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Publication Date

2024-09-01

DOI

10.1016/j.worlddev.2024.106650

World Development 181 (2024) 106650

Contents lists available at ScienceDirect

World Development

journal homepage: www.elsevier.com/locate/worlddev

Appropriation pathways of water grabbing

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ABSTRACT

The appropriation of water by farmers, land investors, mining operations, hydropower corporations, or other actors becomes controversial when it targets relatively scarce water resources that support rural livelihoods, food security, or environmental needs. Some of the distinctive institutional and hydrological conditions underlying water appropriations remain poorly understood, thus limiting the development of suitable policy and governance instruments to protect those users whose access to water is diminished by such appropriations. Research in this field has often focused on water acquisitions through land deals or infrastructure development while overlooking other more subtle pathways of water appropriation associated with pollution, land use change, afforestation, land–atmosphere feedback, irrigation efficiency, and virtual water trade. Such pathways frequently contribute to the loss of access to water by prior users, including rural communities, indigenous groups, women, and the environment, thus playing a critical role in undermining livelihoods, cultural identity, or ecosystem functions. Understanding the socio-environmental interplay between the institutional-legal and hydrological mechanism is crucial to the assessment of how different water appropriation pathways can affect prior users and their rights. Here we examine the different institutional and biophysical conditions that characterize the dynamics of water appropriation and identify the major pathways underlying water grabbing. We investigate the nexus between water tenure arrangements and neglected hydrological pathways of water appropriation to critically evaluate their impact on access to water.

1. Introduction: Water, diverging values and perspectives

Freshwater is a natural entity that is essential for life and is irreplaceable in its function of sustaining terrestrial ecosystems and societies, as well as abiotic processes in the earth system. Water is used by humankind predominately in agriculture and food production, which account for roughly 90% of global water consumption (e.g., Falkenmark & Rockström, 2004). Irrigation water use has steadily increased over the last century (Jaramillo & Destouni, 2015).

Such uses are both strongly globalized and affected by local water scarcity conditions. Globalization of water mainly occurs through the trade of agricultural products and the associated virtual water transfers, whereby human populations in one place rely on water resources available for crop production in other regions of the world (Allan, 1998). About 20–25% of the water consumed in agriculture is (on average) accessed through international trade (D'Odorico et al., 2019). Other globalization mechanisms for water include international investments in water entitlements, agricultural land, and water-related financial assets (Rulli et al., 2013). In some of these cases, water is simply treated as a natural resource underlying agricultural production that is not traded in a separate market. In others, it is explicitly treated as a commodity or has become the target of financial investments. Water is needed for food production and sanitation and is therefore crucial to food security and the fulfillment of the human rights to food and healthy life.

Thus, while from an ecocentric perspective, water is viewed as a natural intrinsic entity, from an anthropocentric perspective it is considered instrumental to human needs such as the enjoyment of human rights or sustenance of subsistence and production systems (D'Odorico et al., 2020). Often, water is treated as a commodity that is traded and used to generate revenues (Figure 1). These different conceptions of water (e.g., Jenkins et al., 2021) are grounded on different sets of values, both intrinsic (i.e., independent of human uses) and extrinsic (i.e., instrumental to current and future uses). Such values may invoke different legal arrangements and rights, including the rights of nature (Boyd, 2017; (Chapron et al., 2019); Cano-Pecharroman, 2019), human rights (United Nations, 1948; Kent, 2005), future person's rights (Engelhardt, 1976; Elliot, 1989), as well as access (Ribot & Peluso, 2003), and property (Dagan, 2021) rights. The specific legal doctrine depends on whether the focus is meeting the needs of nature, human beings, future generations, stakeholders in water resource use or shareholders in businesses relying on water as a commodity (Figure1).

The type of values, use, property regimes, and rights typically determine the way water resources are accessed and used in economic activities. The interplay between hydrological characteristics, physical

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https://doi.org/10.1016/j.worlddev.2024.106650

Available online 16 May 2024

pathways of appropriation, and water tenure can produce very different socio-hydrological outcomes, with benefits and costs often unequally distributed between "winners" and "losers".

2. From water rights to water access

Water tenure is "the relationship, whether legally or customarily defined, between people, as individuals or groups, with respect to water resources." (FAO, 2020: p. 5). Water tenure arrangements are the rights and rules (both formal and informal) determining how individuals and groups can use water resources and the way users relate to one another (Table 1). Such rights and rules can be established by formal law (e.g., legislation or judicial decisions), customary arrangements, or other informal practices that emerge outside the legal and customary domain because of failure in the enforcement of formal water legislation (FAO, 2020; Hodgson, 2016). More recently, some countries have started to recognize the rights of nature, including the rights of rivers and watersheds, establishing a new type of water tenure that is not centered on human uses but on nature's needs (e.g., Cano-Pecharroman, 2018). Water tenure systems typically recognize a bundle of rights, which may include use rights, exclusion rights, transferability rights, governance and management rights, and procedural rights to appeal (and participate to) decisions affecting a water tenure system and the enjoyment of water rights (FAO, 2020).

Contemporary Western legislation on water abstraction and use finds its roots in Roman jurisprudence. Different contemporary legal regimes, mainly the common, civil, and customary law traditions, their historical interaction and overlap, produce different forms of rights and laws that regulate the abstraction and use of water from different sources such as streams, rivers, lakes, and groundwater. In most legal traditions, water rights (i.e., the legal rights on water) have been historically attached to land tenure and land ownership rights. In systems with land-based rights, water is seen as an appurtenance of the land; for instance, land-based rights may establish that owners of land adjoining a watercourse have the right to use its waters (Table 1). Nevertheless, contemporary water reforms, both in the Global North and in the Global South, in common law and civil law countries, have increasingly been moving towards systems of 'modern water rights' which go beyond the traditional land-based approaches (Hodgson, 2016).

Transcending the differences between common, civil, and customary traditions there are four conventional property systems (Cole & Ostrom, 2010) representing general abstract institutional categories that can be used to describe different typologies of (lawful) water acquisition (See Table 2). Actual property systems are often hybrid and more complex than these abstract categories and may entail overlap and interaction of different systems.

