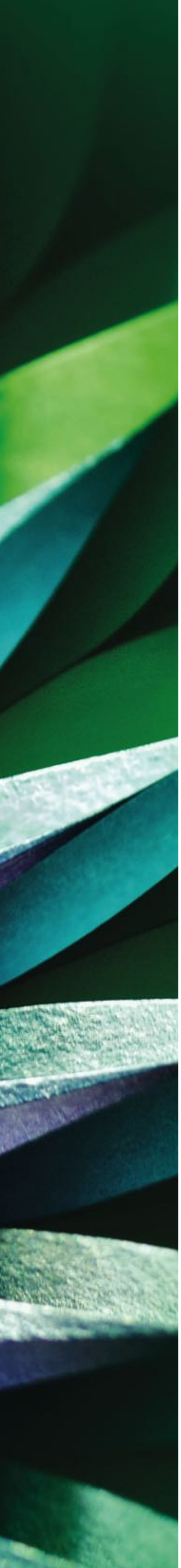

BACKGROUND PAPER

Contemporary Irrigation Issues in Asia

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CONTEMPORARY IRRIGATION ISSUES IN ASIA

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I. INTRODUCTION

Asia has a long history of irrigated agriculture. On the top of the traditional irrigation, the expansion of modern irrigation systems since the 1960s, together with the Green Revolution technologies, has greatly contributed to a continuing food production increase and poverty alleviation in developing Asian countries. Given Asia's relatively high population densities in limited arable lands, it is not too much to say that a land productivity improvement through an augmentation in irrigation investment and an expansion of irrigated area has been the indispensable source of modern agricultural development of the region. The proportion of area equipped for irrigation was 20% of cultivated area in 1961 in Asia, which was the highest among the world regions (e.g., the world average was 10.2 %), increased to 39 % in 2006 by 19 percentage points, whereas the world averages increased merely to 19.7 % by 9.5 percentage points (FAO 2011).

However, irrigated agriculture in Asia is at crossroads, facing two major issues: increasing labor scarcity and water scarcity. The first issue, labor scarcity, is closely related to the success of the Green Revolution. Its success has eventually increased the income of rural farmers, leading to increased schooling investments to their children. Younger generation with higher human capital tends to exit from farming and to seek for nonagricultural opportunities in cities and even abroad. This movement results in drastic demographic changes in rural area in various ways, including

rural labor shortage, diversified occupations even within rural area, and the aging of farmers. With this trend, mobilization of rural labor for local irrigation management becomes more difficult.

The second issue, water scarcity, is getting serious among many Asian countries, if not all, because of multiple factors including physical (climate changes), economic (an increase in industrial and domestic water demands), and political (intercountry water rights disputes along major rivers) reasons. Water scarcity issue is also related to a recent rapid groundwater development by private pumps, which tends to end up with the depletion of water aquifer.

Facing these two major problems, it is becoming more difficult to provide sufficient amount of irrigation water at the right time at a reasonable cost to all the farmers equitably. These problems could be a serious bottleneck on pursuing sustainable profitable farming in Asia. Therefore, a better understanding of contemporary irrigation issues in Asia and designing effective policies are needed for the region. This report summarizes features of irrigation status based on macro level statistics and, then, discusses effective policies for those issues based on lessons from selected case studies.

The structure of the report is as follows. Section II describes irrigation situation in Asia, relying on macro secondary data and literature from various sources. Section III explains key theoretical concepts which facilitate understanding irrigation issues. Section IV draws on micro level case studies for policy implications. Section V concludes by summarizing the issues.

II. IRRIGATION IN ASIA

A. Area Equipped with Irrigation: Past and Future

This section provides a broad view on contemporary irrigation issues in Asia by exploring country-level macro data, supplemented by related literature. A report published by FAO in 2011, The State

of the World's Land and Water Resources for Food and Agriculture, is informative reference for this purpose (FAO 2011). Table 1, which is taken from the report, shows that, in Asia, the proportion of area equipped for irrigation over cultivated land increased from 20 % in 1961 to 39 % in 2006, indicating at the highest record among the regions not only in terms of levels but also of an increase. As a result, in 2006, Asia's area equipped for irrigation stood at 211 million hectares or about 70% of the world area (FAO 2011). According to the report, "South and East Asia account for over half of the world's area equipped for irrigation, and India and (the People's Republic of) China [PRC] alone (each with about 62 million hectares equipped for irrigation), account for 40%. Most of this irrigation is large-scale development within major basins, primarily for paddy rice production."

