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Are water markets globally applicable?

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Abstract

Water scarcity is a global concern that necessitates a global perspective, but it is also the product of multiple regional issues that require regional solutions. Water markets constitute a regionally applicable non-structural measure to counter water scarcity that has received the attention of academics and policy-makers, but there is no global view on their applicability. We present the global distribution of potential nations and states where water markets could be instituted in a legal sense, by investigating 296 water laws internationally, with special reference to a minimum set of key rules: legalization of water reallocation, the separation of water rights and landownership, and the modification of the cancellation rule for non-use. We also suggest two additional globally distributed prerequisites and policy implications: the predictability of the available water before irrigation periods and public control of groundwater pumping throughout its jurisdiction.

1. Introduction

Water scarcity is one of the most high-impact global risks (Mekonnen and Hoekstra 2016, World Economic Forum 2016). Supply enhancement, such as the construction of dams and desalination plants, was the main approach used to counter water scarcity throughout the 20th century (FAO 2012, Gleick 2003). This approach produced enormous benefits, but also had environmental costs associated with facility development. Consequently, increasing attention has focused on measures that complement the traditional approach, promoting the efficient use of a fixed amount of water rather than seeking new supplies (Gleick 2002, 2003). For example, the state of California, in the United States, which is famous for its elaborate system of dams and aqueducts, has launched various non-structural projects in recent decades, particularly in the face of a historic drought (Hogue and Pincetl 2015). One such measure is water reallocation, which enables users to satisfy their water needs by transferring water among sectors without building additional facilities (Grafton *et al* 2012).

Water reallocation is the change in water allocation between agricultural, industrial, domestic, and environmental sectors, or within sectors (e.g. among farmers). Theoretically, this can be managed by a public organization or a market mechanism. Water reallocation implemented by a market mechanism is often called a water market or water trade, which is the focus of this paper. This paper examines domestic-level water markets to determine how national water laws affect the formation of water markets.

A water market is a representative 'soft path' measure (Gleick 2003) that can provide adequate incentives for users to use water resources efficiently (Zekri and Easter 2007, Hernandez-Mora and Del Moral 2015). The case of California shows that the strength of water demand usually differs among water sectors, even under water shortage conditions (e.g. California Department of Water Resources 1992). As long as such differences exist, water markets have an important role in decreasing economic loss by reallocating the diminishing water supply to water users in accordance with the strength of their demand for water (Kennedy 1992, Howitt 1994). Individual measures

have limited effects on water scarcity; however, there is growing interest in water markets as an option for addressing water scarcity (Debaere *et al* 2014, Hernandez-Mora and Del Moral 2015).

Recently, attempts have been made to determine how the combination of reservoirs, desalination plants, and improvements in irrigation efficiency (e.g. drip irrigation) could reduce water scarcity in various regions of the world (Wada *et al* 2014), extending several global-scale water scarcity assessments (Oki and Kanae 2006, Haddeland *et al* 2014, Jimenez Cisneros *et al* 2014). By contrast, little attention has been paid to water markets in the context of water scarcity assessments. This is partly due to the fact that the success of water reallocation depends largely on social institutions (e.g. legal conditions) and the collaboration of natural and social science is necessary to estimate potential application areas.

The purpose of this paper is to present the first global distribution of potential nations and states where water markets could be instituted in a legal sense, by investigating 296 water laws internationally. We also suggest two additional globally distributed prerequisites: the predictability of the available water before irrigation periods and public control of groundwater pumping over its entire jurisdiction.

2. Materials and methods

2.1. Investigation of global water laws

Previous studies showed that the implementation of a water market requires several legal conditions, as discussed in detail below. Hirshleifer *et al* (1969) demonstrated how water laws could promote or hinder the creation of a water market, with special reference to riparian and appropriative rights in the United States. More recently, their analytical perspective was followed by studies that have suggested the importance of three legal conditions: the existence of a rule allowing water reallocation (Grafton *et al* 2012); the separation of water rights and landownership (Chong and Sunding 2006, Grafton *et al* 2012); and modification of the cancellation rule for non-use (Bowden *et al* 1982, Gray 1989, Reisner and Bates 1990, Littleworth and Garner 2007). We substantiated that these three legal conditions are a minimum set of key rules through the cross-country analyses using California, Chile, and the Murray–Darling Basin in Australia as case studies. Then, we examined where these legal conditions are in a global context.