A rights-based evaluation of how individuals and groups can use water resources is, however, unable to fully describe the many ways through which water is being appropriated. A theory of access, which focuses on ability, rather than property theory and rights (Ribot & Peluso, 2003), is useful to evaluate different forms of water appropriation. In fact, while water appropriations are unlawful when they occur in violation of existing property rights of state, community, or individuals (Table 2), such a rights-based analysis would fall short of capturing the complexity of cases of water access and appropriation. Property rights on water are overall difficult to define and establish. There are often multiple overlapping claims, with mixed rights on water. For instance, water can be formally a property of the state but customarily the common property of a community that derives its livelihoods from it (Schmidt & Mitchell, 2014). These ambiguities resulting from a mismatch between water tenure systems (i.e., rules and norms establishing who can use a water resource), water claims (who says 'it's mine'), and water possession (who physically controls the access to water), often expose land and water commons to appropriation and grabbing (Dell'Angelo et al., 2017; D'Odorico et al., 2024). Here we investigate both the relationship between water tenure and water claims conducive to water grabs, and mechanisms providing physical control (i.e., possession) of water resources.

An analysis based on property systems would ignore the history of access and ability to use water. In other words, while formally the acquisition of a water resource through negotiations with the state government may appear to be lawful, de facto it would lead to the usurpation of its prior users who hold informal (customary) rights on that resource (Troell, 2022). Access is not related to formal rights on water but depends on social relationships and power dynamics that regulate and limit actors' ability to use water (Boelens et al., 2022).

As a result of neoliberal globalization, water has been placed under the pressure of commodification, a process through which water resources are turned into a fungible good that can be traded in markets and generate revenues through transactions. In different socio-political contexts "every society sets boundaries on where commodification begins and ends. Where the boundaries lie is a matter of contention."

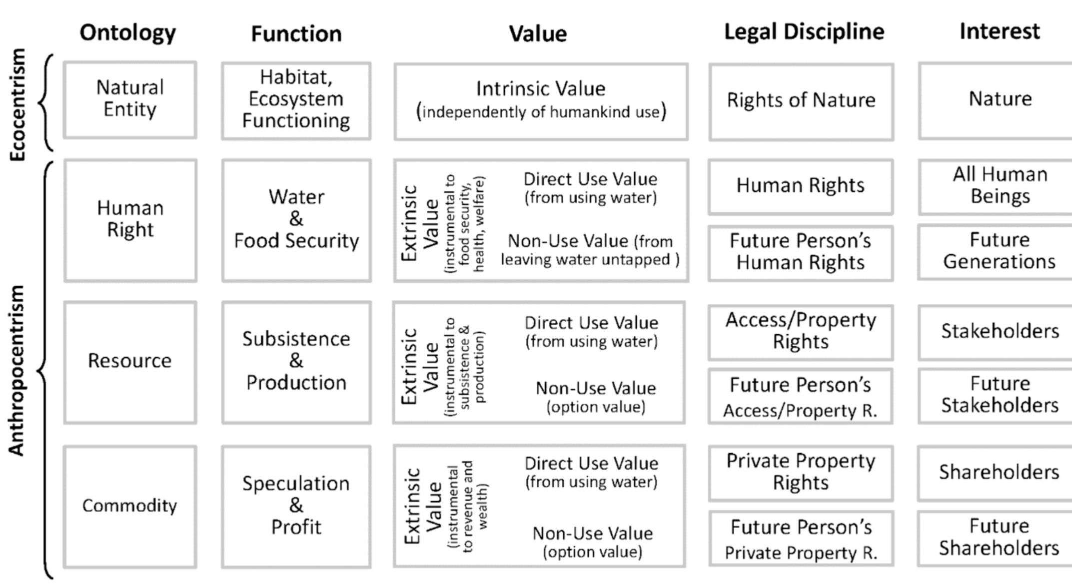

Fig. 1. Ecocentric and anthropocentric perspectives on water. Water can be considered a natural entity, human right, resource, or commodity. Such ontologies are associated with different sets of values, rights, and functions that are instrumental to the wellbeing of nature, human beings, or corporations. (Authors' elaboration).

Table 1
Water traditions and rights (Authors' elaboration, based on FAO, 2022 and Hodgson 2016).

<table>
<tr><td rowspan="11">ANTHROPOCENTRIC</td><td rowspan="5">Customary law tradition</td><td colspan="2">Customary arrangements (on ≈50% of farmland area worldwide)</td></tr>
<tr><td colspan="2">Religious or spiritual practices</td></tr>
<tr><td colspan="2">"Assumed" water tenure arrangements (under the belief that water use permits are either not needed or already secured)</td></tr>
<tr><td colspan="2">"Unrecognized" water tenure (when some uses are not protected or regulated because they are not recognized by the law)</td></tr>
<tr><td colspan="2">Illegal use or "water theft" (tolerated by the authorities as a result of lack of implementation of water laws)</td></tr>
<tr><td rowspan="2">Common law tradition</td><td>Riparian doctrine ("riparian" water rights as an integral component of the right of ownership/property of the land)</td><td rowspan="5">Modern water rights
Water Rights (property rights on water of individuals, communities, or the State)
Water Permits/Concessions/ Licenses (to abstract, derive, and impound water)
Powers conferred to agencies or companies operating in the irrigation, industrial, or water supply sectors (to develop water infrastructure and supply water)
Environmental flows (minimum flow requirements established by the law)</td></tr>
<tr><td>Prior appropriation doctrine (water rights obtained through beneficial use instead of land ownership).</td></tr>
<tr><td rowspan="3">Civil law tradition</td><td>Distinction between public and private waters (land-based)</td></tr>
<tr><td>Private use of water subject to limitations and restrictions (such as servitudes, rights of way, quantity abstraction, and pollution)</td></tr>
<tr><td>Public use of water (generally entailing concessions).</td></tr>
<tr><td>Right to water</td><td colspan="2">Human Right to Water (a putative right which defines the right to water as a human right. This right emanates from the right to food, as about 40% of food production uses irrigation, which accounts for ≈90% of human water consumption. A human right to water for drinking and sanitation has also been recognized by the U.N.)</td></tr>
<tr><td>ECOCENTRIC</td><td>Rights of Nature</td><td colspan="2">Water and Rivers as legal persons (recognized by formal law in a few countries but not in most of the world)</td></tr>
</table>

Table 2
Property regimes on water and associated legal mechanisms of acquisition.