Given an already-high proportion of irrigated area, the potential of further expansion is limited in Asia. Table 2, taken from the same report, indicates that, in Asia, the annual rate of expansion was 1.7% from 1961 to 2006, is projected to slow down to 0.2% from 2006 to 2050. This is a clear contrast to the situation in Sub-Saharan Africa where only 3% of cultivated area is equipped for irrigation in 2006 (Table 1) and has a potential growth at 0.6%, the highest among the subregions excluding Eastern Europe and the Russian Federation (Table 2). In summary, irrigation has been a crucial element in agriculture in Asia and, given the limitation on the expansion of irrigated area, one of the major contemporary issues in Asia is the maintenance or upgrading of existing irrigation systems.

B. Major Players: Public, Semipublic, and Private

How has the past expansion of irrigated area become possible? On financial aspect, an increase in public investment through a strong commitment by international and national governments was

the fuel of the driving force. The cases of the Philippines and Sri Lanka clearly exemplify this feature. Figure 1, which shows a long-term trend of the public irrigation investments at 1995 constant price in the two countries from 1950 to 1995, indicates that public expenditure for irrigation peaked around the 1980s but sharply declined since then (Kikuchi et al. 2001). The investment in the peak period was mostly used for the development of large-scale public irrigation systems in the form of surface water infrastructures and canals to support the progress of the Green Revolution. By now, neither investment for new construction nor that for rehabilitation did carry out.

Along with the declining public involvements, we observed the emergence of a new trend of participatory development approach in the 1980s. Accordingly, the irrigation sectors had observed a shift toward more reliance on local communities for operation and maintenance in the forms of participatory irrigation management (PIM) and irrigation management transfer (IMT).[1] Since a local community takes care of local public goods as well as local administrative matters informally, it can be regarded as an informal local public sector or semipublic sector. Hence, the abovementioned trend can be regarded as a shift or major player from the public to the semipublic sector.

The results of this shift, however, "have been mixed and the impact on water productivity is unclear (Barker and Rosegrant 2007)." Mukherji et al. (2009), which reviewed 108 cases of IMT in Asia with an original ranking method developed by the authors, concluded that 64% were deemed to be

[1] The terms PIM and IMT are defined as follows (Groehfeldt and Svendsen, 2000). "PIM usually refers to the level, mode and intensity of user group participation that would increase farmer responsibility in the management process. IMT is a more specialized term that refers to the process of shifting basic irrigation management functions from a public agency or state government to a local or private sector entity."

failure. As a result, in many cases, large-scale public irrigation systems have been deteriorating with a lesser financial commitment of the public sector as wells as with the limited success of PIM or IMT approaches by the semipublic sector (local community).

Regardless of the significant decline in the large-scale public irrigation systems and the non-compensation of that decline by semipublic community, the irrigated area has still steadily increased in Asia (Table 1). This is because of the increasing role of private irrigation by means of pumps, wells, and small-scale ponds. Table 3 shows the irrigated area where pumps are used for water supply from surface or groundwater.[2] Albeit a limited availability of continuous time series data, the table indicates an increase in pump irrigated areas in Asia, in particular a sharp increase in Bangladesh, India, the PRC, Thailand, Viet Nam, and the Philippines, except central Asian countries where the potential of irrigation was limited by nature. Hence, we claim from Table 3 that, aside from traditional public investments, private investments have been becoming increasingly important for irrigation development.

C. Groundwater Irrigation and New Problems

The increase in the private pump is closely associated with the increase in the use of groundwater for irrigation and resulting depletion of groundwater aquifer. Table 4 shows the area equipped for irrigation by source of water. In most of the countries, except for Central Asia, the area irrigated by groundwater has increased. Among them, prominent changes have been observed in India and Bangladesh where the groundwater area surpassed the surface area in the 1990s and became by far

[2] The figures include not only the area irrigated by millions of private pumps but also by large pumps which are usually owned and operated by irrigation authorities to supply water from rivers or groundwater aquifer to the authorities' irrigation schemes. Although the public pumps are included, it is not misleading to interpret this as a trend of private pump irrigation.

dominant irrigation water source (Figures 2 and 3). Even in other countries, the presence of groundwater becomes greater if we include its conjunctive use with surface water, in which farmers usually use groundwater to supplement the deficit of surface water from deteriorated large-scale public irrigation systems; for example, the area under the conjunctive use in the Philippines was 294,000 hectares (ha) in 2003-2007 which was larger than the area under solo groundwater area of 107,000 ha.

The expansion of groundwater irrigation was achieved mainly by private investments in pumps and wells by millions of individual small farmers scattered over countries. An important feature is that this expansion was done in most of the countries with little coordination among farmers. Hence, it is natural that we observe a so-called "tragedy of commons", that is, in case of groundwater, the overuse of groundwater by each individual farmers at faster pace than its natural recovery rate results in the depletion of groundwater aquifer. Even worse, the overuse of groundwater imperils not only quantity of water but also quality of water as we have observed arsenic or saline water problems typically in Bangladesh. This problem is associated with a concept called a negative externality, which will be explained later. Government policies can play an important role to solve the externality.