To investigate water law globally, we used WaterLex, a database on water laws compiled by the United Nations Food and Agriculture Organization (FAO), to identify locations that could support the implementation of water markets in a legal sense. Note that this analysis was based on the 2015 version of WaterLex. WaterLex has two weaknesses. First, it covered only 78 countries and regions. Second, although it offered general information on water laws, it did not explain how the articles in a water law influence water policy. We circumvented these weaknesses by expanding the research objective, and analyzing how the three legal conditions were met among countries and regions. In this exhaustive inquiry, national and state water laws were scrutinized, because some federal countries delegate the authority to enact water law to state governments. We checked the state water laws of four federal countries (Australia, Canada, India, and the United States). As a result, we examined 296 cases. Since we focused on formal water law, informal, customary water laws were not considered, even though they may have important roles in water management (see supplementary materials for details available at stacks.iop.org/ERL/13/034032/mmedia).

2.2. Computation of area with low runoff during irrigation periods

In addition to legal conditions, natural or environmental conditions may affect the application of water markets. California, Chile, and the Murray–Darling Basin in Australia are all characterized as Mediterranean climate regions; they have dry and wet seasons, and natural river flow peaks occur in winter or spring (Bonada and Resh 2013). Farmers irrigate land in summer when there is little precipitation. This climate enables predictions of the available water before the irrigation period, and makes it easier to prepare for a water market before the irrigation period begins. For example, in the face of the 1991 drought in California, The Drought Action Team created by the Governor's executive order on February 1 forecasted that water supply from the State Water Project and Central Valley Project (the two largest water delivery infrastructures in the State) would be severely curtailed in the upcoming season. On February 15, they recommended the establishment of water reallocation (i.e. the Drought Water Bank). The team requested urgent action, because potential sellers (farmers) were making cropping decisions and potential buyers (cities) were suffering from limited water supply. Immediately following this recommendation, the California Department of Water Resources began contacting potential buyers and sellers to realize the water market (State of California 1991, Coppock *et al* 1994). This enabled farmers to make informed decisions on whether to leave land fallow, and to sell water, before the irrigation period. If the irrigation period and wet seasons overlapped, it would be difficult to promote sufficient water trades among water users.

Agricultural water accounts for 70% of global freshwater withdrawals (FAO 2012) and 92% of global freshwater consumption (Hoekstra and Mekonnen 2012). Meanwhile, domestic and industrial water have relatively low seasonal variations. Thus, the seasonal variation in agricultural water greatly affects total water consumption, including domestic and industrial water. To discuss the necessary conditions to support

water markets, we examined climatic conditions, specifically, the global distribution of areas with low runoff during the irrigation period (see supplementary material for the methods).

3. Results and discussion

3.1. Legal conditions for water markets

Generally, a market cannot work without an underpinning legal framework (North 1991). We showed that three legal conditions are critical to fostering water markets via cross-country analyses, using California, Chile, and the Murray–Darling Basin as case studies (see the supplementary material for data on water trades in these areas). Three conditions are categorized as 'introduction' or 'promotion' factors. The introduction factor is the legal condition under which the government has a rule for water reallocation. Although indispensable for the introduction of a water market system, it is insufficient alone. Promoting a water market requires two additional legal conditions: the separation of water rights and landownership and relaxed cancellation for non-use. Details of three conditions are described below.

First, there must be a water rights system, in which water reallocation is legalized. The existence of a water rights system is a necessary condition of any water market, because there is no commodity to trade if water rights do not exist. However, this condition alone is not sufficient. Water rights are not always tradable, partly due to legal constraints or the lack of a rule on trading. Thus, water reallocation must be clearly allowed by the government. If a government does not legalize water reallocation, it is impossible to implement a water market.