Property systems	Examples of means of water acquisition
State Property	Water concession, license, permit
Private Property	Trade, purchase, market transaction
Common Property	Customary arrangements and practices
Open Access	Unregulated withdrawal and abstraction

(Harvey, 2007, p. 165). Water sits at those boundaries, with some countries allowing for trading of water entitlements, and others not recognizing tradeable property rights on water (Richter, 2016). However, whether the new frontiers of commodification extend to water resources does not only depend on society's moral choices and values attached to water (Figure 1) but also on exogenous forces that impose commodifying practices (Bakker, 2014). In fact, the commodification of water (and other natural resources) often arises from neoliberal policies invoking the institution of property rights allegedly to avoid inefficient use of resources and overexploitation. The adoption of neoliberal approaches to water governance opens new business opportunities for corporations and is often imposed on poorer countries as a condition for access to credit from development banks with the rationale that market drivers will lead to water uses that maximize profits (Shiva, 2002; Harvey, 2005).

Powerful economic actors, such as agribusiness corporations, or investment funds produce and take advantage of neoliberal dynamics of transnational land and water appropriation while securing access to strategic resources, such as water (Dell'Angelo et al., 2018). In this light, it is crucial to address the question of who benefits and who instead is negatively and unjustly affected by the interdependent dynamics of water appropriation to inform the discussion on how to regulate access to water. At the same time, it is fundamental to acknowledge the emergence of informal water markets even in the absence of private property rights (Manjunatha et al., 2016).

3. Water grabbing

Water grabbing is typically defined as a socio-environmental phenomenon of water appropriation that occurs when water resources are relatively scarce, and their appropriation comes at the expense of the environment, livelihoods, food security, and other critical uses (both current and future) (Rulli et al., 2013). Such appropriations take place under conditions of power imbalance and in disregard of the environment, local users, and their customary rights (Box 1) (Mehta et al., 2012). Therefore, to assess the possible occurrence of water grabbing when an actor (either public or private) gains access to water, we would need to find who loses it, evaluate the power relations among actors, and the mechanisms of appropriation (Dell'Angelo et al., 2018a; Loch et al., 2020). In general, water grabbing can occur unintentionally, when the mechanisms of water appropriation are less obvious as in some of the cases presented in this paper. Nonetheless, they can have detrimental impacts on livelihoods or the environment. We argue that intentionality and lack of unforeseen effects are not "sine qua non" for water grabbing.

The academic literature traditionally focused on blue water grabbing through large-scale land acquisitions (Rulli et al., 2013) or on material extractive processes associated with infrastructural development (Mehta et al., 2012). Here we review the other biophysical mechanisms of water appropriation that may constitute water grabs, particularly those related to land use change for agriculture and forestry.

4. Water appropriation pathways

We categorize different mechanisms of water appropriation to highlight some pathways that have been historically overlooked. Water can be appropriated through (a) land acquisitions; and (b) infrastructural development; but also through (c) pollution, (d) changes in cultivated crops; (e) afforestation; (f) land–atmosphere interactions; (g) a switch to more efficient irrigation systems; and h) virtual water trade.

a) Blue water appropriation through land acquisitions

In the case of agriculture, crop production relies both on rainwater (or 'green water') and withdrawals from surface water bodies and aquifers ('blue water') for irrigation. Green water acquisitions are inherent to land acquisitions (Rulli & D'Odorico, 2013). Here we specifically focus only on blue water which fundamentally relates to the direct appropriation of water resources from rivers, lakes, and groundwater. Blue water is used not only for agriculture, but also for municipal needs, mining, and other industrial uses. When (blue) water rights are tied to the land as an appurtenance (e.g., riparian water rights) land acquisitions indirectly entail blue water acquisitions.

Blue water scarcity is a condition of local unavailability of sufficient blue water to sustainably (and entirely) meet the crop irrigation requirements at a given location. In these conditions, a farmer's decision to irrigate diminishes other farmers' ability to irrigate (in the same area) (Chiarelli et al., 2022). In other words, blue water scarcity is associated with potential competition and conflict among alternative water uses, including environmental uses (Dell'Angelo et al., 2018b). Blue water appropriations for irrigation associated with land acquisitions in conditions of agricultural blue water scarcity (GRAIN, 2012;Chiarelli et al., 2022; Siciliano et al., 2017; Antonelli et al., 2015) exclude other farmers from access to blue water for irrigation. Thus, in the presence of unbalanced power relations (ILC, 2011) such water appropriations are "water grabs", particularly in areas prone to malnourishment (Dell'Angelo et al., 2018a; Rulli & D'Odorico, 2014).

Interestingly, large-scale land investors target areas with good access to water resources both in current conditions and under climate change scenarios (Chiarelli et al., 2016). Therefore, while, as stated earlier, water grabbing occurs in regions affected by blue water scarcity, it still targets areas with good access to water resources. Indeed, a recent study (Chiarelli et al., 2022) of about 160 geo-located large-scale land deals around the world highlighted how investors tend to target land with preferential access to surface water and groundwater (i.e., closer-than-average to streams and groundwater) in regions affected by blue water scarcity. Interestingly, blue water scarcity is enhanced by agribusinesses by switching to water-demanding crops (Chiarelli et al., 2022). Thus, water appropriations may occur not only by acquiring and irrigating agricultural land in areas affected by blue water scarcity but also by changing crops, a pathway of water appropriation that is discussed below.

Examples of water appropriation associated with large-scale land investments can be found in many regions of the world (Rulli et al., 2013) that are affected by blue water scarcity and where investors irrigate the land with water from adjacent rivers or underlying aquifers. Here we present the illustrative case of the Madre Vieja River on the South Coast of Guatemala, where the expansion of oil palm, sugarcane, and banana plantations by agribusiness corporations has led to water abstractions at the expense of local farmers and the environment (Box 2).

b) Blue water appropriation through infrastructure

Powerful actors may gain control over water resources through infrastructures for the withdrawal, diversion, or storage of water resources such as dams, reservoirs, gates, diversion canals, or wells. Through these infrastructures, some actors can be given access to water resources, while prior or future users might see their ability to enjoy access to water resources diminished or impeded. Thus, while water infrastructure is often seen as crucial to unleash the agricultural potential of rural nations exposed to seasonal water scarcity, strong hydrologic variability, and unreliable water availability (e.g., Grey & Sadoff, 2007; Hanjra et al., 2009), it is often unclear who would actually benefit from such infrastructure, and who the winner and losers would be. For instance, dams, likely the most iconic type of water infrastructure, are commonly presented as crucial to the economic development of African countries (Grey & Sadoff, 2007), often in disregard of loss of water access by smallholders and pastoralist communities in downstream areas (Carr, 2017; Siciliano & Urban, 2017).