However, in the reality, in many cases, governments have aggravated, rather than resolved, the groundwater problems through a linkage called "the Water-Energy-Food Nexus" (FAO 2014). A typical example can be found in India (Mukhreji et al. 2020, Sidhu et al. 2020, and Fujita and Mizushima, 2021). In western and southern states of India, rural electricity has been heavily subsidized or even free in order to support rural farmers and also to boost food production. Even more, the power tariffs have been charged under a flat-rate policy because of the extremely expensive administrative costs of metering and regular monitoring of millions of electric pumps

over the country. The cheap rural energy policy has massively induced farmers to install electric pumps and switch to groundwater for their irrigation with little incentive of water savings under the flat-rate tariff policy. Although energy-intensive farming with groundwater has boosted up the food production in the short run and also increased the farm income then, in the long-run, it has aggravated groundwater resource degradations in western and southern India. Note, however, that a possible positive outcome from the overexploitation, if any, could be the fact that it induced the development of water markets by encouraging the well owners' (who are usually wealthy) sales of their excess water to the non-owners (who are usually not wealthy). In this manner, the cheap and flat-rate energy policy could contribute an equitable agricultural development (Sidhu et al. 2020).

Contrastingly, eastern India (West Bengal), which has more abundant groundwater resources, has not fully utilized its potential because it has been using the metered power tariffs at a relatively high-unsubsidized rate in recent years (Mukhreji et al. 2020 and Sidhu et al. 2020).

It is ironical that the water-scarce states employ a cheap-flat or free power policy while the water-abundant states do the opposite. Distortions in energy price over the country have resulted in too-much use and too-little use of groundwater, rather than the optimal use, in India. Reevaluating the current policies and designing appropriate ones to guide sustainable and efficient water use is crucial.

D. Rural Labor: Decreasing and Diversifying

Turning now to an overview on demographic changes along the economic development and their effects on irrigation management, Table 5 shows changes in rural and urban population growth rates in the recent periods (1998–2008 and 2008–2018). In many Asian countries which have reached the middle- or high-income stage, the rural population has been or has started declining

(Taipei,China; the PRC; Georgia; Indonesia; Iran; Japan; Jordan; Malaysia; Thailand; Turkey; Bangladesh; Brunei Darussalam; Qatar; Syria; and Tajikistan). Even in countries with growing rural population, the speed of growth is slowing down, relative to high growth rate of urban population (e.g., India). Figures associated with this table exemplify such changes for the countries that are used in our case studies—Japan (Figure 4), the PRC (Figure 5), India (Figure 6), and the Philippines (Figure 7)—where the degree of rural labor scarcity becomes less severe in this order. A negative association between economic development and rural population growth is graphically confirmed in Figure 8, which plots the annual rural population growth rates in 1998–2018 against the annual gross domestic product (GDP) per capita growth rate in the same period.

Rural population includes those who engage in non-farm activities in rural area, underestimating the declining trend of farming population. Thus, to compensate the discussion above, we also show changes in the proportion of employment in agriculture in Table 6. A declining trend become more obvious as we see percentage point changes are negatives for almost all countries. Moreover, in general, the magnitudes of decline are greater for the country with more rapid growth. Figure 9 confirms this point, showing a negative association between the percentage point changes in agricultural employment share and the economic development (GDP per capita growth rates) in 1998–2018.

Along with the economic development, rural population changes not only in quantity but also in quality through human capital accumulation particularly among younger generations. Since it is not easy to find macro level comparable statistics on this aspect among rural population, this report relies on a typical case observed in the Philippines, using the long-term micro level data on rice farming households from 1966 to 2011 in Central Luzon (Moya et al. 2015). The summary statistics indicate that, in 1966, 80% of respondents (farming family members) had at most

elementary level schooling and 60% of income was generated by rice farming, while, in 2011, with the success of the Green Revolution and associated increase in farm income, 60% of the respondents obtained schooling higher than high school level and rice income reduced at 20% of total income, while nonagricultural income and remittances became two dominant sources. This shift stems from the fact that younger generations with higher education left for nonagricultural opportunities in rural or urban area, or even abroad. As a result, aging of farm operators within the rural area has been progressing. (Refer to the article in Box 1 for more details.) Similar mechanisms have been observed in other growing Asian countries (Otsuka et al. 2009).

