

Article

Can Tanker Water Services Contribute to Sustainable Access to Water? A Systematic Review of Case Studies in Urban Areas

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Abstract: Tanker water markets (TWM) supply water services in many urban areas, including those unconnected to public infrastructures. Notwithstanding, they have been associated with outcomes in conflict with sustainability goals of water policy, e.g., through inequitable and unaffordable supply or by contributing to groundwater overexploitation. So far, the literature dedicated to TWM has primarily conducted case studies embedded in diverse local contexts, which impedes the comparison and transfer of insights. In this article, we systematically summarize existing empirical knowledge on TWM and assess to what extent normative claims about the impacts of TWM on sustainability goals are supported by evidence. We use the concept of sustainable access, which combines notions of what constitutes access to water and what characterizes sustainable supply of services. The available evidence suggests that TWM have two key functions in urban water systems: (1) They provide services at otherwise unavailable levels, particularly with respect to the temporal availability and spatial accessibility of the service, and (2) they extend access to areas without or with low-quality network supply, typically low-income communities on the fringe of cities. From the perspective of sustainable access, we find that TWM can provide high service levels and thus fill a specific gap in the landscape of urban water services. Due to comparatively high prices, however, it is unlikely that these services are affordable for all. The combination of heterogeneous access to cheaper (subsidized) piped water and marginal pricing in TWM results in allocation outcomes that are not coherent with existing notions of equitable access to water. However, there is little convincing evidence that TWM necessarily result in unsustainable water use. The literature indicates that urban water governance in the studied areas is frequently characterized by a lack of effective institutions, which impedes the regulation or formalization of TWM.

Keywords: tanker water; water markets; informal water vendors; sustainable access to water



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1. Introduction

Cities around the globe have been and continue to grow at a rapid pace, fueled by population growth and migration from rural areas. In many cases, water-provision infrastructure in the form of piped networks fails to keep up with the pace of urbanization and increasing demands for water quantities, e.g., [1,2], resulting in unconnected areas, intermittent supply, and water-quality issues. To fill this gap, urban water users across low- and middle-income countries frequently obtain water services through self-supply and market water services [3,4]. In the past two decades, the literature has dedicated increasing attention to the latter, which are usually referred to as “small-scale private service providers” [5], “small water enterprises” [6], or “informal water vendors” [7]. Under the umbrella of these terms, diverse types of water services are discussed, ranging from stationary supply through water kiosks or small decentralized networks to “mobile” [8] or “distributing” [9] vendors delivering water with pushcarts, motorcycles, and tanker trucks.

Numerous case studies as well as a number of meta-studies and edited volumes have been dedicated to urban market water services [5,6,10–13]. The literature has approached the topic with different foci, such as water provision for informal settlements [10] and the urban poor [7,11], or implications for policy targets such as the water-related Millennium and Sustainable Development Goals [12,14].

Tanker water markets (TWM) can be defined as a common form of market water service where (i) *private actors* transport (ii) *bulk water volumes* in trucks to sell these (iii) *at the location of their customer*. Analyses focused on TWM have thus far been conducted in case study format. These studies often describe how TWM function, ascertain price levels, deliver quantities [15], and assess to what extent tanker water services are relevant suppliers for urban water users [9,10]. Frequently, such analyses are combined with normative assessments and discuss the desirability of TWM in urban water supply systems, for example for affordable and equitable supply of water services [16] or long-term sustainable resource use [17]. Many studies conclude that tanker water markets currently make crucial contributions to enhancing access to water, because of a lack of viable alternatives [18]. Thus, TWM are frequently considered indispensable, at least in the short run. Notwithstanding this, a number of claims on negative implications for sustainability of these markets have been raised. A frequent critique is that tanker water services are too expensive and therefore result in affordability issues and inequality of access, particularly when low-income households end up paying higher per-unit prices [8,18]. Tanker water markets have also been associated with contributing to the depletion of groundwater aquifers [1] due to the unmonitored exploitation of resources. Finally, TWM have been associated with illegal activities such as corruption or water theft, including claims of “water mafias” [19].

So far, the insights retrieved in TWM case studies remain fragmented. Existing meta studies have reviewed the literature on private water vending [5,6,10–14]—for example, focusing on impacts of urban market water services on access [12] or the implementation of Target 6.1 of Agenda 2030 [14]. Although this has enriched our understanding of the large variety of existing water services in urban areas, an analysis *specific* to TWM has to our knowledge not been carried out. The characteristics of tanker water services, however, substantially differ from other water services, such as bottled water shops or small decentralized networks, for example, with respect to the availability or accessibility of the service. Therefore, such diverse forms of water services provision should be viewed as *heterogeneous* services [4]. By implication, it is necessary to study the specific impacts of TWM for access to water and the sustainability objectives of water policy [20]. This has, so far, not been done under a coherent framework. As a result, it is difficult to compare, transfer, or generalize learnings from individual studies. There are at least four reasons:

1. Individual case studies are often highly localized and the sustainability impacts of TWM strongly depend on the overall water provision system in place as well as the institutional landscape it is embedded in.
2. Studies of TWM have at times substantially different foci, influenced by the involvement of various disciplines, ranging from, among others, urban geography [21], to hydro-economics [22], to political science and governance studies [19], to biophysical assessments of water quality [23].
3. The frequently informal nature of TWM impedes the creation of a sound and comparable empirical basis because of the inherent interest of actors in shadow economy markets to conceal their activities [24].
4. Diverging concepts are used to support normative assessments of sustainability impacts. It is not always clear which benchmarks TWM are compared against and whether the criticism is based on a relevant alternative or an idealized supply situation.

As a result of the fragmented evidence on TWM, we lack a comprehensive understanding of why these markets exist, how they work, and what outcomes they produce, both for access to water and with respect to sustainability objectives. Existing knowledge needs to be consolidated and enhanced not only because TWM are highly relevant across many areas of the world. Drivers such as global climate change and population growth in areas shaped

by urban water scarcity will likely result in their continuing or increased relevance in the future, particularly because public investments in water supply infrastructures significantly fall behind required levels to accomplish access goals [25].

Thus, it seems fruitful to systematically analyze the existing literature on TWM to establish what is known about these markets and what gaps remain to be addressed in future research. In this article, we approach TWM from a sustainability perspective and ask which contributions tanker water markets can make to sustainable access to water [26,27], a concept that can accommodate two crucial objectives:

1. *Positive analysis:* **Access** to water is a key objective of water policy, expressed in Sustainable Development Goal (SDG) 6 [28] and the human right to water [29]. Access is usually understood as gradual, i.e., non-binary, and is shaped by the non-pecuniary dimensions of *spatial accessibility*, *temporal availability*, *water quality*, and *acceptability* (turbidity, taste, odor), as well as by the *price* of water services [30,31]. In our analysis, we assess the degree of access TWM reportedly bring about across the non-pecuniary dimensions of access by establishing the service level or characteristics of tanker water services [4] and comparing their prices to existing alternatives, particularly network water tariffs.
2. *Normative analysis:* In order to make a lasting impact, access has to be **sustainable** [26,27]. This includes balancing social concerns such as equitable and affordable supply with sustainable withdrawals of water resources as well as sufficient refinancing and economic efficiency of water services provision, from both a short-run and long-run perspective [20]. Using existing sustainability objectives of water policy and literature on what normative concepts such as *equitable* and *affordable* supply may entail, we assess to what extent available case studies can provide insights about the sustainability implications of TWM. Given that the balancing of different sustainability objectives hinges on functional and effective institutions [32], we also gather insights from the TWM literature about existing governance structures and challenges within TWM.

By narrowing the scope of this study to focus on TWM and sustainable access, we seek to contribute to the state of knowledge on this specific water service while avoiding general discussions on whether or which market actors should be involved in water supply [33,34]. Because of the variety of existing concepts, definitions, and methods applied in the TWM literature, we briefly establish key concepts in the next section. With a focus on market water services, we examine the following questions: How has access to water been conceptualized? When can access be considered *sustainable*? Subsequently, we establish how we identified relevant literature and which information we sought to retrieve from it (Section 3). In Section 4, we present our results. To contextualize the subsequent analysis, we first summarize existing evidence on the urban water supply systems in which TWM exist and describe how TWM function. We then distill from the reviewed literature (i) the degree of access to water TWM reportedly bring about and (ii) the conclusions with respect to sustainability impacts that are made by existing studies, including the conceptual basis on which these were drawn. In Section 5, we proceed to discuss whether TWM can contribute to sustainable access and which gaps remain for future conceptual and empirical work. Section 6 concludes.