Box 1
Overview of definitions of Water Grabbing (from Dell'Angelo et al., 2018a).

"Powerful actors are able to take control of [...] water resources already used by local communities or feeding aquatic ecosystems on which their livelihoods are based" (Mehta et al., 2012, p. 197)

Illicit diversion of water without compensation or consultation (Wagle et al., 2012)

Mobilization of political, institutional, and economic power to control water for hydropower in disregard of social and environmental impacts (Matthews, 2012)

Downstream water quality affected by a large-scale land deal (Arduino et al., 2012)

Coercive dispossession of a minority to favor water projects (Velez-Torres, 2012)

Water appropriations in conditions of water scarcity and competition with the food security and livelihoods of local populations (Dell'Angelo et al., 2018a; Chiarelli et al., 2022)

It includes both green and blue water grabbing (Rulli & D'Odorico, 2013)

Box 2
Water appropriation through large-scale land acquisitions in the Madre Vieja River, Guatemala.

The Madre Vieja as well as other rivers on the southern coast of Guatemala have been overexploited as a result of water abstractions and diversions to adjacent oil palm, sugarcane, and banana plantations established by agribusiness corporations along these watercourses. Local communities have been negatively affected by the ensuing water scarcity, which has led to the loss of rural livelihoods and environmental degradation. The latter is contributed both by loss of environmental flows and by pollutants from fertilizers, pesticides, and effluents from sugar production plants, whose concentration is strongly enhanced in low flow conditions. Land and water appropriations by agribusiness corporations have collided with the interests of subsistence farmers. In the absence of protection from the government, local communities and activists unsuccessfully filed complaints with the public prosecutor's office for crimes against the environment and human rights, leading to organized protests, social unrest, and the assassination of some activists. Local communities, farmers, and grassroots associations, destroyed the diversion structures built on the river by palm oil companies, thus allowing the river to reach the Ocean after years of no flow. Demonstrations by community associations and social movements drew the attention of the central government and the rest of the country on water grabbing and water contamination in the Madre Vieja and other rivers across Guatemala. (Vidal, 2018; EJ Atlas, 2020).

A recent study (Tatlhego & D'Odorico, 2022; Tatlhego et al., 2022) has shown how irrigation dams built in Africa since 2000 have led to the emergence of irrigated areas in their surroundings, often to the benefit of large-scale agriculture instead of subsistence or small-scale farmers, as evidenced by the increase in average farm size after the construction of these dams (Fig. 2).

Besides irrigation, water appropriation through infrastructure can also occur for mining, hydropower generation, other industrial uses, and municipal needs (Mehta et al., 2012; Siciliano & Urban, 2017). In these cases, however, most of the water withdrawals (in volume) are not used consumptively but are returned to a water body. Thus, because the return flows remain available to other users, these appropriations would not constitute a water grab per se. However, the return flows often become unusable if they lose some of their original properties. Because of such losses water appropriations can be water grabs. For instance, mining and municipal uses pollute the water. In the absence of adequate treatment, these return flows are not suitable for further use and even become an environmental hazard. This is also a form of water appropriation as explained in the following section. In the case of hydropower generation return flows lose a substantial amount of their gravitational potential energy, thereby making them less suitable for some uses (e.g., gravity irrigation).

Not only can water infrastructure be crucial to physical water access and appropriation but also to a broader enjoyment of water rights. Specifically, depending on existing water tenure arrangements, in the absence of infrastructure for water diversion, senior water rights holders (in 'prior appropriation' water tenure systems, senior water rights holders have higher priority to divert water from a water body than junior rights holders) may be unable to negotiate a lease agreement with other users. In fact, in water tenure systems based on prior appropriation, junior water rights holders can use water without owing any compensation to senior holders who forgo their rights. In other words, unused senior rights would be forgone to the benefit of water rights holders who are "next in line". In the absence of diversion infrastructure there is no interest for next-in-line water rights holders to negotiate a paid lease to acquire water allocations they would receive anyway because of lack of use by the senior rights holders. For instance, in the USA water rights that can be claimed by Native American Reservations on the grounds of the Winter vs United States Supreme Court ruling (1908) are often considered to be "strong rights" because of their seniority. However, because "Winters rights" are only recognized for uses instrumental to the fulfillment of the purpose of the reservation, there is no legal mechanism for a reservation to use the water for other purposes or even transfer water rights to environmental uses. In this sense a water diversion infrastructure would give a reservation more power in the negotiation of a lease agreement with other users. Interestingly, land tenure has been identified as one of the factors possibly preventing the financing of diversion infrastructure because the land typically cannot be used as a collateral for loans (Sanchez et al., 2023) (see Box 3).

c) Blue water appropriation through pollution

Contamination is another mechanism of water appropriation

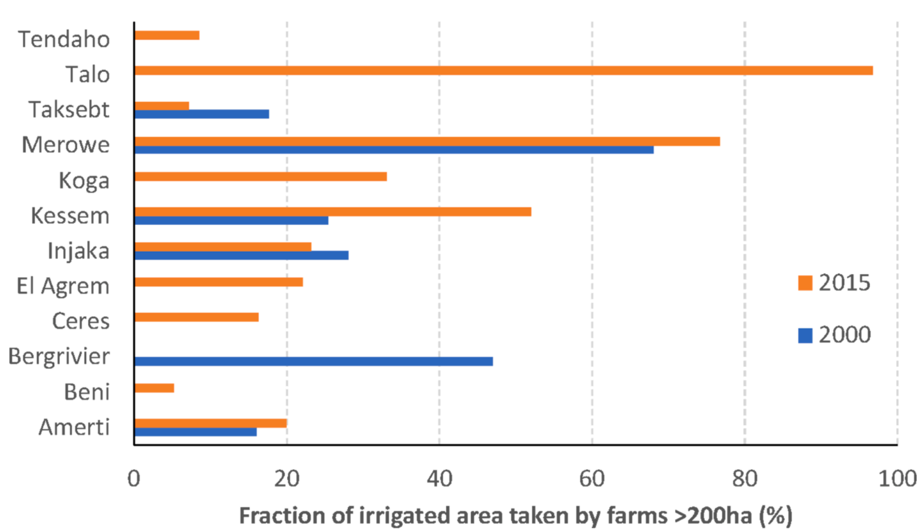

Fig. 2. Change in farm size after dam construction in recent irrigation dams built in Africa since 2000 (Authors' elaboration; data . Source: Tatlhego & D'Odorico)

Box 3
Water appropriation through infrastructure development: The Gibe III Dam on the Omo River, Ethiopia.

