wastewater by farming communities who would prefer freshwater for irrigation.

In Hyderabad the institutional ambivalence towards wastewater irrigation was highlighted by a recent research project on the institutional environment for wastewater irrigation. Despite several departments with responsibilities linked to wastewater irrigation at various levels (for example, Department of Agriculture and Cooperation, Department of Irrigation and Command Area Development, Andhra Pradesh Pollution Control Board, Hyderabad Municipal Development Agency, and local institutions including Water Users Associations, Self Help Groups, Model Farmers, and Agricultural Credit Societies), farmers report no interaction with institutions with respect to wastewater use in agriculture (Van de Water, 2013). Van De Water argues that this institutional vacuum and *laissez-faire* attitude is explained in part by the rapidly evolving environment and local politics related to land acquisition, and the difficulty inherent in regulating a practice undertaken by approximately 150,000 farmers.

Similar reticence was observed in farming communities with choice over their irrigation source. For example, farmers in peri-urban Kaifeng with fields adjacent to river channels containing wastewater were interviewed. They spoke of their reluctance to irrigate with wastewater, even if partially treated, because they did not trust that water treatment would be undertaken. Therefore, they preferred to irrigate using groundwater. The farmer assessment is confirmed by interviews with officials responsible for environmental protection who described the difficulties of enforcing industrial water treatment regulations. This was the result of high costs and technical capacity.

7.5.8 Existing Irrigation Infrastructure

A final determinant of the expansion of wastewater irrigation is the availability of appropriate infrastructure through which to access it. However this is a necessary but not sufficient condition given that irrigation infrastructure makes wastewater available at all three case study sites. For example, peri-urban agriculture near the Musi channel is enabled by an existing irrigation system of weirs and canals and by pumping wastewater recharged groundwater (Schmitt et al., 2010). Downstream of Kaifeng urban wastewater flows in streams and ditches is available to farmers, however they choose instead to rely on groundwater because of water quality concerns. And in Coimbatore there is a complicated series of tanks and anicuts on the Noyyal, which could allow access were it not for the lack of available agricultural land and high levels of water pollution.

7.5.9 Urban Context and Wastewater Irrigation

The preceding analysis of wastewater irrigation in Hyderabad, Coimbatore, and Kaifeng suggests that local urban contexts, primarily the ability of the city to consolidate wastewater flows, and the downstream land and labour availability are key to determining whether wastewater irrigation occurs. Therefore, the assertion that wastewater irrigation mitigates upstream impacts on agricultural production should be treated cautiously. Moreover the Hyderabad scenario, which features prominently in the literature, was not repeated in Coimbatore and Kaifeng suggesting that this is unlikely to be representative of the scenarios in other major cities. Nevertheless, this analysis was based only on three cases and the uptake of wastewater irrigation in their immediate vicinity. A more compete analysis would require more cases and also the investigation of the fate of urban wastewater flows further downstream.

7.6 Raising Economic Agricultural Water Productivity

This section addresses the second research contention. It examines how agricultural-to-urban water transfers can raise the overall economic productivity of agriculture per unit of water applied when viewed from the system level. Consequently, gains in productivity increase allocation efficiency within the agricultural sector in addition to the expected economic gains arising from agricultural-to-urban water transfers. Allocation efficiency, a term derived from neoclassical economics, is maximised when the returns (monetary) from water use across sectors are maximised (Young, 2005). Rising economic productivity and allocation efficiency within the agricultural sector therefore serve to mitigate forgone income caused by reductions in agricultural production upstream from the perspective of the river basin.

Gains in economic agricultural productivity arise because of the different crop choices made in water-donating agricultural command areas versus crop choices made by farmers using wastewater adjacent to affluent urban markets. In this sense, agricultural-to-urban water transfers can be understood as a process that brings irrigation water to the location of highest agricultural demand for cash crops. Cash crops include leafy vegetables such as spinach. However, echoing the findings from the previous section, the extent to which transfers can raise economic productivity is highly context-dependent. The following section uses the example of Hyderabad to illustrate the possible gains in productivity and to discuss some of the context-specific factors which shape this process.

7.6.1 Economic Productivity and the Case of Hyderabad

The case of Hyderabad demonstrates how agricultural-to-urban water transfers can raise the economic productivity of agriculture. The effect is caused by the difference in the crop choices in the command areas of the multiple-use reservoirs supplying water to Hyderabad versus the crop choices of peri-urban famers using urban wastewater. For example the Nagarjunasagar Reservoir, situated on the Krishna River over 114km from Hyderabad, supports three bulk surface water schemes, each diverting 149 MCM/year to the city (see Chapter 4). The main crops grown in Nagarjunasagar's command area vary depending on the season (Kharif or Rabi) but the most significant, in terms of the area under cultivation, are paddy, cotton, and maize (Irrigation and CAD Department, 2009). The water transferred to Hyderabad flows through the urban system whereupon approximately 80% becomes available for reuse in downstream wastewater irrigated areas. Here the relatively low-value paddy of Nagarjunasagar is replaced by higher value crops such as vegetables or paragrass (Starkl et al., 2015). Furthermore, the intensity of agriculture in wastewater-irrigated areas downstream of cities is also higher than that in water-donating command areas. This is because the reliability of flows from the urban area enable increased cropping intensities (Thebo et al., 2014).

The potential economic effect of substituting upstream paddy cultivation for downstream vegetable cultivation can be illustrated by comparing estimates of gross income generated by different crops choices in upstream, water-donating areas versus downstream, wastewater-receiving agricultural areas. Table 23 presents result for Hyderabad. The data is compiled from secondary data (survey data collected by IWMI in 2012 as part of a separate research project) and data from published literature. The table presents the incomes from three downstream wastewater irrigation scenarios against the upstream rice cultivation scenario. Downstream scenarios reflect alternative crops choice – rice, paragrass (fodder), or leafy vegetables – and different water quality options depending on whether wastewater is fully or partially treated. The estimates of gross income for these scenarios are derived from a simple income assessment formula presented in Equation 3.

Equation 3. Gross agricultural income.

Income = Yield × Potential Cropped Area × Market Price

Table 23. Gross income from agricultural production scenarios upstream and downstream of Hyderabad.

1. Upstream **Rice**		2. Downstream **Rice**		3. Downstream **Fodder**	4. Downstream **Vegetable**
26,000	**Water Requirement** *(m^3/ha)*	26,000	26,000	32,850	20,075
519[1]	**Available Water** *(MCM p.a.)*	402[2]	402[2]	402[2]	402[2]
5,993[3]	**Projected Cropped Area** *(ha)*	4,632[3]	4,632[3]	3,667[3]	16,000[3]
10[4]	**Market Price** *(Rs/kg)*	10	10	0.3[5]	15.00[6]
3,000[7]	**Yield per Hectare** *(kg/ha)*	3,020 *(full treatment)*	1,994[8] *(partial treatment)*	212,575[9]	35,000[10]
18	**Total Production** *(kg x 1,000,000)*	14.0 *(full treatment)*	9.2 *(partial treatment)*	779	560
186	**Gross Income** *(Rs x 1,000,000)*	144 *(full treatment)*	95 *(partial treatment)*	234	8,400

Sources and Assumptions: 1. Total water supply to Hyderabad based on HMWSSB (2012) data; 2. Assume 80% return flow from municipal uses; 3. Estimate based on available water x application efficiency of 0.3x crop water requirement for lowland rice, fodder, and vegetables (spinach), respectively; 4. Murthy and Misra (2011); 5. Mahesh (2012), pers. comm.; 6. Food and Supplies Department (2012); 7. Ministry of Agriculture (2006); 8. Blummel and Rao (2006); 9. Krishnagopal and Simmons (2007); 10. Assumes 45-day duration spinach crop grown all year yielding 50 quintals per ha per crop (INSEDA, 2012).

Table 23 highlights the variation in gross income upstream and downstream of Hyderabad depending on crop choice and level of water treatment. For example, only marginal gains in gross income stem from paragrass or rice cultivation as compared to the original upstream rice cultivation. The main benefits, however, accrue if high-value vegetable crops such as spinach are grown. Note, however, that Table 23 reflects conservative estimates of possible increases in economic productivity. This is because the cost of production is not included in these figures, due to limited data availability.