2. Sustainability Impacts of Tanker Water Markets: Concepts of Sustainable Access

In the following, we first establish which conditions shape access to water, and then address normative conceptualizations of what makes access sustainable. Since a comprehensive discussion of both topics is beyond the scope of this article, we approach the overview from a perspective centered around *water services* to enable our subsequent analysis of TWM. This means that the concepts discussed below do not apply to mere water quantities but rather to the service of providing or making these available for consumers.

2.1. Service Levels and Access

As a result of extensive discussions on what a human right to water entails and how the Millennium and Sustainable Development Goals can be implemented, it has been established that access to water is multidimensional [31]. In particular, access is shaped by several key dimensions: the spatial accessibility, temporal availability, and affordability of the water service as well as the quality and acceptability of delivered water quantities [29,31]. The question of to what extent specific water services, such as those rendered in TWM, contribute to access is therefore not a binary “yes or no” question, but a gradient. Apart from the affordability of the service, which is a normative notion and addressed below in Section 2.2.1, all other dimensions of access relate to non-monetary aspects of services provision. Different water services are each associated with a vector of characteristics [4], defining the *service level*: The quality of water quantities delivered by a service provider may be high, for instance, whereas the spatial accessibility or temporal availability of the service are low(er). In other words, access depends heavily on the degree to which a service provider lowers different *access hurdles* [30], which have to be overcome to obtain water available for end uses. The lower the service level is, the higher the amount of remaining hurdles, which the water user needs to overcome themselves through expenditures of time, money, and effort, thereby generating “access” [4]. These efforts are referred to as “household co-production” of water services and do not constitute a problem per se. Instead, they are subject to the optimization of access conditions and relevant for the decisions of households when choosing among water services [4].

The *spatial accessibility* of a service refers to the (economic) effort associated with overcoming the distance between the point of service delivery and the location of the water user [35]. In case the service is provided outside of the residence, the terrain that needs to be crossed and safety along the way can also shape accessibility [36]. In General Comment No. 15 (GC15), which defines the human right to water, the United Nations Committee on Economic, Social and Cultural Rights [29] considers a service accessible if the point of delivery is located “within or in the immediate vicinity” (§ 12c) of the household. For Indicator 6.1.1 of Agenda 2030, the water source has to be “on premises” [37] (p. 10) to meet the access criteria.

The *temporal availability* of a water service, straightforwardly, describes the duration for which water services are supplied. In addition, it encompasses an aspect of quantity, because a low temporal availability of a service may constrict which water quantities can be obtained. This becomes particularly apparent in intermittent water supply systems, which supply piped water services to more than one billion people around the globe and are characterized by scheduled and un-scheduled interruptions of supply [38,39]. Under intermittent supply, many water users employ storage tanks to extend the availability of water quantities beyond the hours during which water services are available [3]. If the storage runs empty before the next phase of supply commences, a quantity restriction is imposed by the availability of service in combination with the storage capacity. Beyond the mere duration of supply, availability may also include the timing, flow rate and, perhaps, punctuality of service delivery [40]. The concept is therefore less straightforwardly operationalizable than spatial accessibility, which could explain why the wording in international policy goals is more ambiguous: For SDG 6, water services should be available “when needed” [28] (p. 36), whereas in GC15, availability implies a water supply that is of “sufficient” regularity for personal and domestic use [29] (§ 12a).

Water *quality* and *acceptability* are two closely connected characteristics of a water service and refer to the properties of supplied water quantities. Whereas acceptability is shaped by the turbidity, smell, and taste of water quantities, quality refers to the presence of biological and chemical hazards in the delivered water quantities. Both characteristics are to some extent physically measurable, but in practice also depend to a significant extent on social notions of purity, subjective perceptions, and preferences, as well as trust in the service provider, e.g., [41]. The question of quality and access is further complicated by the fact that water quantities can have very different uses, for which quality may or may not

be a concern [4]. A high degree of water quality may actually not be required for specific uses but might be associated with a higher price or tariff, or other non-pecuniary access hurdles. Thus, in many areas of the world, drinking and non-drinking water quantities are obtained from different water sources [42,43] and stored separately in the household [44]. The UN's and the WHO's quality requirements, however, merely relate to drinking water: SDG6 defines water quality sufficient for access if it is "free from contamination" [28] (p. 36), whereas the World Health Organization [45] focuses assessments on three major contaminants: fecal contaminants, fluoride, and arsenic.

2.2. Sustainability Objectives of Water Policy

Even if the conditions for access to water described so far can be defined in a satisfactory way and met at a specific point in time, this does not ensure that these conditions are permanent. Over time, freshwater availability may decrease as a result of climate change and population growth, or water services and infrastructures may not be sufficiently refinanced, leading to a deterioration of service levels. Similarly, social concerns, which are of key relevance in the provision of essential services, may not be balanced in an acceptable way. Therefore, policymakers, researchers, and water management practitioners have discussed under which conditions long-term or *sustainable access* to water can be guaranteed [26,27]. The Organization for Economic Co-operation and Development [20], for instance, has defined four sustainability dimensions of water policy, namely, (i) *environmental sustainability*, i.e., the long-term preservation of ecological functions and renewable resources; (ii) *financial sustainability*, the refinancing and long-term reproduction of physical infrastructures; (iii) *economic efficiency*, i.e., the allocation of water quantities to those uses that offer the highest value to society as a whole; and (iv) *social concerns*, mainly the affordability and equity of services provision. These objectives are mirrored to some extent in the targets of SDG 6: Target 6.1 calls for "universal and *equitable* access to safe and *affordable* drinking water for all," whereas other targets (6.3, 6.4) mandate reducing pollution and contamination of water bodies to "ensure sustainable withdrawals" and "substantially increase water-use efficiency" [28] (p. 27).

In Figure 1, we have mapped different formulations for these objectives onto the three pillars of sustainability to categorize the values or normative ideas underlying the formulation of international policy goals. Similar normative ideas surface across many related works in the literature on water management and policy—for example, on water security, integrated water resource management, and more [46–49]. Notwithstanding the seeming consensus on normative objectives for water policy, implementing these while balancing all dimensions is challenging in practice. Similar to other problems of sustainability, e.g., [50,51], there are numerous trade-offs between individual objectives for water policy that need to be "judiciously balanced" [26] (p. 507). Gawel and Bretschneider [26] demonstrate that *hurdles to access* are not merely an unfortunate circumstance, but perform functions for competing objectives of sustainable access. Tariffs or water prices, for example, can signal resource scarcity and gradually exclude certain water uses or discourage wasteful behaviors, thus contributing to conservation goals and the refinancing of services. Conversely, prices can also hamper affordability and exclude essential uses of water. This single tradeoff, for example, provides the rationale for the adoption of increasing block tariffs throughout low- and middle income countries, which is widely discussed [52]. Various works from the water literature attest to further challenges of reconciling objectives such as equity and efficiency [53,54].

This highlights the importance of a *governance structure*, i.e., effective mechanisms, processes, and institutions by which the balancing of diverging interests and objectives can be facilitated. According to the United Nations [32], the implementation of sustainability goals requires functional and effective institutions, referring in a broader sense to the "rules of the game" [55]. In this article, we rely on Voigt's [56] (p. 5) definition of institutions as "[...] commonly known rules used to structure recurrent interaction situations that are endowed with a sanctioning mechanism [...]," where the term "sanctioning mechanism"

encompasses formal government enforcement, self-enforcement of conventions, and anything in between. This definition reconciles formulations developed by North [57] and Ostrom [58], notably including institutions that emerge without being intentionally “devised” [57]. Institutions can facilitate or hinder the implementation of policy objectives: The OECD refers to “appropriate governance structures and procedures” [20] (p. 26), whereas the United Nations calls for “integrated water resource management at all levels” [28] (p. 27) in order to guarantee sustainable access to water. Therefore, the three pillars of sustainability in Figure 1 are carried or connected by *functional and effective institutions*. In the following, these key concepts are briefly explored with a specific focus on market water services.