Access to water resources in the Omo River Basin in southwestern Ethiopia at the border with South Soudan and Kenya has been strongly altered by the construction of the Gibe III dam, one of Africa's largest mega-dams built for hydropower generation and new irrigated agriculture. This infrastructure has taken physical control of Omo River's waters to meet the needs of hydroelectric corporations and agribusiness, leaving the downstream population with very limited access to water and environmental damage. The riverine forest has been destroyed, and the Turkana Lake is desiccating, thus causing major livelihood losses in indigenous pastoralist and fisherfolk communities, food insecurity, transboundary conflict, and migration. The appropriation of water resources by powerful groups controlling the Gibe III reservoir is causing poverty, food insecurity, internal and transboundary conflict, and migration. The construction of the dam is expected to attracts large scale land acquisitions for commercial farming (e.g., sugarcane production) along the Omo river and induce the expropriation of indigenous and pastoralist communities that will lose access to ancestral land and water resources (Carr, 2017).

(Arduino et al., 2012). By polluting a water body, an actor is de facto diminishing that water body's ability to meet other needs, thereby subtracting water from alternative users, including environmental functions. Pollutants can be from agriculture (pesticides, fertilizers), mining, industrial operations, or municipal effluents. In the most extreme case, heavy pollution makes the water unusable by other actors and unsuitable for aquatic life. In that case, water is de facto grabbed from other users and environmental needs. More moderate levels of pollution may increase the concentrations of toxic chemicals without exceeding environmentally acceptable standards. Thus, while environmental quality is degraded it does not critically compromise ecological functions. Even though environmental needs are overall met, these moderate levels of pollution limit water use by other actors. This fact can be better 'visualized' by invoking the grey water framework (Hoekstra, 2020). Every form of pollution has a water cost, or 'grey water footprint', which is the minimum water flow that is needed to keep the pollutant concentration below environmentally acceptable standards. This means that the grey water flow cannot be withdrawn because its abstraction would bring the pollutant concentration above the acceptable standard. When the grey water flows exceed the environmental flows (minimum flow required to quantitatively sustain aquatic habitat), pollution has the effect of either reducing water availability for human consumption or causing environmental degradation. In other words, the polluter de facto takes water away from either other users or the environment (O'Bannon et al., 2014). The case of pollution from sugar processing factories on the southern coast of Guatemala (Box 2) is an example of water appropriation through pollution. Similarly, effluents from oil palm plantations and mills in Indonesia have been reported to degrade water quality thereby limiting water availability for human or environmental needs (Box 4).

d) Blue water appropriation through the shift to water-demanding crops

When farmers switch to crops that are more water demanding, the increase in evapotranspiration within cultivated areas (either rainfed or irrigated)) reduces surface and groundwater flows at the expense of downstream users. Thus, even in the absence of irrigation (and associated blue water withdrawals) the use of water-demanding crops can reduce blue water availability. By planting water-demanding crops, farmers reduce groundwater recharge and runoff, possibly depriving downstream users of water flows they have been previously relying on. For Instance, in an analysis of two land deals in Ethiopia in the Oromya region of the Omo River Basin and in the Gambella region in a tributary of the Nile River, Chiarelli et al. (2022) found the emergence of water scarcity downstream from areas cultivated with water demanding crops such as maize, sugarcane, cotton, and sunflower. Another interesting case of crop shift in predominately rainfed agriculture is the expansion of water-demanding rubber plantations at the expense of staple crops in Southeast Asia (Box 5).

e) Blue water appropriation through afforestation

Decades of research in forest hydrology consistently indicate that forestry practices with increasing tree cover in upland watersheds have the effect of reducing downstream surface and groundwater runoff (Bosch & Hewlett, 1982; Andréassian, 2004; Runyan et al., 2012). Afforestation projects have recently been proposed as an approach to desertification and land degradation reversal in China, sub-Saharan Africa, and the Middle East (Li et al., 2021). For instance, since the late 1970 s China's Three-North Shelter Forest Program planted 10 billion trees to arrest the expansion of the Gobi Desert (Zastrow, 2019); likewise, the Great Green Wall of Africa (from Senegal to Djibouti) was proposed to prevent the expansion of the Sahara (Ndeso-Atanga, 2018;

Box 4
Water appropriation through pollution: The case of oil palm production and milling in the Indonesia.

Palm oil is the world's most traded vegetable oil and is used both as a food and bioenergy source (Carlson et al., 2012). Oil palm plantations have strong impacts on water resource.

In addition to its remarkably high annual crop water requirements (estimated in the order of 12,000 m^3/y (Rulli et al., 2019)), oil palm also affects water resources by threatening freshwater quality. Because of the relatively low fertility of tropical soils, oil palm production relies on the massive use of fertilizers through the application of N, P, K, and Mg (Ng et al., 1999; Goh, 2005), thereby contributing to freshwater pollution, an effect that is further compounded by the release of oil mill waste in the region (Obidzinski et al., 2012). According to some estimates, the grey water footprint of oil palm production in Indonesia is about 950–1600 m^3/ha/y) (Rulli et al., 2019).

Over the past 2 decades, the total oil palm plantation area in Kalimantan has more than doubled (from 2.4 to 5.8 million ha). The consequent deterioration of water quality has led local populations to strive to find access to clean water. For instance, in the Ketapang and Sambas districts, the heavy use of fertilizers and pesticides in oil palm production and effluents from mill operations have heavily contaminated the water bodies. Communities living near the Sambas River have been complaining about the poor water quality and its impact on fish, especially during the dry season. The consequent decrease in catch rates and the inedibility of contaminated fish are undermining rural livelihoods and subsistence systems (Setiyono & Natalis, 2021).