Table 23 confirms that the importance of crop choice for rising economic productivity, but these choices are themselves highly dependent on local factors. For example, in Hyderabad, wastewater irrigated crops fall into broad zones with increasing distance from the city (Amerasinghe et al., 2009). These zones reflect water quality considerations and the issue of perishability of goods for market. For example, vegetable cultivation occurs close to the urban area, largely because these crops are perishable. Beyond the vegetable zone lies paragrass, which provides fodder for the dairy industry, and finally, furthest from the city, is where most rice is grown. This zoning reflects the salt tolerance of particular crops and also the fact that water quality improves with distance from the city. Paragrass, for example, benefits from the high nutrient load of wastewater and yet is also tolerant to high salinity. Paddy meanwhile is sensitive to poor quality water and therefore is grown furthest from the city where the water quality is best[28] and farmers make use of the reliable flows of wastewater discharge to grow a more water intensive crop. This brief discussion highlights that downstream crop choices by peri-urban farmers are subject to multiple considerations.

The case of Hyderabad provides two insights pertaining to the research contention. Firstly it has shown that agricultural-to-urban water transfers can raise economic productivity in the agricultural sector when viewed from the system level. However it has also shown that this increase is highly context dependent. In Hyderabad, potential increases in economic agricultural productivity resulting from crop choices downstream of the city, reflect many locally specific consideration. For example, the local dynamics of the fodder-dairy industry, the local demand for cash crops, and the competing impacts of poor water quality in the Musi.

7.6.2 Water Availability at the River Basin Scale

This section reflects on the question of wastewater expansion and the mitigation of transfer impacts from the perspective of the river basin. From this level, the expansion of wastewater-irrigated areas downstream of cities requires a cautious approach. This is because urban return flows in the form of wastewater are rarely a *new* source of water. Prior to the academic and policy community's recent interest, wastewater would

[28] Ensink et al. (2010) found that water quality improves as a result of natural processes brought about as wastewater flows through irrigation infrastructure.

have passed downstream to other users in river basins. Consequently, when examining the question of wastewater irrigation expansion, only the wastewater generated by new urban growth can be targeted. Otherwise, wastewater irrigation amounts to a spatial water allocation from downstream to upstream. This is particularly relevant for urban agriculture, because studies suggest that the reliability of wastewater encourages double- or triple-cropping thereby increasing consumptive use (Thebo et al. 2014) and further reducing how much water reaches downstream users. Counterintuitively, therefore, the expansion of urban agriculture under wastewater irrigation could result in increased scarcity downstream. Recognition of these upstream-downstream linkages is currently underemphasised in the emerging narrative of 'cities as a source of water'; see for example Amerasinghe et al. (2013). This chapter therefore advocates basin level assessment of plans to exploit urban wastewater to ensure that downstream communities do not become unwitting third parties to this form of water allocation.

7.7 Implications for Water Transfer Theory

Increased wastewater generation by growing cities and its potential use in irrigated urban agriculture raises three implications for agricultural-to-urban water transfer theory. These are: the net impact of agricultural-to-urban water transfers; the consequences for allocative efficiency and administrative efficiency in agricultural-to-urban water transfers; and the importance of considering scale and scope in water transfer analysis (echoing the findings of Chapter 5). These areas are explored in turn here.

7.7.1 Net Impacts on Agricultural Production

The impact of agricultural-to-urban water transfers can be considered in terms of forgone agricultural production / income to individual farmers, to the water-donating region, or to the wider agricultural sector. None of the three case cities considered in this thesis engage in water exchanges or water swaps with their water-donating agricultural regions. Thus the mitigation effects of wastewater irrigation can only accrue to the wider agricultural sector and will not be felt in the water-donating region. In this sense, mitigation through wastewater irrigation reduces the net effect of agricultural-to-urban water transfers on the agricultural sector as a whole.

The evidence in this chapter showed that the magnitude of the potential mitigation effect, both in economic and productivity terms, was highly context specific. Whether wastewater irrigation occurs was linked to the ability of the urban area to consolidate wastewater outflows and the availability of land and labour in downstream areas. While all three case cities generate more wastewater as they grow, it is only in Hyderabad that this was used in downstream wastewater irrigation. Agricultural production downstream of Hyderabad was found to not only mitigate losses in upstream production, but, because of the partial substitution of rice for fodder and vegetable cultivation, represented an increase in economic productivity. Given that Hyderabad was the only example where urban return flows were used in cultivation, the broader potential for urban wastewater to mitigate transfer impacts appears limited. Further research would be required to understand the system level impacts of urban wastewater generation in Coimbatore and Kaifeng. For example it could be hypothesised that wastewater generated in Coimbatore remains within the urban system and recharges groundwater, thereby supporting continued domestic abstraction.

7.7.2 Implications for the Theorisation of Efficiency in Water Transfers

The findings of this chapter have implications for the conceptualisation of efficiency in water allocation policy. Efficiency – applied in the sense of resource governance – is commonly used as a metric to benchmark various aspects of water resources management. However, given the numerous definitions of efficiency, its application as a metric is ambiguous and occasionally controversial. For an extensive review of the water resources efficiency literature beyond the scope of this thesis, the reader is directed to Lankford (2013). Here, however, the focus in on how wastewater irrigation affects the evaluation of agricultural-to-urban water transfers in terms of allocation efficiency (economic welfare) and administrative efficiency (transaction costs).

In circumstances where urban return flows are used to cultivate cash crops, allocative efficiency within the agricultural sector rises because the economic productivity of water use rises. This is an unexpected outcome, given that rising economic efficiency is more typically associated with market mechanisms for water allocation (Livingston, 1995). In this instance, the administrative allocation mechanism – the priority allocation system implemented through Government Orders – has resulted in not only a rise due to the original transfer to Hyderabad, but also an additional affect in the wider agricultural sector. This suggests that the assumption that market mechanisms are more likely to result in allocative efficiency gains is an oversimplification.

The concept of administrative efficiency can also be applied to intersectoral water transfers, normally those arising through institutional mechanisms such as markets. Measures of administrative efficiency typically assess transaction costs, which can affect water transfers by imposing 'institutional friction' (Garrick et al., 2013). Hence high transaction costs, linked to the difficulty of defining property rights, can lessen administrative water transfer efficiency. Transaction costs in this context can be defined as:

> *The resources required to define, establish, maintain use and change institutions and organisations and define the problems that these institutions and organisations are intended to solve* (Marshall, 2013, cited in Garrick et al., 2013, p196)

One characteristic of the water transferring behaviour of growing cities, is that water flows to downstream sectors without recourse to formal institutions. For example, the regulation and definition of property rights to downstream wastewater is often conspicuous by its absence. Thus urban areas act as a transfer agent with very high administrative efficiency. It remains to be seen, however, if this administrative efficiency remains high as the rules and regulations surrounding wastewater irrigation tighten.

7.7.3 Scale and Scope of Analysis

The scale and scope of water transfer research determines how impacts are understood. For example, analysis of transfer impacts focused only on the water-donating agricultural area result in misplaced concerns regarding total agricultural production and food security. If the scale of research is increased to include the wider agricultural-urban-agricultural system, it becomes apparent that agricultural production could be maintained and productivity increased through wastewater irrigation. And finally, at the basin level, the impacts of the transfer on agricultural production can be viewed as negligible given the relatively small demands from the urban and industrial sectors and the size of their return flows. Thus choosing the appropriate scale of analysis and identifying the groups to whom impacts accrue is critical to ensuring that allocation trade-offs are made explicit.

Linked to the idea of scale and scope is the realisation that there are often additional beneficiaries to agricultural-urban water transfer schemes beyond the intended, urban recipients. These are the downstream sectors enjoying an ever-increasing, highly reliable, if low quality, supply of water. Recognition of the wider beneficiaries of agricultural-to-urban water transfers raises a number of policy questions about who pays for water transfers (currently it is normally the city and its residents with contributions from state and central governments through schemes such as the JnNURM in India) and how one should define beneficiaries of water transfers.

7.8 Conclusions

This chapter analysed whether the additional wastewater flows generated by urbanisation can be used to mitigate the impacts of agricultural-to-urban water transfers on gross agricultural production. This question was addressed using data from the three case studies. Hyderabad, a prominent example in the literature, was compared with Coimbatore and Kaifeng. The results show that, despite large volumes of wastewater being generated by all three cities, the use of wastewater downstream is a function of the ability of the urban area to consolidate flows and the conditions related to agricultural production: land and labour availability; pollution; and the perception of wastewater reuse by farmers and water managers.