What implication do the changes in rural labor structures have for irrigation management? Our data review clearly reveals that, among rapidly growing economies, the structure of rural villages has changed from a homogenous labor abundant society to a society characterized by diversified occupation, scarce labor, and aging of remaining farmers. The changes toward these directions will affect not only farming itself of each individual farmers but also collective management of existing irrigation facilities by the group of farmers; it becomes more difficult to mobilize sufficient labors for collective management of large-scale surface irrigation. More details on the mechanism of collective management are discussed in section III.

E. Other Issues Arising With Economic Development

Three other irrigation issues that can arise along with economic development are worth exploring. First, Asia has observed a shift to high-value crops and it is associated with the adoption of modern private irrigation systems. Among high-value crops, such as vegetables and fruits, this report focuses on vegetables for which timely and appropriate water management is crucial for quality products. Using the growth rates of harvested area of vegetables in Table 7 as well as the growth

rate of GDP per capita, Figure 10 indicates a positive association between these two indicators in the latest decade (2008–2018). For vegetable cultivation, modern private irrigation systems such as private wells, sprinkler, and drip irrigation systems are commonly used. Table 8 shows the data from India, the PRC, and Japan where time series data on the irrigated area by sprinkler or localized irrigation (e.g., drip irrigation) are available. Interpreting together with growth of vegetable areas copied from Table 7, Table 8 implies that India and the PRC seem to expand such irrigation systems with the expansion of vegetable area, while Japan expanded to lesser magnitude, presumably reflecting Japan's decreasing trend of vegetable area. In summary, broadly speaking, the expansion of high-value crops lends additional importance to the role of private investment in contemporary irrigation development.

Second, nonagricultural benefits such as disaster prevention/control, environmental services, and amenities from irrigation facilities increase among high-income countries. Table 9 taken from Sawada (2007) shows that, among the hydrometeorological disasters, Asia counts for 37% of floods and 31% of drought and related disasters in the world. The ranking on flood occurrence indicator in 2013 in Table 10 reveals that 9 countries in the top 10 are from Asia. In addition to this, people place more values on quality of living as their income increase, and the demand for environmental services and amenities from hydrological ecosystems goes up. Therefore, the benefits of irrigation systems go beyond farming alone. In other words, the nature of irrigation service changes from local public goods only for local farmers toward (relatively) pure public goods covering not only farmers but also non-farmers as its stakeholders.

Third, water scarcity is getting serious in Asia, albeit Asia is "the gift of monsoon" historically. IWMI (2017) shows that only selected areas suffer little or no water scarcity in Asia particularly in the southern part of the PRC and most countries in Southeast Asia and the Pacific. In other

places, such as in the northern India, Bangladesh, Cambodia, Lao PDR, Myanmar, and Viet Nam, despite the abundance of water resources, access to water is limited due to human, institutional, and financial capital constraints. Moreover, the northern part of PRC and the southern part of India suffer physical water scarcity.

Overall, scarcity problem becomes more complicated when a water allocation issue between agriculture sector and nonagricultural sector arises along the rapid industrialization and urbanization. The data on water withdrawal for industrial use or for municipal use (i.e., water supplied by public distribution network for direct use by population) are available at different time periods by country. Hence, in order to present broad view, we show the X–Y graph of percentage of withdrawal either in 2003–2007 or 2008–2012 period, whichever is more recent, against the log of average GDP per capita in the corresponding period (Figures 11 and 12).[3] We observe a higher withdrawal proportion both for industrial use (Figure 11) and for municipal use (Figure 12) as the income level goes up. This means that economic development put a stronger pressure of water scarcity in agriculture sector, given limited increase in total water supply. A typical example can be found in a case of the southern part of the PRC which is one of our cases in section IV. In an irrigation scheme in the area, a long-term trend (1966–2001) on the water withdrawal from a large-scale reservoir for irrigation or for other uses clearly exemplifies shift of water use from agriculture to the other purposes (Figure 13). This means that, although the area is classified under little physical water scarcity by IWMI (2017), water scarcity in the agriculture sector has been increasing.

[3] These two consecutive periods (2003–2007 and 2008–2012) supply maximum number of countries where data are available. Comparison of growth rates (similar to the other figures in this report) are also impossible because the changes at least between two periods is not available.

In summary, even water-sufficient zones suffer increasing water scarcity for irrigation because of increasing demand for industrial and municipal uses. To solve this problem, there are several approaches. Initially, supply side or engineering side interventions such as infrastructure expansions and the introduction of water saving technologies were sought for. Recently, with a strong support by the World Bank, attention is shifting to demand side or economic approaches to save water, and one of which is the introduction of volumetric pricing, expecting farmers who pay irrigation fee by volume would save water for cost minimization. Examination of the effectiveness of such a market-oriented solution is an emerging issue.