In California, a water market has played an important role during severe droughts, including the recent historic drought, since it was legislated under a state water policy in 1980 (Littleworth and Garner 2007, Cooley *et al* 2015). In Chile, the water law was changed in 1981 (the 1981 Water Code), after the revolution. Water rights were deemed to be private property rights, and a market mechanism was introduced for water allocation (Bauer 2004). In the case of the Murray–Darling Basin, a water market was first allowed in the states of South Australia and New South Wales in 1983, followed by Queensland and Victoria (Grafton and Horne 2014).

Second, water rights and landownership must be separated to enable water trades (Chong and Sunding 2006, Grafton *et al* 2012). If they are linked, there is an obstacle to promoting water markets, because individuals cannot buy and sell water as an independent resource and water use is confined to riparian land, which makes it impossible to satisfy water demands in non-riparian areas. Generally speaking, states in the eastern United States have 'riparian rights', which link water with riparian land, allowing landowners access to adjacent water sources. Conversely, the western states have 'appropriative rights', which allocate water on the principle of 'first-in-time, first-in-right', regardless of whether a water user possesses the riparian land. California and Washington are exceptions to the western United States, which admit both riparian and appropriative rights within their jurisdictions.

Appropriative rights are separated from landownership in the western United States (Littleworth and Garner 2007), although some states such as Nevada and Oklahoma partly restrict transfer for uses separate from the land (Getches *et al* 2015). In the case of the Murray–Darling Basin, the Council of Australian Governments separated all statutory water rights from landownership in 1994 to promote water markets (Grafton and Horne 2014). Water rights in Chile were separated from landownership in the 1981 Water Code (Bauer 2004).

Finally, a forfeiture rule affects creation of a water market. It means that water rights are lost if the water is not used for a certain period (Chong and Sunding 2006). This rule is sometimes called the 'use-it-or-lose-it' principle. Strict application of this rule would hinder a water market indirectly. Few individuals will economize water use when conservation activity is regarded as non-use and the conserved water is subject to cancellation. As a result, noone has an incentive to conserve water, which could otherwise create surplus water for trade (Reisner and Bates 1990). Whether a government legalizes the sales of such conserved water is also important. However, modification of the forfeiture rule is more fundamental, simply because there will be less water for trade in the first place under the 'use-it-or-lose-it' principle. Shorter periods of cancellation for non-use support stronger incentives to keep using water as before. In that case, regardless of whether sales of conserved water are allowed, even temporal, short-term transfer will not be realized.

California coped with this problem from the late 1970s to the early 1980s. The state legislature modified the 'use-it-or-lose-it' principle to extend the cancellation moratorium from three years to five years. Then, it declared that conserved water would not be lost, and that such water was tradable (Bowden *et al* 1982, Gray 1989, Littleworth and Garner 2007). During the drought of 1991, one of the largest water market experiences in California history, the state government repeatedly announced that surplus water created by water conservation would not be cancelled, to promote a water market (California Department of Water Resources 1992).

Extending the cancellation moratorium period is a double-edged sword. While it promotes the efficient use of water resources through a water market, it may cause other inefficiencies by creating dormant water rights. For example, the Chilean government did not prohibit non-use (Bitran *et al* 2014). This enabled parties to acquire more water rights than they actually used. In one case, a power-generating company monopolized