At the river basin scale, two different effects were noted. The first relates to the potential for urbanisation and water transfers to drive-up the economic productivity of agriculture when water is diverted from low-value production far from cities, to high-value cash crop production close to urban markets. This effect is also highly context specific. The second consideration is the effect on downstream water availability given that expanding wastewater irrigation could have implications for downstream water users.

This chapter concludes that, despite the ability of urban areas to generate significant volumes of wastewater, the extent to which this can mitigate water transfer impacts is dependent upon the presence or absence of particular urban attributes and local agricultural policies. Hence, emerging claims that cities are 'sources of irrigation water' should be viewed cautiously and interpreted in accordance with the local urban and basin setting.

8 Conclusions

8.1 Introduction

This thesis set out to examine agricultural-to-urban water transfers using a combination of evidence from three case studies in India and China, and a systematic map, which analysed the content of agricultural-to-urban water transfer research. In the context of a general literature that focuses predominantly on institutional mechanisms and the politics of allocation decisions, the thesis argues that important conceptual elements of how we understand agricultural-to-urban water transfers are overlooked. This has implications for the analysis of transfers and their impacts in water scarce, closing river basins. Consequently, the policy challenges of attempting to balance competing demands and plan river basin allocations are made more difficult, particularly in rapidly urbanising river basins.

The thesis also addresses methodological issues related to the framing of research – the scope and level of analysis – and how this affects the conceptualisation of intersectoral transfers in response to changing water demands. Hence, the research stresses the importance of appropriately delimiting the research scope, and the use of baselines (where available), counterfactuals (where possible), and comparative methods to better inform our understanding of water transfers and how the share of water used by different sectors changes over time.

8.1.1 Overarching Conclusions

The overarching conclusions drawn from this research are, firstly, that the attributes of urban areas, both physical and those related to the governance of urbanisation and the expansion of municipal water services, shape **how** urban areas increase their share of water resources, and also how they release their wastewater to downstream sectors. Secondly, the thesis emphasises the importance of recognising that agricultural-to-urban water transfers do not occur in isolation – they happen alongside significant wider change in urbanising river basins. This coevolution adds complexity to the analysis of water transfers and their impacts. For example, it challenges the conceptualisation of water allocation in terms of 'sectors' for river basins where the distinction between the 'agricultural' and the 'urban' is increasingly blurred. Thus, to understand how a growing city takes water away from agriculture and releases it again as wastewater, it is imperative to understand the nature of the city and its growth.

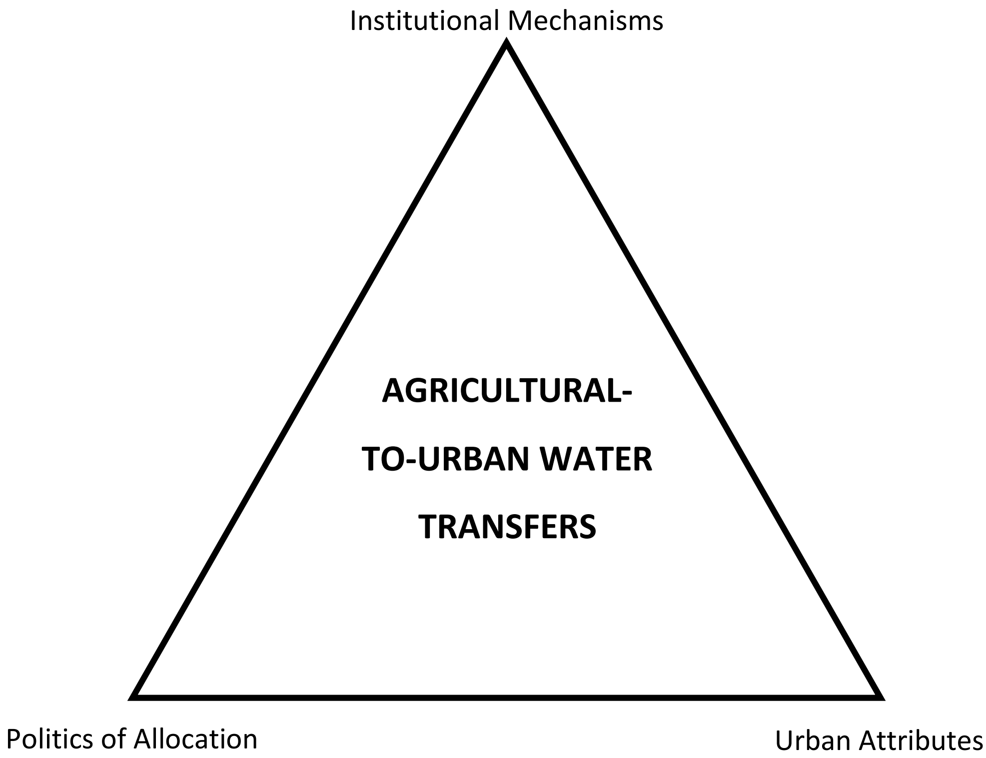
The remainder of this chapter expands on these main conclusions and ties together the findings of the research across the chapters (detailed, chapter specific, research findings are summarised in the closing sections of Chapters 2, 5, 6 and 7 and are not repeated in this concluding chapter). The chapter is structured as follows: section 8.2 highlights the incomplete nature of agricultural-to-urban water transfer theorisation and presents a revised theorisation; section 8.3 explores the links between methodology and the theorisation of agricultural-to-urban water transfers; section 8.4 distils policy relevant findings; section 8.5 outlines areas for future research; section 8.6 summarises the main contributions to knowledge and finally, section 8.7 concludes the chapter.

8.2 A Revised Theory of Agricultural-to-Urban Water Transfers

The claim that agricultural-to-urban water transfer theory is incomplete is central to the thesis. It based on insights from the systematic map and observations from across the three case studies. The systematic map illustrates the gaps in the literature and shows the dominance of studies where the main focus is the design and performance of water markets or administrative mechanisms. Yet, observations from the case studies suggest that these mainstream institutional mechanisms (often themselves heavily mediated by the politics and power relations linked to water allocating decision-making as highlighted for Hyderabad by Celio et al. (2010)) only partially explain how cities obtain and release water. Instead, external, non-water considerations, including physical attributes of the urban environment (population density, rate of expansion, groundwater availability), play an important but currently under-researched role in explaining how cities obtain and release water.

A revised framework for the theorisation of agricultural-to-urban water transfers is proposed in Figure 18. This shows how increases to the share of water used by urban areas can be framed in terms of three elements: firstly, in terms of institutional mechanisms, secondly by the politics of water allocation, and thirdly by the attributes of urban areas, as defined in Chapter 5. Any analysis of agricultural-to-urban water transfers thus requires all three elements to be considered. The consequences of this additional element of transfer theory are outlined in the next section.

Figure 18. A revised framework for understanding agricultural-to-urban water transfers.



8.2.1 Urban Attributes Influence How Cities Gain and Release Water

Framing agricultural-to-urban water transfers in terms of these three elements allows recognition that urban areas gain water share through different flow pathways. Hence, this framework makes indirect and informal water transfer processes (operating alongside formal water transfers) more visible. Using evidence from Hyderabad, Coimbatore, and Kaifeng, the thesis showed how the relative contribution of each type of transfer process was a function of the different urban attributes of each case. Hyderabad and Coimbatore were characterised by high levels of informal water transfer, whereas Kaifeng's urban water supply is derived mainly through institutional mechanisms (applications to increase quotas) resulting in water diversions from the Yellow River to the urban water utility.

Evidence from the comparison of three cities allowed an early and tentative assessment of the explanatory power of different urban attributes. Of the attributes assessed, the rate of urbanisation was shown to be a less powerful explanatory variable than might otherwise be expected from the nascent literature on informal agricultural-to-urban water transfers and urbanisation processes (see Srinivasan et al. (2013)). Instead, evidence from Hyderabad, Coimbatore, and Kaifeng suggests that planning and urban governance regimes that determine the extent and quality of municipal services, are better indicators of informal water transfers. For indirect water transfers, local agricultural policies and the style of spatial expansion were shown to be important. However, isolating individual causal relationships between the urban attributes and transfer types is challenging and requires more detailed research across additional case examples. For example, there is a co-dependence between governance and rate of urban growth.