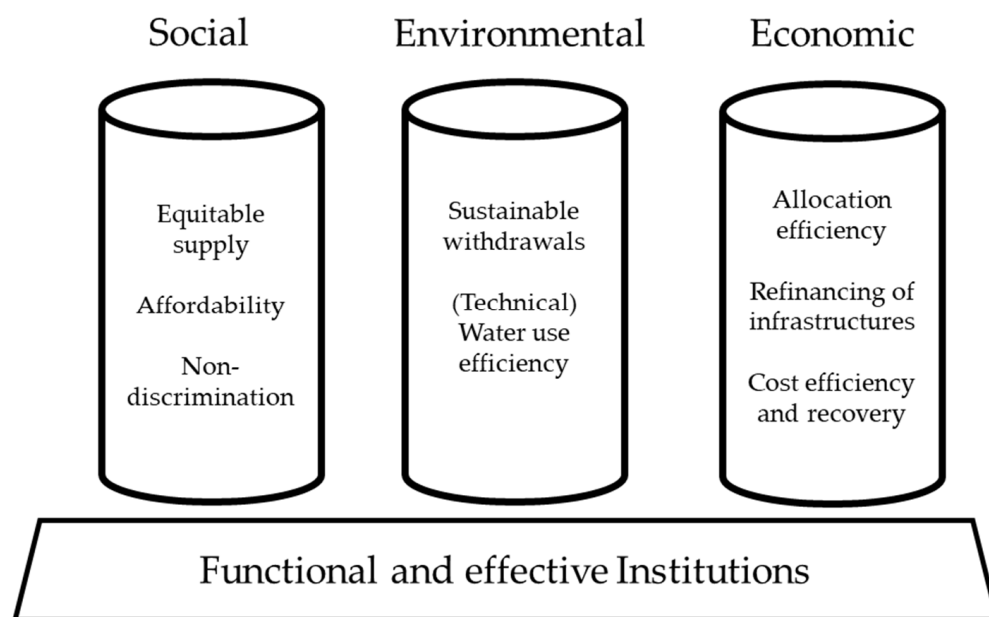


Figure 1. Sustainability objectives of water policy.

2.2.1. Affordability of Services

The affordability of water services is determined by the question of whether households can meet their water needs at a level of cost that is considered acceptable. The rationale for affordability is that water is a prerequisite for human survival, so the economic burden imposed on individuals to meet essential water needs should be low. Affordability therefore depends on both the prices of services as well as the income or purchasing power of individuals. In practice, however, affordability has proven to be hard to define: Although the literature has discussed the issue extensively, e.g., [59–63], the debate on the most appropriate and conceptually sound way of operationalizing when water services are affordable is not resolved [28]. The most commonly used measure [62] is comparing the expenditure of a household for water services against its monetary income (*conventional affordability ratio*). If the share of income dedicated to the purchase of water services exceeds a normatively set threshold (usually ranging from 2% to 7%), the criterion of affordability is not met. Gawel et al. [60], however, discussed the conventional affordability ratio and other available indicators and demonstrated that these may not report critical forms of water indigence: A household can, for instance, remain below the affordability threshold by under-consuming water or by resorting to unwholesome alternatives due to an inability to pay for an improved water service, e.g., [18,64]. In addition, the focus on monetary expenditure alone omits non-monetary cost that can be associated with obtaining access [4,65], primarily the opportunity cost of time—for example, for filling storage containers, which can be quite significant [44]. Such non-monetary cost can create a “hidden affordability issue” [66] (p. 1) and may be a concern for those affected by it. Alternative operationalizations of affordability, seeking to address the shortcomings of the conventional affordability

ratio, are difficult to compute [60] and have high data needs [62]. Thus, although no one would debate that affordability is a central concern for water policy, a satisfactory way of assessing it in real-world situations is still lacking, particularly when considering the availability of data [62].

2.2.2. Equitable Supply of Services

While equitable water services provision is the second key social objective for water policy, the concept of equity itself and its application to water are “often undefined and usually ambiguous” [53] (p. 185). Equity can be defined as a “measure of the fairness of both the distribution of positive and negative outcomes” [47] (p. 577), which makes it somewhat subjective and situational [53]. Perhaps due to the difficulty of grasping the concept, very few studies have addressed equity in urban water markets. Raina et al. [16] discuss horizontal and vertical equity in TWM by assessing allocation outcomes. They define horizontal equity as “equal physical access to the service across different communities and varying income levels” [16] (p. 192), i.e., the absence of discrimination with respect to the service level based on ethnicity, religion, and also locations of residence or income. Vertical equity, as a concept, is based on the idea that individuals with a higher capability to pay should do so, which is, for instance, reflected in progressive taxation systems. In water markets, Raina et al. [16] operationalize this as the absence of discriminatory pricing, particularly the so-called *poverty penalty* [18,64], where low-income groups pay higher per-unit prices. The authors define “equal (or less) proportion of income spent on purchasing water by low-income households when compared to higher-income households” (p. 193) as the indicator for vertical equity. This latter conceptualization, however, seems challenging to apply to market transactions, as high-income households tend to spend a lower percentage of their income on basic supplies such as food (*Engel's law*). Nonetheless, this indicates that the two goals of equitable and affordable water services are closely intertwined and need further conceptual refining.

2.2.3. Sustainable Withdrawals of Freshwater

Definitions of an environmentally sustainable use of freshwater resources usually center around the notion of a maximum sustainable yield [67], i.e., quantities of water allocated to human activities as a proportion of freshwater availability and accessible runoff. The most straightforward operationalization may be obtained through a negative definition: According to Gleick [47] (p. 573), water use would be *unsustainable* “if the services provided by water resources and ecosystems, and desired by society, diminish over time.” Definitions adopted in policy documents, such as for Indicator 6.4.2, rely on the ratio of “freshwater withdrawal as a proportion of available freshwater resources” [28] (p. 27) as a benchmark for sustainable withdrawals. Applying this definition in the study of water services provision in urban areas is, however, challenging because of differences in the scale of analysis: Although hydrological analysis usually occurs on a watershed or river basin level, reliable data and estimates of sustainable water use on a city level are difficult to ascertain. Analyzing individual water services, such as those rendered in TWM, is even more difficult, as these are usually embedded in a complex system of multiple forms of water supply and water uses (agriculture, industry, residential, recreational). If unsustainable patterns of water use are detected, the problem therefore cannot be attributed easily to a specific water service. Rather, unsustainable resources use points towards a mismatch of sustainable supply and demands in the area, which is a complex balancing task for integrated water resource management.

2.2.4. Efficiency of Water Services Provision and Re-Financing of Infrastructures

The efficient allocation of scarce water resources is a key sustainability objective and, in essence, seeks to ensure that water quantities are allocated to the water uses with the highest societal value. This goal is closely related to all others, as inefficient allocation mechanisms can, among other things, result in overexploitation of resources or strong differences in

access conditions [68]. Economic theory postulates that allocative efficiency should be high in water markets [69,70], at least if marginal pricing occurs, with potential benefits for other policy objectives such as affordability. However, depending on the characteristics of water markets, transaction costs can differ considerably [71]. High transaction costs, e.g., due to limited trust or inefficient organization of these markets, may off-set advantages in allocative efficiency [70]. Similar to the challenges of establishing which withdrawals of water are sustainable, it can be challenging to assess which water uses are the most beneficial to society in a complex system of water service supply and demand. This may be the reason why existing studies that assess efficiency chiefly focus on agricultural water markets, and limited information on efficiency in urban water markets is available [14].

A second economic objective for water policy is the re-financing of services, which can guarantee that services are supplied in the long run [20]. This issue is frequently debated for public water supply, where infrastructures and physical assets, such as piped networks, have to be re-financed and tariffs may be subject to political considerations [26]. In private water markets, however, an analysis of the pricing of providers can ascertain whether a full recompense for services provision occurs [15].

2.2.5. Functional and Effective Institutions

To move towards implementing and balancing the aforementioned objectives, institutions matter. With respect to water markets, institutions have been shown to strongly affect allocative efficiency [71]. Institutions can also reduce uncertainty over the quality of services [72], for instance, by mandating quality standards [9]. Likewise, they may monitor and regulate the withdrawal of water quantities [15]. It is therefore relevant for sustainable access to assess to what extent market water services are governed through formal and informal institutions, and whether existing regulations are enforced. In addition, criminal activities such as water theft and corruption may have negative impacts on all of the above-mentioned objectives. Therefore, an assessment of whether such governance challenges are partly attributable to TWM may indicate challenges for sustainable access.

3. Literature Review and Data Acquisition

To obtain TWM case studies, formal scholarly publications and grey literature (e.g., World Bank reports) were identified using the *Google Scholar* search engine under a combination of the keywords indicated in Table 1 to form search queries. Papers from any publication year up to and including 2020 were considered. Given that the number of results obtained through each query went into the thousands, we used the relevance ranking algorithm of *Google Scholar*, which considers a mixture between the incidence and position of key words in the article, as well as its number of citations. We then considered the first 100 results for each keyword combination. Because recent articles may not be included in the top pages when sorted by *Google Scholar's* relevance algorithm, we also filtered for the years 2018–2020 individually to identify recent contributions and, once more, considered the first 100 results.

Table 1. Search queries.