F. Summary

In this section, we have reviewed macro-level statistics. The findings are summarized below as well as in schematic diagram in Figure 14.

(i) Upgrading of existing systems (large-scale public surface irrigation systems) and continuing their maintenance, rather than the development of new systems, is a main contemporary irrigation issue in Asia.

(ii) Need to handle upgrading and maintenance of existing systems under growing importance of private irrigations (wells and groundwater or ponds) by numerous individual farmers, in which a general trend of increase has been further accelerated by the expansion high-value crops which can be efficiently irrigated by sprinkler and drip irrigation systems.

(iii) Need to handle upgrading and maintenance under increasing rural labor scarcity, increasing occupational diversifications, and aging of farmers in the local communities which traditionally managed the irrigation systems.

(iv) Increasing importance of private investment is related to the expansion of groundwater irrigation and, as a result, the depletion of groundwater aquifer emerges as a contemporary issue.

(v) Increase in nonagricultural benefits such as disaster prevention/control,

environmental benefits, and amenities, leads to the extension of stakeholders to non-farmers, making the nature of the irrigation infrastructure closer to pure public goods.

(vi) Increasing water demand in industrial and urban sectors along with the economic development put pressure for water savings in the agriculture sector and, as one of the possible solutions for water savings, we need better understanding on the potential and limitation of volumetric pricing for irrigation water.

III. KEY CONCEPTS

A. Externalities and Government Failures

This section explains four key concepts which are useful for drawing lessons from our case studies: (i) externalities within surface irrigation systems, (ii) externalities in a nonagricultural sector, (iii) externalities in groundwater irrigation systems, and (iv) government failures in agricultural policies.

Externalities in surface irrigation systems are related with technological indivisibility and collective management of the systems, and they are further divided into two aspects: (a) those related with maintenance of irrigation facilities and (b) those related with allocation of irrigation water. We explain the maintenance aspect first. Once a system is installed to supply water to cover a certain command area, the system cannot shrink its supply capacity according to the reduction of the number of users. This is because such systems need to maintain a certain water pressure and a certain water level in order to supply water to the tail-end users. If one user, for example in the midstream, becomes reluctant to fully provide his/her maintenance work or even completely exits from the irrigation system, the remaining users have to shoulder the exiting farmer's maintenance costs to maintain the capacity; this is a negative externality of the exit on the maintenance aspect.

Regarding the allocation aspect, the exit of a farmer makes the continuity of irrigation plots within

water users group broken (Figure 14). After the exits of some farmers from the irrigation system, the users' plots become segmented from each other in terms of continuity in water uses, which makes coordination and supervision for water allocation among remaining scattered water users more difficult. Hence, what matters is the continuation of surface water uses plot. In this regard, segmentation occurs not only when farmers quit farming (which makes the plots fallow), but also when farmers exit from the surface water uses group to private irrigation systems. Although Olson (1965) predicts that the smaller group can make collective action more effectively, such a mechanism may not work in the context of irrigation management if the cost of the former (i.e., coordination difficulty because of segmented plots) is greater than the benefit of the latter (i.e., effective communication in a smaller group). In this manner, the negative externalities are likely to arise in surface irrigation system on both the maintenance and allocation aspects along with the farmers' exit from the surface irrigation system.

Another type of externalities emerges when irrigation water provides nonagricultural benefits, such as disaster prevention/control, environmental services, and amenities. Moreover, in addition to these general benefits, surface irrigation systems have a benefit of recharging of groundwater aquifers. Theoretically, these externalities can be internalized by ensuring all beneficiaries are involved in irrigation management. Practically, however, the nonagricultural benefits are so thinly and so widely spread that it is difficult to get all stakeholders involved. In addition, in case of groundwater, it is difficult to identify the beneficiaries who share aquifer. Such kinds of externalities increase along with economic development as the numbers of nonagricultural residents increase in rural areas, and groundwater irrigation systems become popular.

Because of the existence of these types of externalities explained above, the private incentives for irrigation upgrading and management works tend to be smaller than the socially optimal level. In

the context of surface irrigation management, as labor scarcity increases, the substitution of capital for labor must proceed. However, the necessary investment may not reach to the socially optimal level. It is the role of government that can be observed in supporting capital investment in irrigation systems or the modernization of such systems.

Now we move to the case of externalities in groundwater. The over-dissemination of wells and overexploitation of groundwater is commonly observed. This is indeed a typical case of "the tragedy of the commons." The use of groundwater by some individual entails negative externalities for others who share a groundwater aquifer. Without sufficient groundwater recharges, the groundwater will eventually be depleted. Regulations or interventions on the use of groundwater are needed to control these negative externalities, and governments may play important roles for this aim.