A further consequence of framing agricultural-to-urban water transfers in terms of urban attributes, is that informal and indirect forms of transfer process can be understood as systemic. That is, they are a product of particular urban contexts and, under certain urban conditions, represent volumetrically significant flows of water. Informal transfers and the indirect transfer effects of urbanisation should therefore be accounted in basin planning for those cities where the assessment of urban attributes deems appropriate. This finding advances theory based on observations by Molle and Berkoff (2006), Meinzen-Dick and Ringler (2008), and others related to implicit, stealth, or illegal water transfer processes. These earlier studies were able to give little indication as to the circumstances under which 'implicit, stealth, and informal' transfers would be important contributors to urban water budgets. Whereas, the framing of transfers proposed in this thesis allows tentative prediction on the basis of the attributes of the urban environment.

Equally, urban attributes, including urban wastewater management strategies and the availability of downstream land and labour, influence how cities release water to other sectors. This aspect of water transfer was examined in Chapter 7 where it was shown that there are differences in how each of the case cities acts as points of wastewater release to downstream agriculture. Some of this difference was attributed to urban wastewater management strategies, some to the run-off and topography, and some to the availability of land and labour in the downstream agricultural sector. For example, significant downstream wastewater irrigation was only observed in Hyderabad, and not in Coimbatore and Kaifeng. Thus, at a system level, the impact of rising urban water withdrawals on downstream sectors, is also a function of the type of city and the way it grows.

8.2.1.1 Zero Sum Games

One implication of the explicit inclusion of indirect transfers (brought about through land-use change) in the assessment of how urban areas gain water share, is that the analogy of zero-sum water allocation games becomes less applicable. The zero-sum game frames allocation in terms of water competition using a purely water-centric perspective. However, recognition that changing water demands often occur alongside changes in land use, challenges this view. This is because urbanisation has the potential to reopen river basins because of differences in consumptive water use between agricultural and urban water uses. The consequence is that intersectoral water allocation and transfer could be framed less in terms of a competitive zero-sum game, and more in terms of the management of water-use sequencing between growing cities and the agricultural sector.

8.2.2 Impacts on Water-Donating Areas

The thesis also examined the question of how agricultural-to-urban water transfer impacts are estimated and conceptualised. In Chapter 6, the thesis examined the assumptions underpinning methods of impact estimation, and the types of impacts, which have so far been researched. These assumptions were contrasted against the agricultural-to-urban water transfers and the wider context of urbanisation observed at the three case studies. This analysis highlighted overlooked consequences of agricultural-to-urban water transfers and pointed to areas where theory and methods for impact estimation did not reflect important observations from the case studies. Two important conclusions from this analysis relate to the notion of 'sectors' in allocation theory, and the scale at which water transfer impacts are assessed.

8.2.2.1 Challenging the Notion of Sectors

The notion of 'sectors' in water allocation and transfer theory underpins the analysis of water transfer impacts. However, the utility of this theorisation was challenged by the phenomenon of 'sectoral interaction' observed in the peri-urban areas that provide water to cities such as Coimbatore and Hyderabad. In these water-donating areas, it is increasingly difficult to distinguish between the urban and the agricultural as discussed in Chapter 6. Thus, for water transfers from peri-urban-agricultural zones to core urban areas, conventional analysis of water allocation and transfer, and its impacts, based on sectoral distinctions, breaks down.

8.2.2.2 Understanding Who Gains and Who Loses

One immediate implication of examining agricultural-to-urban water transfers at a system- and basin-level, rather than in isolation, is that additional beneficiaries become visible. Because of the generation of additional wastewater from growing cities, agricultural-to-urban water transfers can cause downstream users – often farmers – to receive extra water. Therefore, additional groups need to be included in the analysis of water transfer impacts. Furthermore, where downstream urban wastewater irrigation occurs, agricultural-to-urban water transfers change net economic agricultural water productivity.

Evidence from Hyderabad, for example, indicates that water transfers from low-value rice cultivation to the city, result in raised economic productivity once downstream cash-crop cultivation using urban wastewater is considered. This unexpected result suggests that efficiency gains within the agricultural sector can emerge when application of the priority allocation system improves sequencing. However, this effect was not observed in Coimbatore and Kaifeng, suggesting that this outcome is atypical of agricultural-to-urban water transfers.

8.3 Methodological Implications

By framing agricultural-to-urban water transfers as a product of three elements (see Figure 18), the thesis raises several methodological points. These relate to the scope, scale, and disciplinary focus of water transfer analysis, and research design elements such as baselines, counterfactuals, and triangulation. To situate the discussion, this section begins by summarising the main research approaches to transfer analysis as revealed by the systematic map in Chapter 2.

8.3.1.1 The Isolation of Water Transfers in Research Designs

The systematic map showed that most of the transfer literature is based on case studies which frequently theorise transfers in isolation from their wider river basin contexts. Methods appropriate for transfer research focused on just the particulars of institutional designs or impacts, differ from those required to understand transfers in the contexts of their river basins. For example, once the effects of urbanisation on transfers are taken into account, transfer analysis is made more complex by challenges related to covariance between drivers of transfers and their impacts. Thus shifting the research focus from detailed analysis of particular transfer elements to a more contextualised, systems-level approach requires research designs that can trace the additional drivers of water transfer and better illuminate effect attribution challenges.

8.3.1.2 *Effect Attribution*

The issue of covariance and effect attribution related to water transfer impacts was explored in Chapter 6. This showed how urbanisation and agricultural modernisation undermine many of the assumptions implicit in conventional economic impact estimation frameworks. Overcoming these difficulties requires research designs that include tools such as baselines and counterfactuals. These research tools enable rival explanations to be identified and discounted. Yet, these are rarely used in water transfer analysis due to a lack of available data. Hence, this thesis adds to growing calls for greater emphasis to be placed on strategies and studies to fill basic data gaps (see for example Wagener et al. (2010)). For example, better groundwater monitoring or the use of remote sensing to monitor crop water demand. Additionally, greater emphasis should be placed on the use of triangulation in case studies to circumvent data paucity.

The thesis also advocates for the greater application of comparative research methods to aid the identification of case specific variables. For instance, one of the most useful aspects of the comparative case method is it helps to distinguish causal mechanisms of interest from the complexity of the case background. Comparative research frameworks therefore offer many of the benefits of using baseline data (which is also essentially a form of comparison) if the method is applied cautiously and with due consideration of its limitations.

8.3.1.3 *Choice of Conceptual Framework*

The final methodological issue raised by the thesis relates to the choice of appropriate conceptual framework for water transfer research. In highly regulated environments, with controlled urban expansion, informal and indirect water transfers are likely to be low – for example in the United States. In these stable contexts, application of conventional research designs, based on institutional mechanisms and their wider political contexts, to understand water transfers and their impacts remain appropriate. However in cities similar to Coimbatore and Hyderabad, where significant volumes of water arise from peri-urban areas and the impacts on local agricultural producers are unclear, then conventional approaches are likely to overlook important sources of water. For example, the importance of the peri-urban zone, and therefore also overlook a stakeholders who may be affected by changes to sectoral water budgets. Thus, this thesis advocates assessment of the water transfer context to researchers as to the most appropriate framework to analyse water transfers and their impacts.

8.4 Policy Implications

The thesis raises two central considerations for water policy. The first relates to river basin planning. In contexts where informal and indirect transfer processes are significant, controlling the flow of water between sectors using institutional mechanisms is challenging. The second relates to contextualising water transfer impacts in terms of wider changes in river basins, and the implications for the setting compensation.

River basin allocation planning is predicated on the assumption that water can be controlled through institutional mechanisms and infrastructure. For highly-regulated, water-mature economies, this may be a reasonable assumption, however two factors make controlling the movement of water between sectors challenging. The first relates to urban settings where informal water use is high. In these circumstances, the decentralised nature of informal supply systems means that controlling resource use is difficult. For example, informal water transfers from agricultural to urban sectors in cities similar to Hyderabad and Chennai result from the aggregate effect of the actions of a large number of private actors (Srinivasan et al., 2013). These are the individual households pumping groundwater in their homes or purchasing water from tankers. Moreover, many informal water flow pathways are based on groundwater abstraction, which, in India and large parts of China, remains highly unregulated (Cullet, 2014). Thus it is difficult to separate questions of water allocation and transfer from groundwater governance.

The second factor affecting river basin planning is the interrelationship between sectoral water use and land. In Chapter 5, this is explored through indirect water transfers. Together, land-use change and informal water use present issues of control for river basin allocation planning. Thus, water allocation should be conducted alongside land-use and urban planning, as well as broader social and environmental plans as advocated elsewhere in the literate (see for example, Speed et al. (2013)).