Tanker Water Keywords	Market Keywords
tanker truck(s)	water market(s)
water tanker(s)	informal water
tanker water	water vendor(s)
water truck(s)	

The articles obtained were then grouped into specific urban centers, here also referred to as case study areas. References and citations tracing from the initial set of papers were used to identify additional literature containing information on TWM. Existing meta studies considering multiple locations were also used to support the results and gather literature, whenever they included novel information. The combined literature for each location

was then reviewed to investigate whether it satisfied a set of selection criteria defined as follows: Firstly, as the focus of this analysis is on sustainable access, the study had to include information on at least one of the sustainability objectives discussed in Section 2.2. Secondly, tanker water provision must be organized via markets to differentiate TWM from publicly owned tanker trucks providing water services at a fixed price as a quasi-extension of the piped network, e.g., [73], or in case of emergencies [74]. Thirdly, evidence had to be sufficient to establish that the TWM supplied a significant share of the urban center's water services, i.e., that tanker water deliveries are not an isolated phenomenon but a structural element of water supply. Finally, as the focus of the study is on urban areas and their peri-urban surroundings, only locations with a population greater than 50,000 or a population density greater than 250 people/km² were considered.

Once the urban areas meeting the defined criteria were identified, the procedure indicated in Figure 2 was followed. In Table A1 in Appendix A, we summarize which data points we attempted to collect for each case study area. To gather contextual information on the water supply system in the studied urban centers—for example, the piped network coverage—peer-reviewed literature was supplemented with grey literature such as reports from international organizations and urban water utilities, conference contributions, technical reports, and working papers (see Table 2 in the next section for examples). This information was temporally matched as closely as possible to the period that the peer-reviewed study considered. This was at times impeded by the “snapshot” character of both peer-reviewed studies and supporting grey literature—for example, when surveys were used to obtain information about household consumption of tanker water at a specific point in time. In Section 5, we address to what extent this affects our results.

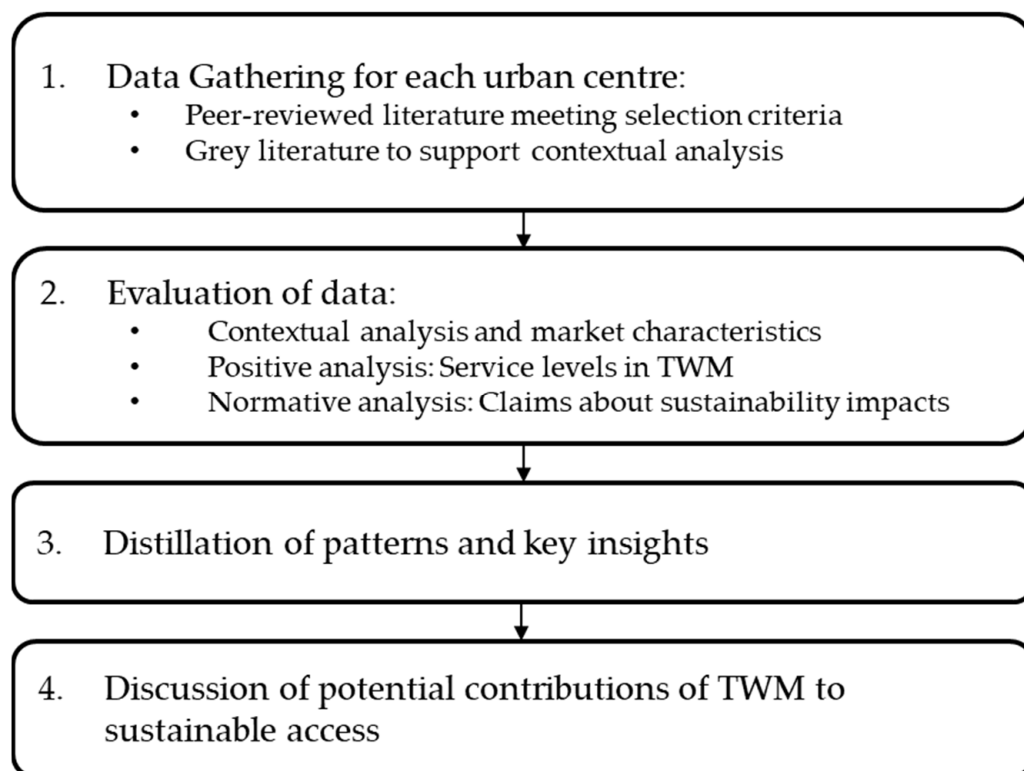


Figure 2. Research procedure.

Table 2. Case study areas included in the analysis.

Case Study Area	Peer-Reviewed Articles	Supplementary (Grey) Literature
Accra, Ghana	[18,75–80]	[81–83]
Amman, Jordan	[84–89]	[15,90,91]
Amran, Yemen	[92]	[23]
Bangalore, India	[1,19]	[93]
Beirut, Lebanon	[74]	
Cape Coast Metropolis, Ghana	[94,95]	
Chennai, India	[17,22,96–98]	
Cochabamba, Bolivia	[9]	
Dar es Salaam, Tanzania	[99,100]	[8,101,102]
Delhi, India	[103–105]	[106]
Festac Town, Lagos, Nigeria	[107]	
Guayaquil, Ecuador	[108]	[109]
Hyderabad, India	[110,111]	
Jakarta, Indonesia	[112,113]	
Kalimpong, India	[114,115]	
Karachi, Pakistan	[116–118]	[119–121]
Kathmandu Valley, Nepal	[16,73,122–127]	
Luanda, Angola	[128,129]	[130–133]
Mexico City, Mexico	[21,134]	
Mumbai, India	[135]	[136,137]
Nsukka, Nigeria	[138]	
Nairobi, Kenya	[139,140]	
Onitsha, Nigeria	[141]	

4. Results

This section firstly presents the results of the literature review. Following this, we provide an overview of the contexts within which TWM are found and discuss market characteristics and conduct. We then analyze the impacts of TWM on sustainable access according to the concepts established in the previous section.

4.1. Outcome of Literature Review

After filtering the results of our literature review as described in the previous section, 23 case study locations and 80 literature items, listed in Table 2, were considered in the analysis. TWM are likely more widespread in urban water supply systems than this number suggests, however, as we encountered a significant number of further locations that failed to meet the selection criteria, mostly because no peer-reviewed articles were available. Examples of detailed TWM reports that were excluded from the analysis are indicated in Table A2 of Appendix A. The literature dealing with the selected cases stemmed from various disciplines, including urban geography [21], hydro-economics [22,84,85,142], political science, and ecology, e.g., [1,19,103], as well as biophysical assessments of water quality e.g., [23,76,77]. The most common research method adopted in the studies was fieldwork consisting of surveys and interviews, predominantly of households, e.g., [16,114], but in some cases of tanker water providers, e.g., [18,90]. Other methods adopted included desktop research, workshops and discussion groups [81], water-quality tests [23,122,123], and simulation models [85,142].

4.2. Contexts of TWM

The reviewed literature reported TWM operating in Africa, South America, and Asia (cf. Figure 3) within a variety of climatic conditions, ranging from hot and dry (Jordan and Yemen), to hot and wet (Uganda, India, and Ecuador), to temperate and wet (The Himalayas).

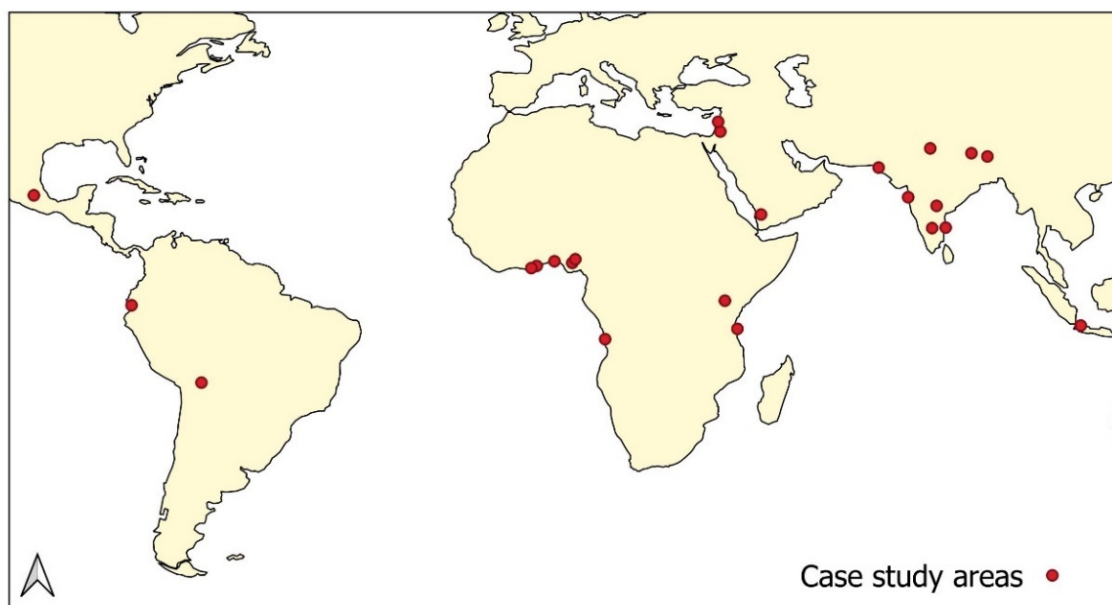


Figure 3. Locations of urban centers meeting criteria for inclusion in the study.