Finally, let us discuss government failures because the roles of governments could increase. For a clearer understanding of the formation of irrigation policies, it is important to distinguish two kinds of government failures. The first can occur when asymmetric information exists between the government and the users. The government may fail to provide appropriate support if it cannot precisely estimate the benefits realized among potential beneficiary farmers. If the government underestimates the benefits, the level of support can be lower than the socially optimal level. A possible solution is to get the farmers involved in the project design, which is well-known as a participatory development approach. However, as we explained earlier, the results of this approach are not always successful.

Another type of government failure is related to the political economy. This problem occurs in a way that the government, expecting votes, tends to provide public goods in favor of a particular

group of people. As many studies argue, this framework can convincingly explain why agricultural protection rises when the comparative advantage of the agriculture sector declines and political pressure, or rent-seeking, from the farmers' group increases. In the context of irrigation policies, the government may use the subsidy for irrigation to obtain supports from the farmers, resulting in over-investment in irrigation facilities, pumps, and wells. Note that agricultural protection can be implemented by many means, such as output price support, input subsidies, income support, and trade regulation. Among them, the support for irrigation facilities can be also used as a means of protection.[4]

Using the key concepts introduced herewith, we may summarize our analytical question such that how we can internalize three types of externalities, which arise under the progress of contemporary irrigation issues, without suffering possible government failures.

B. Analytical Frameworks: Ostrom and Hayami

A popular approach, after the academic success of Ostrom's group's research, was to rely on a community to internalize the externalities in irrigation management (Ostrom 1990, and Ostrom et al. 1994). When Ostrom had explored the conditions for successful collective management of common pool resources, among which irrigation is a typical example, communities in developing countries were more or less characterized by the existence of relatively abundant and homogenous laborers.[5] Hence, the main issue was how to mobilize these laborers for collective management.

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[4] One may argue that support for irrigation is better than price support as the formers increase productivity while the latter spoils productivity improvement incentives. Nevertheless, even the irrigation support must be implemented at a social appropriate level when it is used.

[5] Common pool resources are the goods characterized by non-excludability and non-rivalrous. The former means that you cannot exclude unpaid users and the latter means that use by one person does not reduce the availability for the

However, such a background has already changed in many Asian countries toward the features characterized by labor scarcity, diversified occupation, and aging. Hence, it is becoming more difficult to coordinate collective management within a community. This may be one of the reasons for mixed results of the participatory approach as reviewed by Mukherji et al. (2009). Further, in case of irrigation, as an economy grows, irrigation yields benefits beyond a community (increasing benefits in nonagricultural and groundwater refilling functions). Hence, externalities may not be internalized easily by a community alone. Rather, it is worth incorporating the role of government to compensate for the limited role of the community. In addition, the function of market mechanism needs to be considered first because private irrigation is getting popular and, second, because volumetric water pricing comes into the element of contemporary irrigation issues.

An approach more suitable to deal with contemporary irrigation issues is the one proposed by Hayami (2009). His approach explicitly incorporates the role of the state (government), the market, and the community in economic development. This approach explores the role of each organizations which are characterized as follows. "[T]he market is the mechanism that coordinates profit-seeking individuals through competition under the signal of parametric price change. The state is the mechanism that forces people to adjust their resource allocations by the command of the government. On the other hand, the community is the mechanism that guides community members to voluntary cooperation based on intensive social interactions..." (Hayami 2009) Although these three organizations are clearly distinguished conceptually, in practice, they can

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others. Hence, potential users tend to be free-riders on use, and thus the resources tend to be overused. De Janvry and Sadoulet (2016) summarized the conditions for successful cooperation into five broad categories: (i) The resource must have well defined property rights and group membership. (ii) There must be positive individual expected gains from successful cooperation. (iii) Members' actions must be observed by others, and others must be able to monitor them. (iv) Sanctions must be enforceable in case of default. (v) There must be time to learn cooperate.

overlap, in particular between the state and the community. For example, a village community, which takes care of local public goods with coercion in more informal manner than the state does, can be regarded as a small state. In this respect, we may regard the state as a public sector and the community as a semi-(or informal-)public sector, both of which can be clearly contrasted with the private sector under the market where players purely follow their individual incentives. The relationship is depicted as a triangle of three organizations in Figure 15.

Each organization has advantages and disadvantages as summarized in Table 11. The community has a comparative advantage in supplying local public goods as they can avoid both a free-rider problem and an asymmetric information problem through strong social ties within the community. However, a disadvantage may lie in its limited capacity in utilizing resources outside of the community, thus resulting in stacking to a local optimal even when a better global optimal exists. Other possible disadvantages include *collusive* action, rather than collective action, to maintain benefit of the vested interest group. A related disadvantage is the inflexibility of traditional community and resulting failure in the adjustment to economic changes. Hence, the local optimal solution under collusive action and status quo may persist.