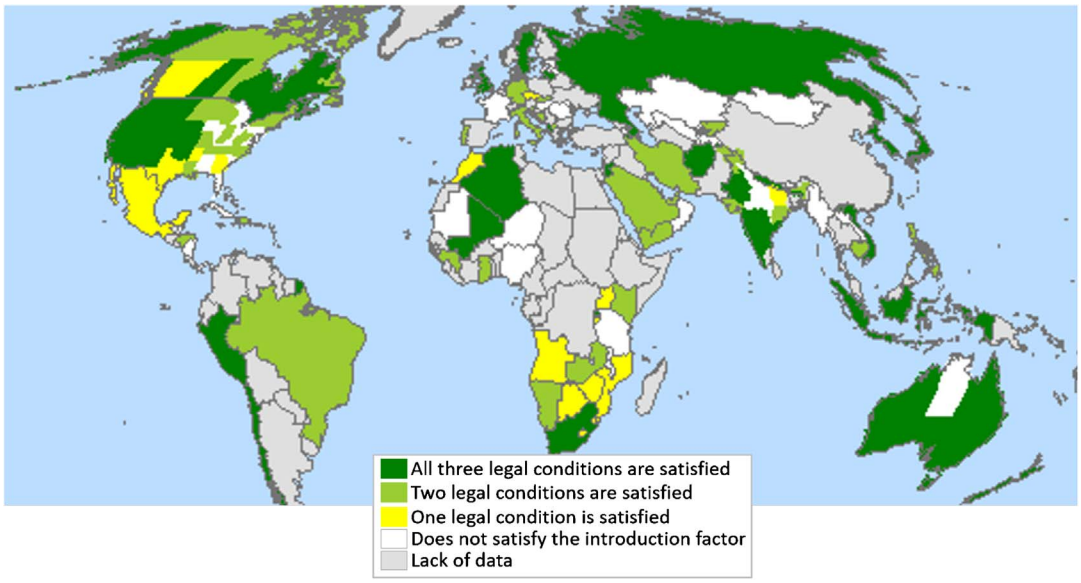

Figure 1. Global distribution of the three legal factors necessary to support water markets. The details leading to each classification are shown in figure 2. The green areas are the countries or regions most suitable for a water market in a legal sense.

the water rights to an entire river. The government decided to impose an escalating fee against non-use in 2005 to avoid such inefficient water allocation. According to this policy, a party that does not exercise its water rights is required to pay a non-use fee (Borzutzky and Madden 2013, Bauer 2013). In summary, the period of cancellation for non-use should be neither too long nor too short.

3.2. Areas where water markets are potentially applicable

Figure 1 shows which countries and regions meet the legal conditions for a water market. This map is based on an investigation of the water laws in 296 cases. The colors yellow, yellow-green, and green correspond to an increasing degree of satisfaction. Figure 2 shows how we classified the areas in this order in figure 1 (see supplementary material for details).

Fifty-eight cases satisfied all three legal conditions, and are colored green in figure 1 (see supplementary table). In addition to the western United States, the Murray–Darling Basin, and Chile, several Asian countries (e.g. Indonesia, Vietnam, Korea and some states in India), South Africa, Russia and various other countries satisfied all three legal conditions. These are potential areas where water markets can be implemented in a legal sense.

There were 66 countries and regions that did not satisfy all of the legal conditions. These could be divided into two groups. The first group is the yellow-green jurisdictions that satisfied two legal conditions (the introduction and one of the two promotion factors) (e.g. Brazil and Philippines). The second group is the yellow regions that satisfied one legal condition (the introduction factor only) (e.g. Mexico). The 55 countries in white did not even satisfy the introduction factor: 30 had no rules for water reallocation (e.g. Hungary and Romania), and 25 prohibited water reallocation (e.g. Kazakhstan). The countries in grey lacked sufficient information for analysis.

Considering a few examples, South Africa satisfies three legal conditions, and water markets have been developed there (Nieuwoudt and Armitage 2004). However, its neighbors Namibia and Zambia meet only two legal conditions. To implement a water market, they need to loosen the moratorium period of cancellation for non-use (the current moratorium period in both countries is three years), so that water users can create surplus water for trade through conservation. Figure 1 shows the same problem will occur in other dry countries such as Iran and the Kyrgyz Republic. The hurdle of law amendment is higher in Angola, Botswana, Lesotho, Mozambique, Swaziland, and Zimbabwe, where only the introduction factor was satisfied. It is necessary to separate water rights and landownership and to relax the moratorium period for cancellation for nonuse. This difficulty can also be applied to Mexico and Morocco. While these results come from an analysis of national water laws, we also considered state water law. For example, although India is widely known for its informal and customary groundwater market (Manjunatha *et al* 2011), various formal laws exist at the state level. The water laws in some states in India, where water is relatively scarce, satisfy the three legal conditions.