All urban centers included in the study had an existing piped water network covering parts of the population, with 30–97% of households having access to in-house piped water services. In all cases, however, the supply of water through the network was intermittent, and in one case [107] not operating at all. Intermittency ranged from water services being available during certain hours each day [96,119,122] to only being available a few times in a month [115,130], and supply durations were often found to vary spatially within each urban center [81,99].

A common pattern across most case study locations was that low-income households were more likely to have less or no access to piped water services than wealthier water users. The reviewed articles provided a variety of explanations for this pattern, such as network expansion being prevented by connection fees [81] or the legal status of informal settlements [80]. Many of the reviewed articles investigated rapidly expanding urban centers, where low-income households frequently located themselves in fringe areas with more affordable housing that the piped water network had not yet reached—for example, Goba Ward in rapidly expanding Dar es Salaam [99].

Households with and without access to piped water services were found to frequently seek alternative water sources. In every urban center, a multitude of water services existed [5,99,128], with TWM operating alongside other services, including water kiosks (sachet and bottled water), standpipes, reservoirs (water tanks), motorized/animal/tricycle-powered carts, pushcarts, manual water carriers, mechanized bore wells, wells, rain tanks, and micro-networks managed by the community. Water services were provided by both private and public enterprises. As a result of the range of alternative options, TWM were found to have varying importance in the respective water supply systems. In Dar es Salaam, water tanker trucks supplied 2% of the population [12], whereas in Onitsha, more than 60% of consumed water quantities were supplied directly or indirectly via water tankers during the dry season, as the majority of the population did not have a functioning piped water connection [141].

4.3. Market Characteristics and Conduct

4.3.1. Water Sources, Supply Chain, and Customers

TWMs are often part of water service supply chains involving both public and private entities (cf. Figure 4). TW suppliers obtain water quantities from surface bodies, groundwater wells, and the public water network. This could be facilitated by a government entity, e.g., surface water from rivers provided by government filling stations [128], or through

private owners of borewells. Such borewells can either be located within an urban center, or in peri-urban and rural surroundings [110], with the TWM facilitating a rural-to-urban transfer of water quantities. The review also identified reported cases of water abstracted via unlicensed wells [15], or directly from rivers and streams [115,130]. Frequently, tanker water providers were found to use different sources of water in the same location—for example, both public utility connections and private mechanized boreholes [18].

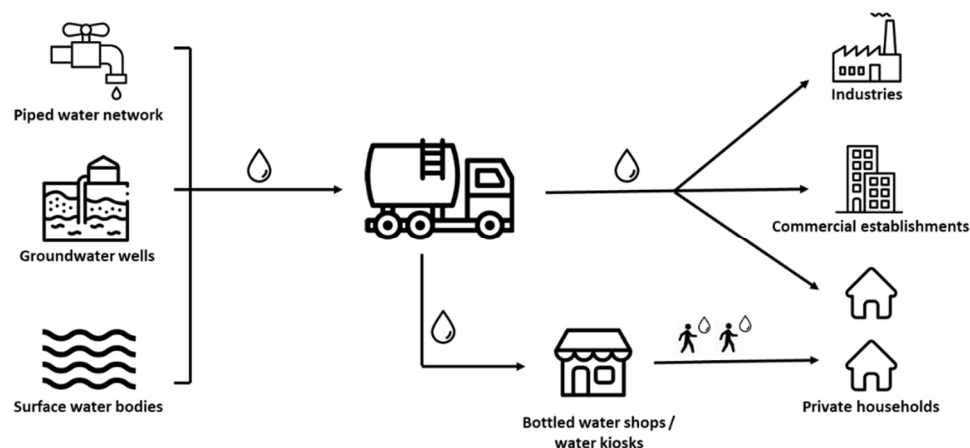


Figure 4. Supply chain of water services in TWM.

Tanker water services are demanded by a variety of consumers, ranging from private households, e.g., [84,86], to public organizations and construction sites [15], to commercial establishments [85] and industrial production facilities [111]. Depending on the location, source of water, and intended uses, tanker water has both potable and non-potable applications. Tanker water providers frequently deliver water quantities directly to final users. In such cases, three modes of arranging tanker water deliveries were found: (i) by telephone [15], (ii) by meeting TW suppliers at well-known congregation points [81], and (iii) by waiting for them as they move around the city and use acoustic signals to attract customers [9]. Tanker water providers can also render water services to other water businesses, such as bottled water shops, who then on-sell in smaller volumes [82]. Frequently, both direct and indirect forms of TW sales exist in the same location. The ability to purchase water services directly from TW suppliers depends on available storage capacity, as minimum quantities have to be purchased in most cases [101]. Although this ability is higher among non-residential clients and for private households with higher income, low-income households and residents of informal settlements frequently purchase from vendors further down the supply chain.

4.3.2. Ownership, Competition, and Pricing

TW businesses were found to usually be owned by self-employed individuals operating a truck (owner-drivers) or by entrepreneurs with a small number of vehicles and employees. In eight out of 23 locations [15,18,96,119,128,129,134,138], TWM were reported to operate competitively, whereas in another seven areas [74,92,94,99,107,139] no claim to the contrary was made. In four locations [1,113,127,135], however, there was mixed evidence concerning competition: Although it reportedly existed in certain areas, increasing market power was observed within other parts of the urban center. Monopoly rents were, for example, extracted in specific areas of Kathmandu [127]. In four locations [9,108,115,141], representing about 17% of our sample, high market power and monopolization were reported for the entire market. Swyngedouw [108] observed spatial oligopolies in the city of Guayaquil, which allowed TW suppliers to charge prices significantly higher than their marginal cost. Similarly, Whittington et al. [141] reported tanker businesses in Onitsha capturing monopoly rents, particularly during the dry season. We also included the TWM in Cochabamba, Bolivia, in this category, where the tanker water provider association set

“fair” prices, according to Wutich et al. [9], which implies absence of marginal pricing. There are, however, also cases in which the prices for tanker water services are affected by rent-seeking behavior by those controlling the source of water [111,119,130].

The price of tanker water services charged to the final consumer has a number of determinants. Based on interviews with tanker water providers, Raina et al. [127] and Sigel et al. [15] provide comprehensive assessments of the cost structure in tanker water businesses. In almost every location included in our sample, marginal prices increased with the distance the water is transported, due to higher fuel, labor, and other variable costs. This can result in substantial spatial disparities in TW prices [1,85,96]. In areas with limited tanker-filling points, this difference in price was most pronounced—for instance, in Luanda, where prices for tanker water services varied by more than a factor of two [130]. In several localities the price was also found to vary depending on the source and quality of the water [15,82]. Prices were reported to seasonally vary in most of the urban centers. In almost every case, the dry season or summer resulted in an increase in prices, as network supply decreased or groundwater tables fell. Traffic and road quality are further factors that were reported to impact prices in several locations [83,120,130], whereas in others it was reported that waiting times at public utility filling stations could result in price increases if operators have to wait for several hours to fill their trucks [81,143]. In some case study areas, it was found that cheaper prices could be negotiated for regular customers [9,75] or when larger volumes of water were purchased [15]. These factors can contribute to differences in prices reported between residential and commercial customers [85,96], due to larger volumes and frequencies of deliveries being requested by businesses [15].

4.4. Service Levels in TWM

4.4.1. Spatial Accessibility

The spatial accessibility of TWM services was found to be high across almost all case studies. This is particularly the case when accessibility is compared to piped water supply, as TW providers often render their services in areas that are unconnected to the public network. As a mobile form of water vending, TW services tend also to be more accessible than stationary alternatives such as water kiosks. Notable exceptions are informal settlements and areas with narrow or damaged streets, where vehicles cannot maneuver and residents are therefore unable to purchase tanker water services [144]. The delivery mode found to be most common across TWM case studies was “on premises,” i.e., in line with the accessibility operationalization suggested for the monitoring of access goals.