A further policy implication of the research in this thesis, relates to the setting of compensation[29] for agricultural producers facing the prospect of reduced irrigation water. The difficulty arises because urbanisation and agricultural modernisation alter the context in which agricultural production occurs. For example, Chapter 6 illustrates

[29] Note that in the Indian context, farmers are not compensated for losses of irrigation water resulting from agricultural-to-urban water transfers. Compensation is only available if irrigation supplies are reduced after the start of a crop season (Interview, PWD, 2013).

how the impacts of water transfers are modified by both urbanisation (famers increasingly engage in off-farm employment) and policies to improve the productivity of agriculture. Therefore, not only is it difficult to estimate water transfer impacts, but it is also difficult to contextualise potential losses against the range of other stressors experienced by farmers in water-donating areas. In relatively stable river basin contexts, transfer processes and impacts can be effectively assessed using conventional approaches based on institutional mechanisms and economics. For transfers occurring in rapidly urbanising and modernising river basins, a broader, more interdisciplinary form of assessment is required, and these also need to be interpreted with respect to wider changes experienced by farmers.

8.5 Recommendations for Further Research

This section presents several areas for further research. These relate to the role of non-policy determinants of the movement of water between sectors; the extension of the typologies presented in Chapter 5; greater emphasis on understanding the hydrological impact of urbanisation on river basins; and research to address the gaps in the evidence highlighted by the systematic map in Chapter 2.

This thesis has used the example of urbanisation to show how transfer processes and impacts at different scales are affected by factors beyond water policy and its institutional mechanisms. However, the river basins of countries similar to India and China are not only experiencing rapid economic development and urbanisation, but also widespread change in their agricultural sectors. Agricultural transformation and modernisation will also have significant impacts on sectoral water use. For example, China's agricultural sectoral withdraws have declined by 20% per hectare since 1990 (Doczi et al., 2014). While improvements to agricultural productivity are receiving increased attention in the wider literature (Scheierling et al., 2014, Lankford, 2012), the links to agricultural-to-urban water transfers remain underdeveloped and there are relatively few examples in the literature (see Loeve et al. (2007) as an exception). Thus, relevant further research should be undertaken on the relationships between urbanisation, transfers, and ensuing impacts on agricultural water productivity in water-donating regions.

A second area of further research is to expand and test the typologies linking urban attributes and water transfer processes presented in Chapter 5. Currently, the typologies are populated using data from only three empirical studies and one literature study of Los Angeles. Adding more cases to the typology would aid the isolation of causal relationships and help to elucidate the links between urban water governance, planning, and informal and indirect forms of water transfer. As the typology currently stands, with few case examples, its ability to infer water transfer scenarios is limited.

A third further research area relates to the relationship between urbanisation and water resources. Hydrological models of how urbanising areas obtain water are normally based on data from government departments, such as bulk surface water transfers, and the data generated by urban water utilities. But in many of the Global South's growing towns and cities, water services are dominated by informal service providers (Ahlers et al., 2014), operating in zones where the centralised water network is either absent or unreliable. In these data poor contexts, quantifying urban water flows is fraught with uncertainty. Hence more information and evidence on urban groundwater abstraction, recharge within urban boundaries, and urban water demand would enable the research community to better understand the volumetric significance of informal and indirect modes of water transfer.

In light of the above, the thesis advocates greater emphasis on the collection of hydrological data to support the analysis of agricultural-urban water transfers. Furthermore, this would aid the analysis of how urbanisation affects basin water resources. An improved understanding of the hydrological aspects of water transfers would also aid the analysis of the links between water transfers, urbanisation, and climate variability. This is particularly relevant for emerging research and theorisation surrounding the need for flexible allocation and transfer policies. See for example, Hellegers and Leflaive (2015) and Speed et al. (2013).

The final area for further research relates to the evidence gaps highlighted in the systematic map in Chapter 2. While it has been previously been noted that the agricultural-to-urban water transfer literature is unduly weighted towards water markets and the United States (Celio, 2009, Molle and Berkoff, 2009), the systematic map revealed additional research gaps. These relate to the geographic scope of the research base, the framing of transfers in research analysis, and the type of research design. For example, the map showed that many of the world's water scarce river basins are underrepresented in the English language agricultural-to-urban water transfer literature. These include the Indus Basin, the Jordan, and many of the river basins in central Asia. Furthermore, there is a need for research designs that examine transfers in the context of the wider river basin and use approaches beyond single case studies.

8.6 Original Contributions

This thesis offers several modest original contributions arising from the examination of agricultural-to-urban water transfers. Methodological contributions arise from the use of the systematic mapping and stepwise comparative methods in the study of agricultural-to-urban water transfers. For example, to date, no other study has applied the systematic mapping method to the agricultural-to-urban water transfer literature. Equally, while individual single case studies of water transfers have been conducted at each of these case sites, this is the first study to compare their similarities and differences regarding transfer processes and impacts with a view to theory development. From this research, new insights about processes of water transfers to these cities emerge. Theoretical contributions relate the development of a revised framework theorising how growing urban areas increase their water share. This framework emphasises the importance of examining urban attributes and their influence on processes of water transfers.

8.7 Conclusions

The task of reconciling competing demands for water between sectors is made more difficult by the effects of urbanisation, which draws water and people out of agriculture, and drives socioeconomic change. Decision-makers, faced with rising demand for food in urbanising river basins, therefore, require robust tools to analyse how water moves between sectors, the scale of transfer impacts, and to identify the groups to whom impacts accrue. Yet much of the research available on agricultural-to-urban water transfers provides an incomplete account of how towns and cities obtain water in the context of closing, rapidly urbanising river basins.

Consequently, this thesis calls for agricultural-to-urban water transfer research that looks beyond institutional mechanisms and explicitly acknowledges the role of urban attributes in influencing how cities gain water share. This includes analysis of the indirect ways that urbanisation affects the agricultural sector, as demonstrated by the complex interlinkages between urbanisation, water, and agriculture observed in Hyderabad, Coimbatore, and Kaifeng. Emphasising the role of 'the urban' in agricultural-to-urban water transfers, and analysing this issue at the appropriate scale, would allow allocation decision-making to be based on a more informed understanding of water transfers and how they are mediated by their river basin contexts.