Besides these conditions, the applicability of water markets may depend on other legal factors, such as the legal definition of groundwater. For example, it may be difficult to establish water markets where groundwater is treated as an open-access resource. Figure 3 shows regions where groundwater is defined as an attachment of the overlying land, and is not subject

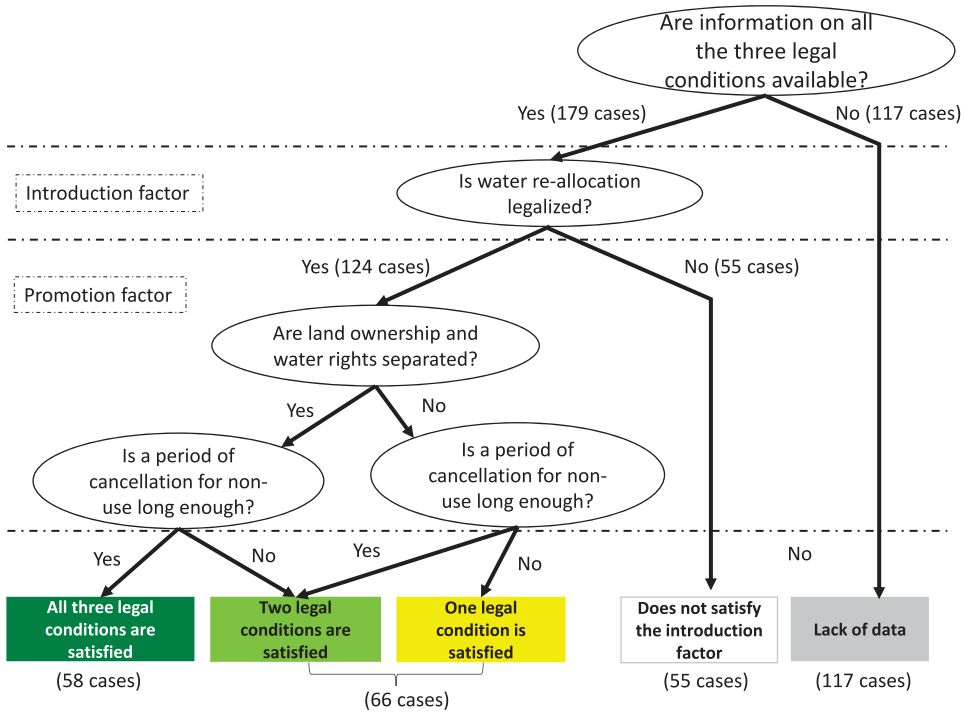

Figure 2. Flow chart to determine the applicability of water markets.

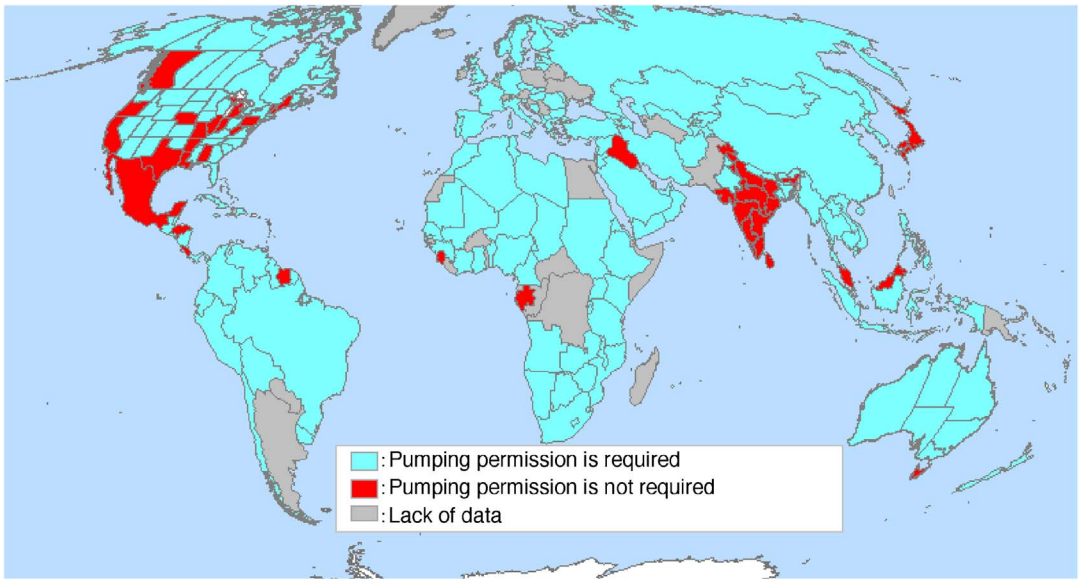

Figure 3. Global distribution of groundwater pumping regulations. Red areas have no permission system for groundwater pumping throughout the entire jurisdiction. In those areas, modification of groundwater pumping rules is required to promote a water market.