4.4.2. Temporal Availability

Similarly, the temporal availability of TW services tends to be higher than that of other services, as TWM frequently balance piped network intermittency or seasonal shortages of water in specific areas [84,96,122,131,134]. Although TWM usually do not restrict consumed quantities, seasonal spikes in demand combined with quantity restrictions or queuing at sources can lower temporal availability [15]. Moreover, tanker water providers frequently do not deliver marginal quantities of water [91,101]. For households with insufficient storage capacity, this can present a challenge, which is why neighbors coordinate deliveries together [114,136]. It also implies that the higher temporal availability of the service may not necessarily result in high temporal availability of water quantities for those with low storage capacity, as they can neither store a sufficient quantity nor call a tanker delivery for every marginal quantity of water they demand. In many TWM, nonetheless, it seems possible to order deliveries of water “when needed,” i.e., the demanded quantity can be purchased at the desired time or storage can be filled once depleted.

4.4.3. Quality and Acceptability

With respect to the quality and acceptability of water supplied via TWM, the evidence is mixed: Issues with water quality were reported across six case studies. In five locations, i.e., in about 22% of the reviewed case study areas, the authors physically tested

for water quality, and the issues reported included bacteriological contamination—for instance, through *E. coli*, turbidity total iron, total dissolved solids (TDS), chloride, and ammonia [23,73,74,94,119,122]. Another study inferred water-quality issues from household surveys in which respondents reported poor quality, or from linking heavy rainfall and increased incidence of water-borne diseases to TW supply from rivers [128]. The source of water contamination was in some cases attributed to tanker water-handling practices—for instance, irregular cleaning and lack of disinfection [74,94,95,145]. In other cases, contamination was reported to have occurred earlier in the supply chain—for instance when water was sourced from rivers [128] from shallow private wells or the piped network [119]. In other cases, it was suggested that a lack of hygienic water storage in tanks of vendors further down the supply chain [81], or at the household itself, contributed to contamination [23]. It is noteworthy, however, that available alternatives were frequently reported to have quality or acceptability issues, and the review found five cases where water quality provided by the TWM was perceived to be equal to or higher than all alternatives [15,96,99,107,141]. Some TWM were reported to allow a certain degree of contractual freedom with respect to the desired quality level of water quantities. In four case studies [9,73,75,135] TW was reportedly used for both drinking and non-drinking purposes, and therefore different quality levels of “tanker water” were available in the same area. In most empirical studies, however, there was no indication that the quality level of delivered water quantities was negotiable.

4.4.4. Prices

The most intuitive understanding of TW prices in relative terms can be gained by comparing them to network water tariffs or other alternative water services in the same area. This, however, is difficult to accomplish in exact terms because there usually is not a uniform volumetric price for tanker water quantities due to the pricing mechanisms described in Section 4.3.2. The network tariff, on the other hand, frequently varies depending on consumed quantities, if an increasing block tariff is applied. In addition, network connections can be associated with basic charges or connection fees. Against the background of these limitations, the review focused on averages whenever they were reported and found that the average price of tanker water exceeded the piped network tariff considerably in almost every case. The range of variance was found to be 4–5x [19,119], to 40x [128], to as much as 400x [108] above per-unit network water prices. There are, however, a few cases in which the tanker water price was found to be lower than the tariff for network water services—for instance, in the case of commercial establishments in certain locations of Amman [85,90] or for the higher-block commercial consumers in Chennai (90% of highest tariff block rate, cf. [96]). Where tanker water is on-sold by actors along a supply chain, the end price per unit increases. In Accra, Ghana, for instance, water reservoirs that used tanker water sold their water on average at 24x of the network tariff and approximately double the price charged by tanker water vendors directly [18].

4.5. Normative Assessments: Sustainability Impacts of TWM

In the surveyed literature, the predominant focus with regard to sustainability impacts of TWM was on social aspects of access to water, i.e., equity and affordability. Fewer case studies were concerned with sustainable use of water resources, whereas institutions of urban water governance were regularly discussed.

4.5.1. Affordability of TW Services

Claims about affordability issues related to tanker water services were made explicitly and implicitly in 14 locations, or roughly 61% of the sampled areas. In eight cases [8,17,21,74,124,129,137,141], affordability issues were diagnosed based on the conventional affordability ratio, i.e., comparing expenditure for tanker water services to household income. In Nsukka, Nigeria, for instance, where more than half of the population uses tanker water services, the average per capita water consumption ranged at 35 L/day, whereas 7% of monthly income was spent on average to obtain water [138]. In Section 2,

potential blind spots of the expenditure ratio were discussed to point out that there may be other forms of affordability issues not captured by it. Not all case studies used or gathered empirical data on income and expenditure, yet potential affordability issues may be inferred, e.g., if very small quantities are consumed or if households do not use tanker water services even if they are the only source of only improved water service available to them. Five of the reviewed case studies [9,78,88,112,138] pointed towards such potential affordability issues: In Jakarta, Indonesia, for example, a household survey found that the average per capita daily water consumption of the clients of water vendors amounted to merely 14.6 L [113], which clearly falls below minimum quantities required for human health [146]. It is noteworthy, though, that many studies reporting affordability issues investigated water access conditions in informal and low-income areas, where residents did not have any or very limited access to alternatives such as network water services. Such studies, therefore, did not focus on water users that potentially can afford tanker water services, e.g., more affluent water users in formal housing areas or commercial establishments. Notwithstanding, the available evidence points towards the existence of affordability issues in numerous TWM case studies—not necessarily for all water users, but those residing in low-income and informal communities.

4.5.2. Equitable Supply

Studies that address the equitable supply of water services usually assess the entire water supply system of the area, where access conditions differ strongly, particularly with respect to network water supply. Many studies, e.g., [1,74,85,96,129,141], report that heterogeneity in access to comparatively cheap piped water services affects equity outcomes, in particular the per-unit prices paid by different consumers. Heterogeneous access to network water impacts the allocation of other water services, including TWM: Those who have less access to network water, typically low-income households and informal settlements, purchase more tanker water services and thus pay higher prices. Some of the reviewed studies [108,135] describe this heterogeneity as a systematic exclusion of low-income communities with limited political power. Beyond these assessments of equity across entire water supply systems, the literature was also reviewed for evidence on equitable supply *within* TWM. In terms of horizontal equity, the review clearly showed that TWM do not bring about uniform prices, i.e., water users in comparable situations may pay significantly different prices (see Section 4.3.2). Similarly, there is no evidence for vertical equity. In fact, many case studies attest to the existence of a “poverty penalty,” where higher per-unit prices are paid by those with lower income [16,130,141]. These equity outcomes, however, were not found to be a discriminatory practice but resulted from the pricing mechanisms described above. Low-income households frequently purchase smaller volumes of tanker water [8] and are located on the periphery of urban centers, farther away from water-sourcing points, which results in higher transport costs [130]. These households frequently also have less or no access to network water, which increases their overall spending per volumetric unit due to existing price differences.

4.5.3. Sustainable Withdrawals

In several studies [1,2,17,111,125,135], claims were made that link TWM directly to unsustainable water use. These were found to be case studies in (peri-)urban areas struggling with groundwater depletion: Goldman and Narayan [1] (p. 107), for example, attribute groundwater overexploitation in Bangalore, India, to private wells and a large and unregulated TWM, claiming “thousands of water tankers plying the city streets, collectively sucking dry the water aquifers [13].” In none of the studies discussing the overexploitation of groundwater resources, however, were TWM the only or even dominant form of water use. Thus, attributing the responsibility for unsustainable resource use to TWM seems premature and more integrated, quantitative studies of water supply from different sources for different sectors are required [142]. TWM make competing water uses visible by transferring water volumes between spaces (rural and peri-urban to urban areas) as well as

sectors (agricultural to residential, commercial, industrial), which can create tensions. A recurring observation in several TWM case studies [2,19,111,125] was that TW suppliers sourcing their water in peri-urban areas caused falling aquifer tables, resulting in a reduced availability of groundwater for local farmers, which use the water for irrigation purposes. In contrast to this, there are also cases in which TWM were reported to be the result of water stress, not its cause: Srinivasan et al. [22] studied a tanker water market during a drought in Chennai, India, and concluded that the TWM gained significant importance *after* the groundwater tables were falling, as households lost their ability to extract water from private wells.