Appendix: Systematic Map

Author	Reference	Year	Journal	Country	Water Source	Focus	Water Reallocation Mechanism	Data and Research Design	Methods Reporting	Research Questions or Objectives Stated	Design	Baseline Established	Report on Selection Framework for Case Study	Limitations/Assumptions of Study Discussed
Bao, C (Bao, Chao)1; Fang, CL (Fang, Chuang-lin)1	Water Resources Flows Related to Urbanization in China: Challenges and Perspectives for Water Management and Urban Development	2012	Water Resources Management	China	Not Stated	Impact on Donor Area; System Level	Formal Market	Secondary	Not Described	FALSE	Other	FALSE	FALSE	FALSE
Barajas, I.A.,	Interregional transfer of water in Northeastern Mexico: The dispute over El Cuchillo.	1999	Natural Resources Journal	Mexico	Surface water	Transfer Mechanism; City; System Level	Administrative	Primary	Not Described	FALSE	Single Case	FALSE	FALSE	FALSE
Bhattarai, M.; Pant, D. and Molden, D. AND Bhattarai, M and Pant, D	Socio-economics and hydrological impacts of melamchi intersectoral and interbasin water transfer project, Nepal. Water Policy 7(2): 163-180 AND Local Water Management Institutions and the Bulk Intersectoral Water Transfer: A Case Study of the Melamchi Water Transfer Project in Nepal	2005 & 2004	Water Policy	Nepal	Surface water	Impact on Donor Area; Transfer Mechanism	Administrative	Primary	Partial	TRUE	Single Case	FALSE	FALSE	FALSE
Brewer, J., Glennon, R., Ker, A., Libecap, G.,	Water Markets: Western Water Transfers from Agriculture to Urban Uses, 1987-2005	2006	International Society for New Institutional Economics	United States	Both	Transfer Mechanism	Formal Market	Secondary	Full Description	TRUE	Large N	FALSE	FALSE	TRUE
Byrnes, J., L. Crase, et al.	Water options contracts to facilitate intersectoral trade.	2008	Sustainable Irrigation Management	Australia	Not Stated	Impact on Donor Area; Transfer Mechanism	Formal Market	Secondary	Full Description	TRUE	Single Case	FALSE	FALSE	TRUE
Celio, M., C. A. Scott, et al. AND Celio, M. and M. Giordano	Urban-agricultural water appropriation: The Hyderabad, India case." AND "Agriculture-urban water transfers: a case study of Hyderabad, South-India." Paddy and Water Environment	2010 & 2007	Geographical Journal AND Paddy and Water Environment	India	Surface water	Impact on Donor Area; Transfer Mechanism; City	Administrative	Primary	Partial	TRUE	Single Case	TRUE	FALSE	TRUE
Chang, Chan and Ronald C. Griffin	Water Marketing as a Reallocative Institution in Texas	1992	Water Resources Research	United States	Surface water	Impact on Donor Area; Transfer Mechanism; City	Formal Market	Primary	Partial	TRUE	Single Case	FALSE	TRUE	TRUE
Charney, Alberta H. and Gary C. Woodard	Socioeconomic impacts of water farming on rural areas of origin in Arizona	1990	American Agricultural Economics Association	United States	Both	Impact on Donor Area	Formal Market	Primary	Partial	FALSE	Single Case	FALSE	TRUE	TRUE
Chiueh, Y. W.	The price elasticity of transferring agricultural water to industrial water during non-drought period in Taiwan.	2012	Paddy and Water Environment	Taiwan	Both	Transfer Mechanism; Other	Formal Market	Primary	Full Description	TRUE	Other	FALSE	FALSE	FALSE
Colby, B.G.	Transactions costs and efficiency in Western water allocation	1990	American Journal of Agricultural Economics	United States	Not Stated	Transfer Mechanism	Formal Market	Primary	Full Description	TRUE	Comparative	FALSE	FALSE	TRUE
Crase, L., B. Dollery, et al.	An intersectoral comparison of Australian water reforms	2008	Water Policy	Australia	Surface water	Transfer Mechanism	Formal Market	Secondary	Not Described	TRUE	Comparative	FALSE	FALSE	FALSE
de Leeann, M., S. Landfair, et al.	Water right prices in the Rio Grande: Analysis and policy implications.	2011	International Journal of Water Resources Development	United States	Ground water	Transfer Mechanism	Formal Market	Primary	Full Description	TRUE	Other	FALSE	FALSE	TRUE
DeWalt, D.	Rural To Urban Water Transfers In Arizona: An Economic Analysis	1987		United States	Both	Impact on Donor Area; Transfer Mechanism	Formal Market	Secondary	Partial	TRUE	Single Case	FALSE	FALSE	TRUE
Diaz-Caravantes, R. E.	Balancing Urban and Peri-Urban Exchange: Rural Livelihoods in Mexico	2012	The Geographical Journal	Mexico	Both	Impact on Donor Area; System Level	Administrative	Primary	Full Description	TRUE	Single Case	FALSE	TRUE	FALSE
Díaz-Caravantes,R. E., and Sánchez-Flores, E.	Water transfer effects on peri-urban land use/land cover: A case study in a semi-arid region of Mexico	2011	Applied Geography	Mexico	Both	Impact on Donor Area	Land-Use Change	Primary	Full Description	TRUE	Single Case	FALSE	TRUE	FALSE

Author	Reference	Year	Journal	Country	Water Source	Focus	Water Reallocation Mechanism	Data and Research Design	Methods Reporting	Research Questions or Objectives Stated	Design	Baseline Established	Report on Selection Framework for Case Study	Limitations/Assumptions of Study Discussed
Dudley, S. C.	From growing crops to growing cities: SRP's transition from ag to urban.	2009	Irrigation and Drainage	United States	Both	Other	Land-Use Change	Secondary	Partial	FALSE	Single Case	FALSE	FALSE	FALSE
Eden, S., Glennon, R., Ker, A., Libecap, G., Megdal, S., Shipman, T.,	Agricultural Water to Municipal Use: The Legal and Institutional Context for Voluntary Transactions in Arizona.	2008	Envirotech Publications	United States	Both	Transfer Mechanism	Formal Market	Primary	Full Description	TRUE	Single Case	FALSE	FALSE	TRUE
Feldman, David L.	Preventing the repetition: Or, what Los Angeles' experience in water management can teach Atlanta about urban water disputes	2009	WATER RESOURCES RESEARCH	United States	Both	Transfer Mechanism; City	Formal Market	Secondary	Not Described	TRUE	Comparative	FALSE	FALSE	FALSE
Frisvold, G., and Emerick, K.,	Rural-Urban Water Transfers in the U.S.-Mexico Border Region	2005		United States	Not Stated	Transfer Mechanism	Formal Market	Secondary	Full Description	TRUE	Other	TRUE	FALSE	FALSE
Fullerton Jr, T. M.	Water transfers in El Paso County, Texas.	2006	Water Policy	United States	Surface water	Transfer Mechanism	Formal Market	Secondary	Not Described	FALSE	Single Case	FALSE	FALSE	FALSE
Gardner, R. L.	The Impacts And Efficiency Of Agriculture-To-Urban Water Transfers - Discussion.	1990	American Journal of Agricultural Economics	United States	Not Stated	Transfer Mechanism	Formal Market	Expert Opinion	Not Described	FALSE	Other	FALSE	FALSE	FALSE
George, B., H. Malano, et al.	An integrated hydro-economic modelling framework to evaluate water allocation strategies I: Model development. Agricultural Water Management 98 AND An integrated hydro-economic modelling framework to evaluate water allocation strategies II: Scenario assessment.	2011	Agricultural Water Management	India	Both	Other	Administrative	Secondary	Full Description	TRUE	Single Case	TRUE	FALSE	TRUE
Hearne, R. R.	Water markets as a mechanism for intersectoral water transfers: the Elqui Basin in Chile	2007	Paddy and Water Environment	Chile	Surface water	City; Other	Formal Market	Primary	Not Described	FALSE	Single Case	FALSE	TRUE	FALSE
Heinz, I., M. Salgot, et al.	Evaluating the costs and benefits of water reuse and exchange projects involving cities and farmers." Water International 36 AND Water reclamation and intersectoral water transfer between agriculture and cities - a FAO economic wastewater study. Water Science and Technology 63	2011	Water International	Multi-Country or Theoretical	Both	Impact on Donor Area; System Level; Other	Formal Market	Secondary	Partial	TRUE	Comparative	FALSE	FALSE	FALSE
Howe C.W., J.K. Lazo, and K.R. Weber	The Economic Impacts of Agriculture to Urban Water Transfers on the Area of Origin: A Case Study of the Arkansas River Valley in Colorado	1990	American Agricultural Economics Association	United States	Not Stated	Impact on Donor Area	Formal Market	Primary	Full Description	TRUE	Single Case	TRUE	TRUE	TRUE
Howe, C. W. and C. Goemans	Water Transfers And Their Impacts: Lessons From Three Colorado Water Markets	2003	JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION	United States	Not Stated	Impact on Donor Area; Transfer Mechanism	Formal Market	Secondary	Partial	TRUE	Comparative	FALSE	TRUE	FALSE
Huang, C. C., M. H. Tsai, et al.	Experiences of water transfer from the agricultural to the non-agricultural sector in Taiwan	2007	Paddy and Water Environment	Taiwan	Surface water	Transfer Mechanism	Administrative	Secondary	Not Described	FALSE	Comparative	FALSE	FALSE	FALSE
Huang, J., B. G. Ridoutt, et al.	Cropping Pattern Modifications Change Water Resource Demands in the Beijing Metropolitan Area.	2012	Journal of Integrative Agriculture	China	Both	Impact on Donor Area	Administrative	Primary	Full Description	TRUE	Single Case	FALSE	TRUE	TRUE
Jiang, Y., Y. Luo, et al.	Agricultural water transfers in China: Current issues and perspectives.	2012	Procedia Engineering	China	Not Stated	Impact on Donor Area; Transfer Mechanism; Other	Formal Market	Expert Opinion	Not Described	FALSE	Other	FALSE	FALSE	FALSE
Karimi, A. and R. Ardakanian	Development of a Dynamic Long-Term Water Allocation Model for Agriculture and Industry Water Demands.	2010	Water Resources Management	Iran	Both	System Level	#N/A	Scenario Modelling / Hypothetical Case	Full Description	TRUE	Other	TRUE	FALSE	TRUE
Kendy et al.	Can urbanization solve inter-sector water conflicts? Insight from a case study in Hebei Province, North China Plain	2007	Water Policy	China	Both	System Level; Other	Land-Use Change	Primary	Not Described	TRUE	Single Case	FALSE	TRUE	FALSE