to pumping permission in its entire jurisdiction. They include Honduras, Japan, Mexico, and most states in India. In such cases, where there is no cap or limitation on groundwater pumping, water users may increase groundwater pumping, instead of buying water from other water users to cope with water shortage. Promoting a water market in such areas requires modification of the groundwater pumping rules.

Not only legal conditions but also natural or environmental conditions may affect the application of water markets. California, Chile, and the Murray–Darling Basin are all characterized by low precipitation during their irrigation periods, and irrigation is the primary use of water. This climatic condition enables the prediction of the available water before an irrigation period, and makes it easier to prepare for a water market before the irrigation period begins. This prerequisite for water markets, the predictability of available water before an irrigation period, is at least partially satisfied in the shaded areas in figure 4. Here, low river runoff

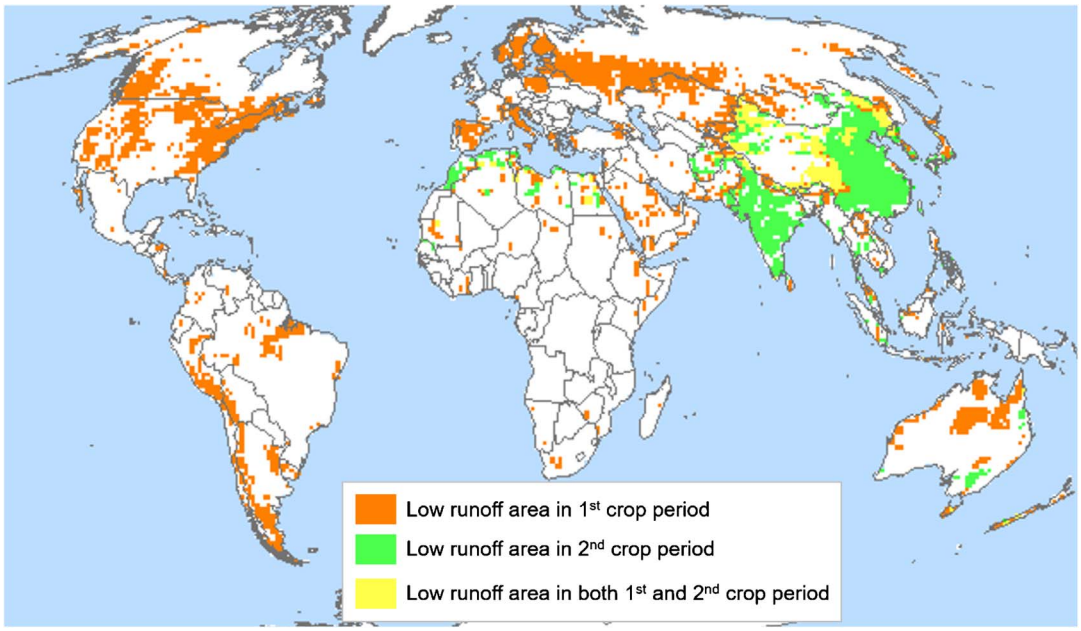

Figure 4. Global distribution of areas with low runoff during irrigation periods (i.e. where the cumulative daily runoff during an irrigation period is < 20% of the annual runoff). This map shows potential areas with predictable water availability before the irrigation period.

was used instead of low precipitation, because water resources can be supplied from upstream, and runoff is more suitable for assessing water availability (e.g. Oki and Kanae 2006, Wada *et al* 2014).

According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5), a decline in future water availability under global warming is projected in Mediterranean regions and the regions of Southern African mentioned above (Jimenez Cisneros *et al* 2014). Mediterranean regions are also an area in which this climatic prerequisite is generally satisfied because of its dry summers and wet winters (figure 4). Given this climatic prerequisite, a water market may be a possible countermeasure to intensifying water scarcity under a warming climate, but the cancellation periods for non-use are short (e.g. three years for Italy and one year for Portugal). As mentioned above, such a cancellation policy should be relaxed to promote water markets in these countries (figure 1).