Comparing with the community, the state has a relative advantage in supplying national or global public goods, while it may suffer government failures which are explained earlier. The market can achieve efficient resource allocation of private goods in a broad space covered by the market by means of price signals as the indicator of scarcities of the goods and resources. But the market can also fail when the conditions for perfect competitive markets do not hold.[6] Another important

[6] The conditions include (i) non-excludability and non-rivalrous for private goods, (ii) non-existence of monopoly, (iii) non-existence of scale economy, (iv) non-existence of asymmetric information, and (v) non-existence of prohibitively high transaction costs. Refer to standard micro economics textbooks for more details.

limitation of the market is that the efficient resource allocation by the market may not necessary be equitable. We can find the roles of state and community in realizing equitable distribution at national or local level respectively.

The three organizations do not work independently, rather they complement each other. For example, the market system functions smoothly when the government establish judicial systems and laws related to market transactions. As a complementary role of the market, we may show that the community failure in collusive action or the government failure in rent-seeking could be avoided through a competition at the markets because inefficient organizations under local optima cannot survive in the long run.

With this setup of our framework, Figure 16 classifies the irrigation issues identified in the previous section into the organization where the issues mainly arise. Since the nonagricultural benefits are the externalities beyond the community, it is classified under the role of state (indicated as (S1) in the box of State). By doing so, however, the possibility of government failures in the form of protectionism or excessive support to agriculture sector increases. At the market organization, an increase in private irrigation and associated problems (a negative effect on existing collective irrigation management and/or groundwater depletion) occur when individual farmers follow private incentive at the market (e.g., cheaper pumps and free electricity) (M1). The volumetric pricing is also classified in the market because it provides market signal of water (M2). Last, an issue in the community is its changing characteristics (toward a labor scarce, less homogenous, and aging agrarian community) and resulting decline in collective management of existing surface irrigation systems (C1).

The ultimate goal under this framework is to consider the right combination of community, market,

and state to achieve the selected development objectives, that is the sustainable irrigation management in our case.[7] Based on the case studies, the next section seeks the right combination of these three organizations.

IV. CASE STUDIES

A. Japan: A Historical Review of Irrigation Policies[8]

To understand the roles and limitations of the government, we pick up Japan's irrigation policies from the 1910s (Meiji period) to the 2010s and evaluate them in this subsection. Traditionally, in *Edo* period, irrigation infrastructures were managed by local communities, with some exceptional cases of vast irrigation systems which received supports from local or national authorities (Tamaki and Hatate 1974). Even after the Meiji Restoration, the government maintained this style, allowing traditional communities to construct and manage the local irrigation systems. The local leaders, usually large landlords in the rural area, bore the financial burden, and put their efforts into mobilizing local resources. In this regard, we can claim that the community was the main player in irrigation construction and maintenance. Figure 17 shows the proportion of financial support for irrigation development under the name of land improvement projects by the central and local governments from 1910 to 2004.[9] We can observe that public financial support was rather low in the 1910s.

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[7] The same claim can be found in the textbook by de Janvry and Sadoulet (2016, p. 10) where they emphasize that "[s]uccessful development thus requires in effective state, market, and civil society that each fulfills its functions (according to the chosen balance of roles to achieve the selected development objectives) and, as much as possible, compensate for what the others eventually fail to do."

[8] This subsection draws heavily on Kajisa (2019).

[9] Nakajima (1998) created this figure from 1910 to 1995. We replicated Fig. 18 with the original data from 1910 to 1995 and extended the years using Ministry of Agriculture, Forestry and Fisheries (various years).

There was a turning point in the 1920s regarding the roles of the community vis-à-vis the government. The local landlords lost their interest in investing in the irrigation during this period. The reasons included (i) a low rice price because of increased imports from the colonies, (ii) a decline in land rent because of tenancy disputes with tenants, (iii) the fact that the costs to coordinate stakeholders which was traditionally shouldered by the landlords increased as the development area went beyond his/her own territory, and, above all, (iv) an increase in investment returns from emerging modern industrial sectors relative to the returns from the agriculture sector. As the local leaders' financial initiative declined, the government supplemented the financial burden in this period. Figure 17 shows that support started increasing in the 1920s. This attitude continued until the 1950s when Japan achieved rice self-sufficiency.