Author	Reference	Year	Journal	Country	Water Source	Focus	Water Reallocation Mechanism	Data and Research Design	Methods Reporting	Research Questions or Objectives Stated	Design	Baseline Established	Report on Selection Framework for Case Study	Limitations/Assumptions of Study Discussed
Klein-Robbenhaar, J. F.	Balancing efficiency with equity: Determining the public welfare in surface water transfers from Acequia communities.	1996	Natural Resources Journal	United States	Surface water	Impact on Donor Area; Transfer Mechanism	Formal Market	Secondary	Not Described	TRUE	Single Case	FALSE	TRUE	FALSE
Komakech, H. C., P. Van der Zaag, et al.	The last will be first: Water transfers from agriculture to cities in the Pangani River Basin, Tanzania.	2012	Water Alternatives	Tanzania	Surface water	Transfer Mechanism; Other	Administrative	Primary	Full Description	TRUE	Comparative	FALSE	TRUE	FALSE
Leidner, A. J., M. E. Rister, et al.	The water market for the middle and lower portions of the Texas rio grande basin.	2011	JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION	United States	Surface water	Transfer Mechanism	Formal Market	Secondary	Partial	TRUE	Single Case	FALSE	TRUE	FALSE
Levine, G.	The Lerma-Chapala river basin: a case study of water transfer in a closed basin	2007	Paddy Water and Environment	Mexico	Both	Impact on Donor Area; Transfer Mechanism	Administrative	Primary	Not Described	FALSE	Single Case	FALSE	FALSE	FALSE
Levine, G.	The Lower Rio Grande Valley: a case study of a water market area	2007	Paddy and Water Environment	United States	Surface water	Transfer Mechanism	Formal Market	Expert Opinion	Not Described	FALSE	Single Case	FALSE	FALSE	FALSE
Levine, Gilbert Barker, Randolph Huang, Cheng	Water transfer from agriculture to urban uses: lessons learned, with policy considerations	2007	Paddy and Water Environment	Multi-Country or Theoretical	Surface water	Transfer Mechanism	Formal Market	Secondary	Full Description	TRUE	Comparative	FALSE	FALSE	FALSE
Libecap, G. D.	Chinatown: Owens Valley and western water reallocation-getting the record straight and what it means for water markets	2005	Texas Law Review	United States	Both	Impact on Donor Area; Transfer Mechanism; City	Formal Market	Secondary	Partial	TRUE	Single Case	TRUE	TRUE	FALSE
Loeve, R., Dong, B. et al.	Transferring water from irrigation to higher valued uses: a case study of the Zhanghe irrigation system in China	2007	Paddy and Water Environment	China	Surface water	Impact on Donor Area; Other	Administrative	Primary	Partial	TRUE	Single Case	FALSE	FALSE	FALSE
Loeve, R.; Hong, L.; Dong, B.; Mao, G. and Chen, C.D.	Long-term trends in intersectoral water allocation and crop water productivity in Zhanghe and Kaifeng, China. Paddy and Water Environment 2(4): 237-245.	2004	Paddy and Water Environment	China	Both	Impact on Donor Area	#N/A	Secondary	Partial	TRUE	Comparative	FALSE	FALSE	TRUE
Lucero, L. and A. Dan Tarlock	Water supply and urban growth in New Mexico: same old, same old or a new era	2003	Natural Resources Journal	United States	Both	Other	Formal Market	Expert Opinion	Not Described	TRUE	Single Case	FALSE	TRUE	FALSE
Matsuno, Y., Hatcho, N., Shindo, S.,	Water transfer from agriculture to urban domestic users: a case study of the Tone River Basin, Japan	2007	Paddy and Water Environment	Japan	Ground water	Transfer Mechanism	Administrative	Secondary	Not Described	FALSE	Comparative	FALSE	FALSE	FALSE
McEntire, J.	Water farms and transfer conflicts in Arizona, USA: A proposed resolution process	1989	Environmental Management	United States	Ground water	Transfer Mechanism; Other	Formal Market	Expert Opinion	Not Described	TRUE	Single Case	FALSE	FALSE	FALSE
Mcmahon, T.G. and Smith, M.G.	The Arkansas Valley "Super Ditch"- An Analysis of Potential Economic Impacts	2013	Journal of the American Water Resources Association	United States	Surface water	Impact on Donor Area; Transfer Mechanism	Formal Market	Secondary	Full Description	TRUE	Single Case	FALSE	TRUE	TRUE
Meinzen-Dick, Ruth and Ringler, Claudia	Water Reallocation: Drivers, Challenges, Threats, and Solutions for the Poor	2008	Journal of Human Development	Multi-Country or Theoretical	Both	Impact on Donor Area; Transfer Mechanism	Formal Market	Literature Review	Not Described	FALSE	Literature Review	FALSE	FALSE	FALSE
Merrett, S.	The urban market for farmers' water rights.	2003	Irrigation and Drainage	Multi-Country or Theoretical	Both	Transfer Mechanism	Formal Market	Scenario Modelling / Hypothetical Case	Not Described	TRUE	Other	FALSE	FALSE	FALSE
Michelsen, A.M., Young, R.A.,	Optioning agricultural water rights for urban water supplies during drought.	1993	American Journal of Agricultural Economics	United States	Not Stated	Transfer Mechanism	Formal Market	Scenario Modelling /	Full Description	TRUE	Single Case	FALSE	TRUE	TRUE

Author	Reference	Year	Journal	Country	Water Source	Focus	Water Reallocation Mechanism	Data and Research Design	Methods Reporting	Research Questions or Objectives Stated	Design	Baseline Established	Report on Selection Framework for Case Study	Limitations/Assumptions of Study Discussed
								Hypothetical Case						
Molden, D.	Water responses to urbanization	2007	Paddy and Water Environment	Multi-Country or Theoretical	Both	Impact on Donor Area; Transfer Mechanism; City; System Level	Formal Market	Expert Opinion	Full Description	FALSE	Other	FALSE	FALSE	FALSE
Molle, F. and J. Berkoff	Cities vs. agriculture: A review of intersectoral water re-allocation	2009	Natural Resources Forum	Multi-Country or Theoretical	Both	Impact on Donor Area; Transfer Mechanism; City; System Level; Other	Formal Market	Literature Review	Full Description	TRUE	Literature Review	FALSE	FALSE	FALSE
Nakat, A.C., Turner, C.D	Water use and transfer scenarios in El Paso County, Texas, USA	2004	Water International	United States	Both	Other	Formal Market	Scenario Modelling / Hypothetical Case	Full Description	TRUE	Single Case	FALSE	FALSE	TRUE
Nunn, S. C.	Developing city water supplies by drying up farms: Contradictions raised in water institutions under stress." Agriculture and Human Values 4	1987	Agriculture and Human Values	United States	Both	Impact on Donor Area	Formal Market	Expert Opinion	Not Described	TRUE	Comparative	FALSE	FALSE	FALSE
Nunn, S. C. and Ingram, H.	Information, the decision forum, and third-party effects in water transfers	1988	Water Resources Research	United States	Both	Impact on Donor Area; Transfer Mechanism	Formal Market	Expert Opinion	Not Described	TRUE	Comparative	FALSE	FALSE	FALSE
Packialakshmi, S., N. K Ambujam, et al.	. "Groundwater market and its implications on water resources and agriculture in the southern peri-urban interface, Chennai, India." Environment, Development and Sustainability 13	2011	Environment, Development and Sustainability	India	Ground water	Impact on Donor Area; Transfer Mechanism	Informal Market	Primary	Partial	TRUE	Single Case	FALSE	TRUE	FALSE
Prtichard, A. and Scott, C.	Interbasin water transfers at the US–Mexico border city of Nogales, Sonora: implications for aquifers and water security	2013	Water Policy	Multi-Country or Theoretical	Both	Impact on Donor Area; Transfer Mechanism; City; System Level	Administrati ve	Primary	Full Description	TRUE	Single Case	TRUE	FALSE	TRUE
Ramos, A. G. and A. Garrido	Formal risk-transfer mechanisms for allocating uncertain water resources: The case of option contracts	2004	Water Resources Research	Spain	Surface water	Impact on Donor Area; Transfer Mechanism	Formal Market	Secondary	Full Description	TRUE	Single Case	TRUE	TRUE	TRUE
Riaz, K.	Tackling the issue of rural–urban water transfers in the Ta'iz region, Yemen	2002	Natural Resources Forum	Yemen	Ground water	Transfer Mechanism; Other	Formal Market	Expert Opinion	Not Described	TRUE	Single Case	FALSE	FALSE	FALSE
Richter et al	Tapped out: how can cities secure their water future?	2013	Water Policy	Multi-Country or Theoretical	Both	City	Formal Market	Secondary	Not Described	TRUE	Comparative	FALSE	TRUE	FALSE
Rosegrant, M. W. and C. Ringler	Impact on food security and rural development of transferring water out of agriculture."	2000	Water Policy	Multi-Country or Theoretical	Both	Impact on Donor Area; Transfer Mechanism	Formal Market	Literature Review	Not Described	TRUE	Literature Review	FALSE	FALSE	FALSE
Ruet, J., M. Gambiez, et al.	Private appropriation of resource: Impact of peri-urban farmers selling water to Chennai Metropolitan Water Board	2007	Cities	India	Ground water	Impact on Donor Area; Transfer Mechanism; City	Informal Market	Primary	Partial	TRUE	Single Case	FALSE	FALSE	FALSE
SAJOR, E., AND ONGSAKUL, R.	Mixed Land Use and Equity in Water Governance in Peri-Urban Bangkok	2007	International Journal of Urban and Regional Research	Thailand	Surface water	Impact on Donor Area; Transfer Mechanism; City; System Level	Land-Use Change	Primary	Full Description	TRUE	Single Case	FALSE	TRUE	FALSE
Schupe, S. J., Weatherford, G. D. & Checchio, E.	Westem Water Rights: The Era of Reallocation	1989	Natural Resources Journal	United States	Both	Impact on Donor Area; Transfer Mechanism	Formal Market	Expert Opinion	Not Described	TRUE	Other	FALSE	FALSE	FALSE
Scott, C. A. and N. P. Pablos	Innovating resource regimes: Water, wastewater, and the institutional dynamics of urban hydraulic reach in northwest Mexico.	2011	Geoforum	Mexico	Both	Impact on Donor Area; Transfer Mechanism; City; System Level; Other	Informal Market	Primary	Partial	TRUE	Single Case	FALSE	TRUE	FALSE