Some regions have two major annual crop periods. In these areas, the climatic prerequisite can be evaluated separately for each of the irrigation periods. For example, a water market might be considered difficult to implement in warm, humid Asian regions during the first crop season, because the rainy season and irrigation period coincide and water users are likely to hope for sufficient rainfall during the rainy-irrigation season; however, as indicated in figure 4, a water market may be possible during the second crop season during which water users can expect little rainfall. While we discussed the suitability of areas where water availability can be predicted before the irrigation period for water markets, we did not discuss seasonal climate forecasting. Seasonal climate forecasting may provide data to support water markets in additional regions beyond those discussed here.

In addition to this climatic prerequisite, a region may require sufficient reservoirs to store water before the irrigation period, which is believed to be the case for the three case study regions. The three case study regions have highly varying river flows due to their dry and wet seasons (Bonada and Resh 2013). Moreover, annual variations in stream flow are high in these regions (Dettinger *et al* 2000). Under such variable conditions, it is important to secure a stable supply of water during the irrigation period (dry season) to establish a water market. Reservoirs can somewhat stabilize river flow (e.g. Lytle and Poff 2004), since they can store water during the wet season and supply water during the dry season. Farmers and decision-makers can predict the available water based on the amount of water in reservoirs before the irrigation period and prepare for water trades.

Finally, it is necessary to mention a few limitations of this paper. Although we only discussed legal conditions, future research studies should consider other social-science factors such as water pricing that reflects the cost of transportation (Bakker 2005), water use accounting, an immediate identification system between buyers and sellers (Garrick *et al* 2013), water rights registration systems, and the enforcement of water rights (Wheeler *et al* 2017). Where these factors are not satisfied, a water market will not work well due to high transaction costs. Clarifying the global distribution of those conditions is a future research topic. Research examining factors other than legal requirements would also explain why successful water markets are rare.

Note that a water market is not a panacea. For example, the original Chilean model of a water market introduced with the 1981 water code was regarded as a leading example of a free-market approach to water allocation (Bitran *et al* 2014). It promoted the reallocation of water resources to high-value uses in some watersheds, but it failed to consider groundwater and environmental flow (Bauer 2013). Such a water market would have enormous third-party effects. This problem is likely to arise, especially in regions where there is no permission system for groundwater pumping (see figure 3). In such areas, groundwater easily becomes an alternative source of tradable water. Although groundwater trading may be an effective short-term solution to water shortages in such a region, this could result in groundwater depletion. It could also decrease the flow of adjacent rivers, causing ecological damage and water shortages in the downstream area. Water markets promote the efficient use of water, as long as such third-party impacts are considered fully.

Even if a water market could be evaluated positively from the perspective of efficiency criteria, it might not be able to satisfy equality criteria. The water market in California in 1991 reduced economic activities in water-selling regions and had negative effects on farm employment because some of the water for sale was created by fallowing (California Department of Water Resources 1993). Bauer (2013) also asserts that, generally speaking, the water market exacerbated the inequality of income distribution in Chile. This suggests that policymakers should consider both efficiency and equality when they consider the introduction of a water market. How to balance efficiency and equality in water resource management is an issue that remains to be investigated.

4. Concluding remarks

Water markets are receiving attention as a 'soft path' measure for coping with water scarcity. However, there is no global perspective on the applicability of water markets. In this paper, focusing on three legal conditions as minimum requirements to support water markets, we created a global map of the potential applicability of water markets. This first global map was accomplished through the collaboration of a social scientist and environmental scientists.

Future research should consider other social conditions such as water pricing, water use accounting, and water rights registration systems (Bakker 2005, Garrick *et al* 2013, Wheeler *et al* 2017). In addition, a water market needs to be evaluated using both efficiency and equality criteria before implementation. Despite the remaining issues discussed above, this study provides a foundation for emerging research toward the sustainable management of water resources across the globe.

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