Box 5
Water appropriation by shifting to water-demanding crops: The expansion of rubber plantations into staple croplands across Southeast Asia (Chiarelli et al., 2020).

About 50% of the world's rubber supply is contributed by natural rubber, with about 90% of the global production coming from plantations in Southeast Asia (Chiarelli et al., 2020). The escalating global demand for rubber (which doubled in the last two decades) is driving an expansion of rubber plantations into forests and croplands through large-scale land concessions across Southeast Asia (Fox & Castella, 2013; Ahrends et al., 2015). The switch from staple crops to rubber production is motivated by the higher revenues of rubber, which according to a 2009 study, can reach up to USD 2200 per hectare per year compared to about USD 400 per hectare per year from tea or rice crops (Qiu, 2009). Rubber plants are typically not irrigated and use a lot of water to the point that they are called "water pumps" for their ability to sustain high rates of root uptake and associated (green) water flows into the atmosphere (Tan et al., 2011; Giambelluca et al., 2016; Chiarelli et al., 2018). The water demand of rubber plants can be as high as 2.5 times that of rice (on a per unit area basis). A study based on the integrated use of hydrological modeling and remote sensing (Chiarelli et al., 2020) has shown that in Southeast Asia the switch from staple crops to rubber is often followed by a decrease in runoff and groundwater levels in agreement with observations (Tan et al., 2011) and an increase in seasonal water scarcity. The most extreme hydrological impacts are found in smaller basins of Thailand, where rubber plantation has expanded to 78% of the area, almost halving monthly runoff in the dry season thereby reducing water availability to other users (Chiarelli et al., 2020).

Gadzama, 2017). A few other global pledges, programs, and campaigns have been spearheaded and endorsed by billionaires, NGOs, Governments, UN Agencies, and indigenous groups (Ndeso-Atanga, 2018) for land degradation reversal and 'nature-based' climate change mitigation (Bastin et al., 2019). Recent studies have examined the degree to which these projects may exacerbate water scarcity (Wang, 2019) and lead to new competition with previous water users or diminish farmers' ability to adopt irrigated agriculture. In this sense, tree restoration may induce the dispossession of downstream communities (Fedele et al., 2021). Indeed, this form of water appropriation for environmental needs may have important detrimental impacts on downstream water users. A recent study (Ricciardi et al., 2022) has evaluated the increase in water scarcity that would result from the worldwide afforestation of regions suitable for planting trees (Fig. 3) and found a dramatic increase in blue water scarcity (hence competition for water and potential for water grabbing) across semiarid Africa and Australia and the Brazilian Cerrado. These areas are particularly vulnerable to water appropriation from afforestation projects.

Afforestation projects have been repeatedly found to reduce water availability to other uses. An emblematic example is the case of eucalyptus tree plantations for soil stabilization or land degradation reversal (Box 6).

To date, very few countries have adopted legislations acknowledging and regulating water appropriations caused by afforestation. In South Africa, The National Water Act (1998) treats timber plantations as a form of water withdrawal conducive to stream flow reduction. Therefore, commercial plantations are registered as water users and require a water license (DWAF, 1999).

Conversely, forest removal has been documented to increase streamflow and groundwater levels (Andréassian, 2004). This well-known hydrologic impact of deforestation has inspired land and water management programs to adopt tree removal as a water conservation measure. For instance, the city of Cape Town (South Africa) has been cutting trees to increase water availability (Turpie, 2018; AfricaNews, 2020; Crawford, 2020; Roelf, 2021). In rural areas, forest clearcut or thinning can be used to increase water yields or achieve water neutrality whereby a private water user can compensate the increase in water consumption in some areas of a watershed by removing trees in other parts of the same watershed (Nel et al., 2009). Forest thinning has recently been adopted as a forest management practice to reduce forest fuel and mitigate the risk of severe forest fires. The consequent increase in water yields is an additional benefit that could fund such a forest management practice (Roche et al., 2020). The tenure and governance of these additional water resources has seldom been analytically investigated. Who does the increased water availability due to forest management belong to? Can it be traded with other users? While the power dynamics controlling the access to the additional water availability still need to be adequately investigated, the answer to these questions is expected to depend on water tenure arrangements (both formal and informal) and the associated bundle of rights (see Table 1).

f) Water appropriation through land–atmosphere feedback

The cases considered so far focused on the impact of forest cover on runoff. However, when land use change affects relatively large areas (greater than 10^4-10^5 km^2) precipitation might change too. For instance,

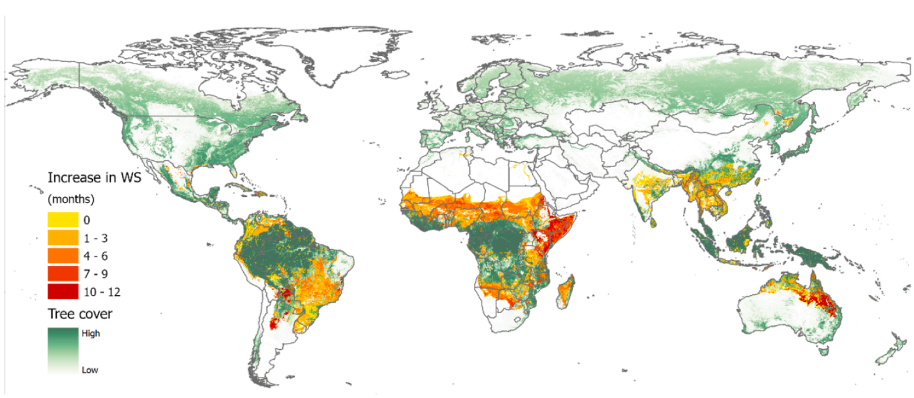

Fig. 3. Competition for water between afforestation and agriculture. The increase in the number of months affected by blue water scarcity as a result of afforestation projects in areas (allegedly) suitable for tree establishment (Authors' elaboration; data). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
Source Ricciardi et al., 2022

Box 6
Water appropriation by afforestation: The case of eucalyptus plantations.