4.5.4. Efficiency of Water Services Provision and Re-Financing of Infrastructures

The reviewed TWM literature contained few contentions about the efficiency of water services provision, perhaps due to the limited information on the topic and complexity of the question. The information obtained about pricing and competition (see Section 4.3.2) indicates that in many TWM marginal pricing occurs. Monopolization, however, can reduce efficiency [119], whereas from a technical point of view, transporting water in trucks is considered less cost-efficient. The marginal cost of piped supply therefore may be lower [111] and TW deliveries associated with more costly externalities due to energy-intensive transport [147] or traffic jams [130]. In addition, there can be considerable transaction cost in TWM—for instance, due to the way tanker deliveries are organized [9] or because of waiting times [81]. It seems relevant, however, to note that most alternatives to tanker water services were associated with high transaction costs as well (such as queuing and waiting for piped supply). TW deliveries were frequently selected by consumers due to the comparative ease of obtaining water quantities [15,122]. The interpretation of welfare effects of TWM seems to depend on the perspective applied: If it is assumed that TWM cannot be replaced in the short run, they contribute to welfare [85], while assuming that the same quantities could be supplied via the piped network frames tanker water deliveries as a welfare loss [134].

With respect to the long-term refinancing of services provision, no evidence was found in the review that this was a challenge for providers of TW. A notable exception was described by Awepuga [143], an excluded report (cf. Table A2) not considered in this review, where the informal character of the TWM prevented the providers from obtaining loans to purchase trucks. Although this issue was not reported elsewhere, it may still affect TW providers in other locations without formal institutions (see next section).

4.5.5. Functional and Effective Institutions

The reported degree of legality and regulation of TWM varied considerably across the different case study areas, and sufficient information on this was only available in 14 of 23 cases, i.e., about 60% of our sample. The review identified three main groups of institutional arrangements:

1. Formal institutions and regulations for TWM, such as licensing requirements of providers or quality regulations, exist in seven out of 14 locations and are partially enforced. In all of the studied areas, however, there was evidence of informal or illegal operators working alongside these formal TWM. In Kathmandu, for instance, Shrestha and Shukla [73] reported that although a regulatory entity for TWM was created years ago, most TW providers were unaware it existed. The lack of adequate regulation and enforcement was reported to result in providers not adhering to hygiene standards or obtaining water quantities from contaminated sources, e.g., [76]. In Luanda, the public utility provided a water treatment station at which TW providers must chlorinate water quantities before selling them, but quality checks were only performed on those who voluntarily stopped, which were the minority [130].
2. In six out of 14 case study areas, tanker water provision is a legal activity, but there are no formal institutions or regulations governing the provision of tanker water services [17,74,77,107,115]. Alba et al. [77], for instance, reported that a guideline for

tanker water services has existed as a draft document for a decade but has not been passed officially.

3. In one case, the tanker water market was found to be illegal, but there is no effective enforcement preventing the provision of tanker water services [119].

Beyond public oversight, TWM providers reportedly formed associations in several locations, at times performing self-regulation with respect to minimum service quality and in other cases to fix prices and restrict market entry [75,81]. The review also found a number of case studies associating TWM with illegal activities such as water theft and political corruption. In several South Asian cities, politicians were found to be actively involved in the TWM, which were characterized as complex webs of TW suppliers, bureaucrats, police, and tanker water providers allowing the involved actors to benefit financially or politically [19,118]. In Bangalore, for instance, local politicians claimed to “provide water” for their constituents via the use of tanker trucks to “gain votes and reinforce electoral support” [1] (p. 105). In Karachi, arrangements between local politicians and tanker water providers were purported to delay the extension of public water services and create artificial shortages to protect and expand their business model [116,121]. In other locations, TW providers reported paying bribes due to lacking licenses, the state of their vehicles, or extortion by local officials and police [18,143]. In these cases, the reviewed case studies did not indicate regulatory attempts at protecting TW businesses from such harassments. Theft of water quantities from both the public network as well as surface water bodies through TW operators was reported in a number of urban centers [2,75,120,131,148].

5. Discussion

The majority of studies dealing with tanker water markets acknowledge that these make at times crucial contributions to providing water services in rapidly urbanizing areas. For every case study area, we found articles reporting issues with respect to at least one of the sustainability objectives of water policy described in Section 2.2. Many acknowledge, however, that these are the result of an entire urban water supply system struggling to achieve sustainable access, not necessarily TWM. Notwithstanding, there are recurring narratives in the literature, for instance that TWM bring about affordability issues because the clients of tanker water providers “pay the highest price for water, often of doubtful quality” [18] (p. 148). Others link tanker water providers to the depletion of groundwater resources [2,111] framing them as “mafias” [19] setting a “trap” [78] (p. 223) to exploit low-income communities [108]. Against this background, we systematically analyzed the TWM literature to assess their impact on (i) access to water and (ii) sustainability objectives of water policy. To do so, we used the concept of sustainable access [26], which accommodates both positive and normative aspects of the research objective.

The results we presented in the previous section paint a differentiated picture of tanker water markets. We first assessed the service level in TWM to better understand the contributions they make to access to water. We found that tanker water services are frequently rendered at a high level in the non-pecuniary dimensions of access, particularly with respect to the *spatial accessibility* and *temporal availability* of the service. In both dimensions, TWM often have higher service levels than piped network supply or other alternatives. In terms of water *quality* and *acceptability*, the evidence is mixed: Quality issues were reported in 26% of our sample, indicating that TWM do not necessarily promote access to safe drinking water. The review also found, however, that the quality of alternatives can be low as well, and tanker water was perceived by water users to be of the highest relative quality in 22% of the studied areas. It is also noteworthy that some TWM allow water users to choose water-quality levels and adjust prices accordingly, though this is by far not the case everywhere.

The review revealed that the price of tanker water services exceeded network tariffs significantly in almost all cases, which confirms what other studies on water vending found [5,149]. The higher service level frequently comes at a large difference in cost, making tanker water services, as Guragai et al. [122] (p. 438) put it, “expensive yet convenient.”

Although our analysis identified a significant number of cases (~17%) in which monopolies in TWM were reported to distort pricing mechanisms, marginal pricing was more common or no claim to the contrary was made. The difference in final consumer prices compared to network supply partially results from the fact that prices increase with transportation distance and other factors, such as traffic. Garrick et al. [149] (p. 21) speculate further that “the higher prices charged by these vendors reflects the elevated costs of supplying a service with inherent scale economies through informal channels.” Once adequate infrastructure for piped water provision is in place, network effects reduce marginal cost of provision, in addition to a technically more efficient transport of water quantities. Besides this, however, it is worth noting that piped water supply is frequently subsidized. Piped tariffs, therefore, do not necessarily signal scarcity or the full-cost services provision to the same extent as marginal prices for TW services—for instance, when seasonal water scarcity results in price increases [149].

With respect to normative claims on the sustainability effects of TWM, we found that most studies discussed the social implications of water supply via TWM. Our contextual analysis showed that TWM often operate in areas where strong differences with respect to network water provision exist. Frequently, wealthier water users have greater and more continuous access to low-cost network water, whereas low-income households live on the fringes of the city or within informal settlements, where network coverage is low or nonexistent. Thus, not all water users benefit from the aforementioned network effects and the comparatively high prices of tanker water services are not affordable for all. This results in a “double-burden” [108] (p. 394) for those with no or low network access who cross-subsidize piped water services for others while paying higher per-unit prices for tanker water services. The heterogeneity of network supply therefore has indirect costs and benefits across the entire water provision system. Based on existing notions of equity, this is an impediment to sustainable access. Beyond the effects of network supply heterogeneity, there are considerable variations in prices within TWM or between different consumers. These are not necessarily the result of discriminatory practices of suppliers, though, but built into the way most TWM function: Because the sales price is a function of the distance the water is transported, customers in more remote areas are not served or pay markups to reflect the higher marginal cost of provision. In addition, those with lower storage are frequently unable to purchase the entire truckload and end up paying higher per-unit prices. This demonstrates that TWM have limited capacity to advance affordability and equity goals of water policy. Notwithstanding this, many water users depend on tanker water services for accessing water, as they lack viable alternatives. Policymakers intent on addressing affordability and equity concerns in the short term should therefore consider transfer payments to those disadvantaged by the piped network supply system. In the longer term, an expansion of public supply access could address these affordability concerns.

The review found a smaller number of studies dealing with TWM in areas characterized by water scarcity and groundwater stress. It seems, however, difficult to attribute the unsustainable exploitation of this common pool resource to merely one out of typically several competing uses. Tanker water markets may contribute to overextraction of water from aquifers, but frequently agricultural, commercial, and—in the case of many Indian cities [96]—residential water users do as well. The key challenge, rather, seems to be the mismatch of demand and sustainable supply of water quantities, not a particular service that meets specific demands. Instead, integrated water resource management and a discussion about which of the competing water uses should be prioritized are required. The informal and decentralized nature of TWM, however, may make it difficult to comprehensively regulate and monitor water withdrawals. In Jordan, for instance, illegal groundwater abstractions occur despite existing institutional structures aiming to govern groundwater abstraction and the tanker water market [15].