Author	Reference	Year	Journal	Country	Water Source	Focus	Water Reallocation Mechanism	Data and Research Design	Methods Reporting	Research Questions or Objectives Stated	Design	Baseline Established	Report on Selection Framework for Case Study	Limitations/Assumptions of Study Discussed
Scott, C., F. Flores-López, et al.	Appropriation of Río San Juan water by Monterrey City, Mexico: implications for agriculture and basin water sharing	2007	Paddy Water and Environment	Mexico	Surface water	Impact on Donor Area; Transfer Mechanism; City; System Level	Administrative	Secondary	Partial	FALSE	Single Case	FALSE	FALSE	FALSE
Shively, D. D.	Water right reallocation in New Mexico's Rio Grande Basin, 1975-1995."	2001	International Journal of Water Resources Development	United States	Both	Transfer Mechanism	Formal Market	Secondary	Full Description	TRUE	Other	FALSE	FALSE	TRUE
Solis, P.	Water as rural heritage: reworking modernity through resource conflict in Edwards County, Kansas	2005	Journal of Rural Studies	United States	Surface water	Impact on Donor Area	Formal Market	Primary	Partial	TRUE	Single Case	TRUE	TRUE	TRUE
Squillace, M.	Water Transfers for a Changing Climate	2013	Working Paper, University of Colorado Law School	United States	Both	Transfer Mechanism	Formal Market	Secondary	Full Description	FALSE	Other	FALSE	FALSE	FALSE
Srinivasan, V., K. C. Seto, et al.	The impact of urbanization on water vulnerability: A coupled human-environment system approach for Chennai, India.	2013	Global Environmental Change	India	Ground water	Transfer Mechanism; City; System Level; Other	Informal Market	Primary	Full Description	TRUE	Single Case	TRUE	FALSE	FALSE
Strauss, S	Water Conflicts among Different User Groups in South Bali, Indonesia.	2011	Journal of Human Ecology	Bali	Both	Impact on Donor Area; Other	Land-Use Change	Primary	Full Description	TRUE	Single Case	FALSE	TRUE	TRUE
Sun, R., M. Jin, et al.	Urban and rural groundwater use in Zhengzhou, China: Challenges in joint management	2009	Hydrogeology Journal	China	Ground water	Impact on Donor Area; Transfer Mechanism; City	Administrative	Primary	Full Description	TRUE	Single Case	TRUE	FALSE	FALSE
Tan, Y. C. Lai, J. S. Adhikari, K. R. Lu, A. Y.	Who benefits from allocating agricultural water to other sectors in Taiwan?	2009	Irrigation and Drainage	Taiwan	Both	Impact on Donor Area; Other	Land-Use Change	Secondary	Not Described	FALSE	Single Case	FALSE	FALSE	FALSE
Taylor, R. and R. Young	Rural-to-Urban Water Transfers: Measuring Direct Foregone Benefits of Irrigation Water under Uncertain Water Supplies." Journal of Agricultural and Resource Economics 20	1995	Journal of Agricultural and Resource Economics	United States	Surface water	Impact on Donor Area; Other	Formal Market	Secondary	Partial	FALSE	Single Case	TRUE	FALSE	TRUE
Van Rooijen, D. J., H. Turral, et al.	Sponge city: Water balance of mega-city water use and wastewater use in Hyderabad, India	2005	Irrigation and Drainage	India	Both	System Level	Administrative	Secondary	Full Description	TRUE	Single Case	FALSE	FALSE	TRUE
Wagle, S.; Warghade, S. and Sathe, M.	Exploiting policy obscurity for legalising water grabbing in the era of economic reform: The case of Maharashtra, India.	2012	Water Alternatives	India	Surface water	Transfer Mechanism	Formal Market	Primary	Not Described	TRUE	Comparative	FALSE	FALSE	FALSE
Wang, Y.	A simulation of water markets with transaction costs	2012	Agricultural Water Management	China	Surface water	Transfer Mechanism	Formal Market	Scenario Modelling / Hypothetical Case	Full Description	TRUE	Single Case	TRUE	FALSE	TRUE
Whited, M.	Economic Impacts of irrigation water transfers on Uvalde County, Texas	2010	Journal of Regional Analysis & Policy	United States	Ground water	Impact on Donor Area	Formal Market	Scenario Modelling / Hypothetical Case	Full Description	TRUE	Single Case	TRUE	FALSE	TRUE
Whittlesey, N.	The Impacts and Efficiency of Agriculture-to-Urban Water Transfer: Discussion	1990	American Agricultural Economics Association	United States	Not Stated	Impact on Donor Area; Transfer Mechanism	Formal Market	Expert Opinion	Not Described	TRUE	Other	FALSE	FALSE	FALSE
Wu, Wenyong; Di, Suchuang; Chen, Qianheng; et al.	The compensation Mechanism and Water Quality Impacts of Agriculture-Urban Water Transfers: A Case Study in China's Chaobai Watershed	2013	Water Resources Management	China	Not Stated	Impact on Donor Area	Administrative	Primary	Full Description	TRUE	Single Case	FALSE	FALSE	FALSE

Author	Reference	Year	Journal	Country	Water Source	Focus	Water Reallocation Mechanism	Data and Research Design	Methods Reporting	Research Questions or Objectives Stated	Design	Baseline Established	Report on Selection Framework for Case Study	Limitations/Assumptions of Study Discussed
Zhang, J. L.	Barriers to water markets in the Heihe River basin in northwest China	2007	Agricultural Water Management	China	Both	Transfer Mechanism	Formal Market	Primary	Full Description	TRUE	Single Case	FALSE	TRUE	TRUE
Zheng, H., Z. Wang, et al.	A Water Rights Constitution for Hangjin Irrigation District, Inner Mongolia, China	2009	International Journal of Water Resources Development	China	Surface water	Transfer Mechanism	Formal Market	Primary	Partial	FALSE	Single Case	FALSE	FALSE	FALSE
Zhou, Y., Y. Zhang, et al.	Economic impacts on farm households due to water reallocation in China's Chaobai watershed	2009	Agricultural Water Management	China	Surface water	Impact on Donor Area	Land-Use Change	Primary	Full Description	TRUE	Other	FALSE	FALSE	TRUE

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