Native to Australia eucalypti are fast growing trees that can be found on every continent (except Antarctica). In some regions eucalyptus trees have been imported and planted as a measure for land stabilization, soil sheltering from wind and water erosion, and land degradation reversal. While some studies are showing only limited improvements in soil nutrient status in areas afforested with eucalyptus (Belay et al., 2015), there is consensus that these trees sustain high rates of water consumption, thereby causing groundwater depletion (Gindaba et al., 2013) and declining surface runoff (Jaleta et al., 2017).

large-scale irrigation may affect regional precipitation through land–atmosphere interactions (Puma & Cook, 2010). Likewise, large-scale deforestation can reduce precipitation through vegetation-atmosphere feedbacks associated either with precipitation recycling (i.e., the fraction of regional precipitation contributed by water vapor from regional evapotranspiration) or vegetation impact on the surface energy balance, boundary layer stability, and convective precipitation formation (Bonan, 2008; Runyan et al., 2012; Lawrence & Vandecar, 2015). Thus, extensive deforestation could lead to a decrease in downstream water availability, possibly taking water away from other users or the environment (Runyan & D'Odorico, 2016). Even though its quantitative assessment is affected by strong uncertainties, scholars have already started to think about the governance of precipitation recycling (Keys et al., 2017; 2019; 2024). Interestingly, in some cases changes in land use or land cover may impact precipitation onto downwind regions (e.g., Ray et al., 2006), thereby contributing to diminishing access to water therein through land cover change and teleconnections. These dynamics can be better explained in terms of precipitation recycling by conceptualizing the precipitation onto a certain region (shaded area in Fig. 4) as contributed by water vapor coming from (i) evapotranspiration from the same region (precipitation recycling), (ii) evapotranspiration from upwind regions, and (iii) ocean evaporation. Because evapotranspiration is strongly enhanced by the presence of forest vegetation, upwind deforestation is expected to locally increase runoff and reduce evapotranspiration, thereby leading to a decrease of precipitation in the target region (and water availability therein). Thus, in this case water appropriation takes place through land use change, the consequent modification of green water flows (instead of blue water flows as in the previous section), thereby leading to a decrease in blue water availability in the target area (Keys et al., 2017). Of course, atmospheric flows are defined with stronger uncertainties than topography-driven runoff. They are typically investigated with air parcel trajectory models to statistically determine the air flow paths and the source regions contributing to water vapor and precipitation in the target area. Moreover, the presence of water vapor is not sufficient to determine the occurrence of precipitation, which depends on complex cloud microphysical processes that are difficult to simulate in regional climate models. Lastly, the impact of land use change on precipitation is not only controlled by changes in water vapor flows to the target areas. Land use change may alter the surface energy balance and consequently modify climate conditions both locally, and globally, through teleconnections. For instance, model simulations have shown how midlatitude afforestation may alter both the local energy budget and the tropical circulation, leading to a northward displacement of the Intertropical Convergence Zone and the Hadley Cell, which is expected to induce an enhancement of tropical precipitation (Swann et al., 2012) regardless of whether the precipitation increase is contributed by atmospheric moisture from the new midlatitude forests. Such teleconnections have just started to be investigated, while their impact on water appropriation and water tenure are frontiers for new research in this field.

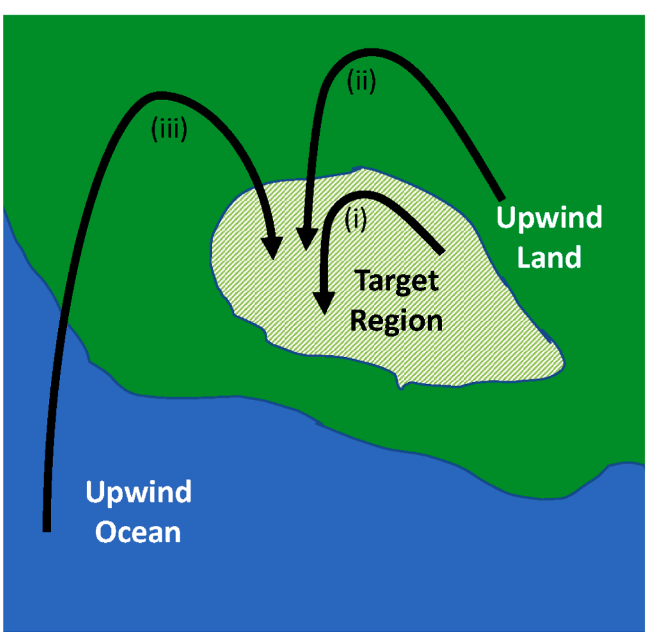

Fig. 4. Sources of atmospheric moisture contributing to precipitation in the target region (Authors' re-elaboration of Keys et al. (2017).

g) Blue water appropriation from the adoption of more efficient irrigation systems

The adoption of more efficient irrigation systems (e.g., the switch from surface, furrow, or sprinkler irrigation to drip irrigation) is often seen as a solution to water scarcity in that it enhances consumptive water uses while minimizing water losses as drainage and runoff (or "return flows"). While at the farm scale return flows can be viewed as a water loss, at the watershed scales they play an important role in sustaining environmental flows, groundwater stocks, and downstream uses. There is overwhelming evidence that in water scarce regions farmers who switch to more efficient irrigation systems do not reduce their withdrawals but either irrigate more land, perform double cropping, or plant crops that are more water demanding (Foster & Perry, 2010; Scott et al., 2014). Known as "irrigation paradox" this switch to higher efficiency systems does not result in water savings but in a reduction of return flows at the expense of prior or future downstream users (Pfeiffer & Lin, 2010; Ward & Pulido-Velazquez, 2008). This potential mechanism of water appropriation has often been overlooked (Owens et al., 2022) (see Box 7).

h) Virtual appropriation of water through trade

Trade can be seen as an underlying (or 'indirect') pathway of water appropriation that acts through a variety of 'direct' mechanisms of actual access to water such as those described above. The production of several goods, particularly agricultural commodities, takes a huge amount of water, which is estimated to exceed by orders of magnitude (in terms of either mass or volume) the commodities themselves. Some regions of the world are in conditions of chronic water deficit because they do not have enough water to produce all the food needed by their populations. Physically importing all the water needed by each country to meet its demand for agricultural products would simply be unfeasible because such water amounts would be too cumbersome and heavy to transport. However, it is feasible and affordable to produce agricultural

Box 7
Water appropriations through increased irrigation efficiency: The case of West Kansas.