This example points towards a lack of functional and effective institutions capable of steering TWM in the direction of sustainability goals. Our analysis found that there is a

variety of institutional arrangements governing TWM, including formal institutions such as regulations and guidelines, self-regulation through associations, and the absence of any formal institutions. Existing attempts to formally govern TWM, however, were found to be limited in their success. The introduction of water-quality standards [130] or licensing schemes [1], for instance, has not been successful. In addition, reports of illegal activities such as political corruption, water theft, and harassment of water vendors suggest that challenges for urban water governance exist. In some locations, the binary distinction between regulating public authorities and private market actors in the TWM is altogether inapplicable, as water vending is strongly intertwined with administrative and political spheres of society. Thus, demands for the formalization or regulation of TWM need careful consideration, as they are predicated upon the assumption of enforceability, which has been limited according to our results.

Our study revealed that assessments of TWM markets and their impact on sustainable access to water are difficult to carry out. This is due to at least two reasons: One, there is considerable heterogeneity among TWM with respect to the source of water, the customers served, the degree of competition and regulation, and the price of the service. Secondly, no consensus on what makes water services provision sustainable and how to assess this has yet been reached, resulting from different disciplinary perspectives and diverging definitions of key concepts. Some indicators the reviewed studies used to support normative assessments, such as the conventional affordability ratio, are insufficient to capture all relevant aspects of the underlying problem.

As a consequence, although our analysis is a first, sound assessment under the framework of sustainable access, it also has limitations. Some case studies may not have reported on all characteristics of tanker services relevant to our analysis, i.e., this review is not necessarily a comprehensive assessment of *all* impacts of TWM on sustainable access to water for the case studies considered. Thus, although we provided percentages of studies reporting specific sustainability impacts in our Results section, the picture may be incomplete, as a study concerned with water-quality assessments may not have investigated the affordability of services, and vice versa. Additionally, as studies typically focus on challenges or areas with problematic water access conditions, such as informal settlements [17,99,140], *positive* sustainability impacts may have been underreported. Moreover, our approach to expanding the descriptive information on water supply systems, network tariffs, etc., by reviewing supporting grey literature was impeded by the fact that most case studies were “snapshots” of a TWM at a specific point in time and not in every case was information on all characteristics available. As a result, the contextual information we have on specific case study areas may be incomplete.

Future research needs to gather more robust and comparable empirical data to provide a basis for a clearer understanding of TWM. Moreover, key concepts related to access and sustainability objectives need to be refined to support normative assessments. Currently available concepts are insufficient, as we discussed in Section 2, or have blind spots: Although equity questions within urban boundaries were addressed by us to some extent, transboundary trade-offs or conflicts were ignored, e.g., when “peri-urban villages are losing access to groundwater as informal water markets have improved access to water for urban residents” [2] (p. 1092). This and other sustainability implications should be investigated in future research. The efficiency of allocation through different water services warrants a particular focus in future work, as it is highly relevant, for instance, in the discussion on competing water uses mentioned above. This and other reviews, e.g., [14], found no in-depth empirical analyses of efficiency in TWM at this point. Finally, further sustainability impacts, such as externalities of TWM, e.g., carbon emissions or contributions to traffic congestions, but also livelihood opportunities in the informal economy, should be considered when weighing their role in urban water supply systems of the future.

6. Conclusions

In many urban water supply systems, tanker water markets are currently making relevant contributions to access to water. TWM have sparked strong opinions and diverging assessments as to whether they are desirable from a sustainability perspective. The existing literature suggests that TWM are heterogeneous with respect to the way they function and the outcomes they produce. Therefore, a differentiated perspective on their role in urban water supply systems should be adopted. We reviewed available in-depth studies of TWM to find evidence for their impacts on *sustainable access* to water. Our study showed that sustainable access is multi-faceted and depends on many factors within a water supply system, as other contributions in the literature have pointed out as well [27,150]. To assign sustainability issues to a specific water service, therefore, can be misleading. Assessments of sustainability impacts must apply a consistent and fair framework to all heterogeneous water services shaping access in an urban area, which includes piped network services. The following key insights of our analysis of TWM substantiate the benefits of such a perspective:

1. Tanker water services are usually rendered at high service levels, which may otherwise be unattainable in the area. This is particularly the case for temporal availability and spatial accessibility of the service, which are frequently higher than those of alternatives such as piped network supply. The evidence for water quality is mixed: It was found to be below international standards for drinking water in 26% of case study areas, but in others reported it to be comparable or even better than other options. Tanker water services come at a higher price for end consumers and can reflect high service levels or performance in terms of particular “access” categories. Their market emergence thus indicates existing gaps in water services provision, particularly the deficiencies of underfinanced public piped water supply.
2. Frequently, TWM arise in response to a highly heterogeneous supply of network services, which often do not reach low-income communities at the fringe of cities to a sufficient degree. Tanker water services fill this gap, but their prices exceed (subsidized) network tariffs considerably. Piped water networks achieve a more technically efficient transport of water quantities with a greater up-front investment and benefit from positive network effects, and are often characterized by subsidized tariff structures that do not achieve full cost recovery. The per-unit prices of tanker water services, on the other hand, are subject to steep increases in marginal costs of provision and in dependence of transportation distance. Final market prices therefore vary spatially and between water users, though usually not due to discriminatory practices. Tanker water services are thus unlikely to “fix” existing issues with unequal water supply and are not affordable for all water users. Ensuring equitable and affordable water services for all is commonly considered a government responsibility, and political action may be required to achieve it. Income transfers to those depending exclusively on TWM can constitute a short-term solution. As the availability of storage typically reduces the per-unit prices paid for tanker water and increases the time span, intermittent network supply can be used to meet water needs. In-kind support with large storage containers may also be a considerable option to support low-income households. In the long run, improving and extending piped services may address the social dimensions of sustainable access.
3. The review indicated that some TWM are embedded in systems where renewable supply and demand for water quantities are not in balance. In such cases, TWM can contribute to unsustainable resource consumption, but in a system of multiple competing resources uses and often poor governance, TWM themselves are not exclusively “responsible”.
4. There are different institutional arrangements governing TWM, ranging from licensing and quality requirements or the monitoring of resource extraction, to entirely unregulated markets. Due to the frequently informal and decentralized nature of TWM, appropriate enforcement of regulation has proven to be challenging.

Although this study consolidated existing knowledge and perspectives on TWM, many questions about their impacts on sustainable access to water remain unanswered. Given that TWM are likely to remain an important issue, as the expansion of piped services is not keeping up with urbanization and population growth, it is important to understand them better by both gathering more data and addressing conceptual weaknesses of sustainability objectives. In water management and policy, the contributions of TWM to access goals should be recognized and their impacts have to be considered in integrated water resource management.

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Appendix A

Table A1. Data collected for the case study locations.

	Characteristic	Data Type
Contextual info	Climate	Köppen classification
	Existing network water presence	Y/N
	Dwellings with in-house access to piped water	%
	Network water supply frequency	text
	Other available water services	text
	Population density	pp/km ²
	Usage characteristics of TW	Sole use/substitute/backup
	Market share of water market	Share (%)
TW Market	Source of tanker water	Text
	TW price compared to public supply	Ratio (%)
	Tanker water market is:	
	-Legal	Text
	-Regulated	Text
	-Enforced	Text
	-Competitive	Text
	Seasonality of supply and demand	Y/N
	Spatial differentiation	Text
	Provider organizations	Text
	Type of business ownership	Text
	Demographic characteristics of TW drivers	Text
	TW price determinants	Text
	Organizing of sales	Text
	Commercial/industry main TW customers?	Y/N

Table A1. Cont.

	Characteristic	Data Type
Impact on sustainable access	Spatial accessibility of service	Text
	Temporal availability of service	Text
	Water quality and acceptability	Text
	Sustainability impact attributed to TW, according to concepts and indicators developed in Section 2.2:	Text
	-Affordability	
	-Equitable supply	
	-Sustainable withdrawals of freshwater	
	-Efficiency of water services provision and re-financing of infrastructures	
	-Functional and effective institutions	

Table A2. Examples for excluded studies containing in-depth TWM information.

Loaction	Reference	Exclusion Reason
Kampala, Uganda	[151]	Report (not peer-reviewed)
Tamale, Ghana	[143]	Master thesis (not peer-reviewed)
Idah, Nigeria	[145]	Conference proceedings (not peer-reviewed)

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