Irrigated agriculture across Western Kansas relies on groundwater from the Ogallala, one of the largest aquifers in the world. The aquifer has been heavily depleted with an overall 50m water table drop since the 1970s, a situation that cannot be sustained in the long run. To address this problem, in the 1990s the state of Kansas started offering incentives to subsidize the cost of updates from surface irrigation to higher efficiency center pivot sprinkler systems. This update was meant to use water more efficiently, thereby reducing groundwater withdrawals. However, data from 1996 to 2005 show that, for most crops, withdrawals did not decrease with increasing irrigation efficiency. In most cases the withdrawals remained about the same (Pfeiffer & Lin, 2010). Water rights systems typically set a limit on withdrawals or irrigation applications rather than consumption. Thus, there is no incentive for farmers to reduce their withdrawals, which likely explains why farmers might have kept using the same amount of water to sustain higher yields or to plant water-demanding varieties. Unchanged withdrawal rates with increased irrigation efficiency correspond to an increase in water consumption and a corresponding decrease in return flows, with consequent water losses for downstream users and/or the environment (Pfeiffer & Lin, 2010).

commodities elsewhere and export them to trade-dependent countries. The seminal work by Tony Allan (1998) highlighted how, through trade, the global water demand is displaced worldwide. In fact, the trade of goods produced using water is associated with a virtual transport of water embodied in these products. Embodied water is not physically present in those goods but went in their production and is therefore commonly termed "virtual water" (Allan, 1998), or "water footprint" (Hoekstra & Chapagain, 2011). Thus, trade contributes to a globalization of water resources (about 25 % of water used for food production) whereby consumer's pressure on water resources is transferred to other regions of the world (e.g., D'Odorico et al., 2019). It is still unclear to what extent international trade contributes to international water grabs through unbalanced power relations that shape global trade patterns. While research in this field has highlighted the role of trade as contributor to unsustainable water consumption (Dalin et al., 2018; Rosa et al., 2019), the effect on water justice and unequal exchange dynamics still needs to be adequately investigated (D'Odorico et al., 2019; Hoekstra, 2020).

i) Water access control through energy supply

In water withdrawal and distribution systems relying on mechanized lifting with electrical pumps access to water can also be controlled through access to energy. For instance, in India water managers often use electricity rationing as a politically more viable approach to control groundwater pumping than the removal of existing electricity subsidies for irrigation. Thus, power supply is used to physically control access to (and use of) water (Ryan & Sudarshan, 2022; Mitra et al., 2023).

5. Conclusion

Defining water appropriation from a legal and biophysical perspective is an analytical challenge because it involves a variety of political and normative dimensions (Johnston, 2003; Swyngedouw, 2009; Rodríguez-Labajos & Martínez-Alier, 2015). It is not surprising that, differently from land acquisitions and land grabs, there has been no legislation to specifically define and address water appropriations and water grabs. Indeed, this phenomenon has seldom been the focus of official position documents, reports, declarations, guidelines, and laws from national governments or international organizations. Even the "Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests" (FAO, 2012), despite their lack of enforceability, remained overall silent about water tenure and water appropriation. There are certainly several underlying political and normative obstacles to the development and adoption of policies on water grabbing but a major problem remains the existence of a grey area in identifying the mechanisms through which water appropriation, use, and exclusion take place.

This paper provides an overview of the different institutional, legal, and biophysical conditions that characterize the dynamics of water appropriation and identifies some important pathways to water access. Indeed, while the literature in this field has historically focused on appropriation through land acquisitions, mining, and infrastructural development, we shed light on other pathways which have been overlooked and require closer scrutiny, namely, contamination, crop-shifting, afforestation, land–atmosphere interactions, and irrigation efficiency (Table 3). These mechanisms of water appropriation are not as intuitively connected with forms of access to and exclusion from water resources but, when scrutinized, they raise very similar challenges and potentially lead to water appropriation to the benefit of more powerful economic actors at the expenses of local communities, traditional users, indigenous people, fisherfolks, and small-scale farmers, and the ecosystems on which their livelihoods depend.

Water appropriation mechanisms take place within specific political-economic, institutional, and legal frameworks. Different legal regimes, mainly the common, civil, and customary law traditions, their overlap,

Table 3
Biophysical pathways of water appropriation that can lead to water grabbing.

Appropriation mechanism	Description	Water type	References
Land acquisition	*Land investors gain access to water*	*Green & blue*	Rulli et al. (2013); Dell'Angelo et al. (2018a)
Infrastructure	*Dams, wells… provide physical control of water while excluding others*	*Blue*	Wagle et al. (2012); Tatlhego and D'Odorico (2022)
Pollution	*Pollution makes water unusable & limits how much water can be withdrawn without exceeding pollution standards*	*Blue*	Arduino et al. (2012); O'Bannon et al. (2014)
Water demanding crops	*Higher crop water demand reduces downstream flow & groundwater*	*Blue*	Chiarelli et al. (2022)
Afforestation	*Forest establishment reduced*	*Blue*	Ricciardi et al. (2022)
Land-atmosphere feedback	*Land use change may reduce or increase precipitation in other areas*	*Green & blue*	Keys et al. (2017)
Increasing irrigation efficiency	*More efficient irrigation reduces return flows for downstream users*	*Blue*	Owens et al. (2022)
Trade	*Trade entails a virtual appropriation of water from production regions*	*Virtual*	Allan (1998)
Power supply rationing	*Energy rationing limits water access*	*Blue*	e.g., Ryan & Sudarshan (2022)

and historical interactions, produce different forms of water rights that regulate the use and abstraction of water from natural sources such as streams, rivers, and groundwater (Hodgson, 2016). As water grabbing is not legally disciplined, a rights-based approach falls short in identifying and addressing the threats raised by different mechanisms of water appropriation. Unravelling the interplay between the institutional-legal and hydrological dimensions of water appropriation is fundamental to the understanding of how different water appropriation pathways can affect previous water users and their water rights (either formal or customary). As the scholarly discussion on this critical issue is now ripe, policy makers are called to produce new instruments to govern this phenomenon.

CRediT authorship contribution statement

Paolo D'Odorico: Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing. **Jampel Dell'Angelo:** Conceptualization, Formal analysis. **Maria Cristina Rulli:** Conceptualization, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgements

Funded by European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie Innovative Training Network NEWAVE - grant agreement No 861509. P.D. was funded by the USDA Hatch Multistate project #W5190 capacity fund.

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