After the Second World War, Japan experienced rapid industrialization and economic growth from the mid-1950s to the mid-1970s. This led to a rapid reduction in the labor endowment in the agriculture sector, diversification of rural occupation, and aging of remaining farmers. From the relative resource endowment point of view, this means that the need for the substitution of capital for labor increased for efficient irrigation management. However, as we explained earlier, this substitution process does not occur automatically at socially optimal level because of the existence of different types of externalities in surface irrigation systems. In reaction to this, the Government of Japan strengthened its support for the modernization of existing irrigation systems in this period in order to substitute capital for labor. Financial support increased from about 60% in the 1960s to 80% in the 1990s, and then to more than 90% in the 2000s (Figure 17).[10] The projects in these periods included lining canals with concrete, the replacement of canals with pipelines, the rehabilitation of water intake, the cleaning of dams and rivers with heavy machines, and

[10] There was one exceptional period showing a decrease in the mid-1950s after the achievement of rice self-sufficiency.

automation and the remote control of water flows. These modernization projects substituted capital for labor. We can argue that, in Japan, the issue (C1) in Figure 16 was solved by the state intervention.

In the same period, the nonagricultural benefits from irrigation facilities increased. The nonagricultural residents in rural area used the irrigation infrastructure as their drainage. The environmental and amenity benefits also increased as the nonagricultural residents increased. Since these benefits are positive externalities, the increase in public support for irrigation facilities can be justifiable. This experience corresponds to (S1) in Figure 16.

At the same time, however, it is important to note that increased government interventions raise the possibility of government failures. Kajisa (2019) argues that land improvement investments largely supported by the government under the trend of increasing agricultural protectionism in this period did not realize productivity improvements and associated cost reductions of the sector and, thus, can be evaluated as an overinvestment. After the 2000s, Japanese agricultural policies have been drastically revised and the support for the land improvement investment had declined. Note, however, that the income subsidies to the farmers, which have less incentive for productivity improvement than the support for land improvement, have been maintained (as of 2017) as a major mean to support the agriculture sector. In this manner, the government failure in the form of the excess protection on the domestic agriculture sector has been continuing.

In summary, Japan's experience teaches us that, under increasing labor scarcity, increasing occupational diversification, aging in agriculture, and increasing nonagricultural benefits, it is important to provide public support for the substitution of capital for labor, and, at the same time, to introduce an appropriate mechanism to avoid government failures of excess supports.

B. People's Republic of China: The Effectiveness of a Volumetric Pricing Policy

Facing a rapid increase in water demand for urban and industrial use, the PRC aimed to achieve water savings in the agriculture sector, particularly in paddy farming by introducing volumetric water pricing, to replace area-based pricing. This subsection evaluates the outcomes of this policy, based on a case study by Kajisa and Dong (2017) in an irrigation system (Zhanghe Irrigation System) in Hubei, PRC.

In a surface gravity irrigation system, effective collective action among water users is needed to save water under volumetric pricing. This is because a feasible pricing method measures the volume at a canal's intake for water users group (WUG), rather than at individual parcels, and the total fee is charged to the group. The total fee is then divided among the group members by cultivated area. Therefore, the group has an incentive to save water, while individual farmers *within* a group may overuse water unless they are closely supervised. Institutional change must play an important role in preventing this free-rider problem within a WUG.

The study shows that the introduction of volumetric water pricing at the group level induces institutional change to prevent each member's overuse of water when the volumetric price levels are moderate. However, when the price is set high enough, many farmers exit a WUG for private pond irrigation. This tendency is associated with an increased probability that the remaining members give up undertaking institutional change and, thus, fail to implement stricter collective management for water savings. This may be because of the increased management difficulties among the remaining members whose fields become discontinuous over the irrigated area after the exit of some farmers to private ponds. As a result, we find a paradoxical evidence that the reservoir water is not saved at a high volumetric price level.

We can draw two lessons from the PRC's case which have both positive and negative aspects. First, it implies that volumetric pricing is an effective method for water savings (M2a in Figure 16), but needs a careful implementation because water savings failed when strict collective management became difficult under the decrease in water users and the progress of discontinuity of irrigation plots (M2b). Based on Japan's experience, we suggest that the public authority may support the substitution of capital for labor, so that the system can be managed properly with fewer remaining users. A possible option is to support investments in canals and water control devices to make water flow more visible (and thus measurable) and controllable (ideally, the system should be something similar to a domestic water system). However, we also have to think about cost-benefit ratio because the suggested system is an expensive one with substantial amount of capital investment. Second, coordination between public surface irrigation system and private ponds is needed because the private irrigation has a negative externality in decline in collective management. It is important to think of social optimal design in the co-existence of the public surface system and the private pond irrigation system.

C. The Philippines: An Experiment of Volumetric Pricing

In seeking for an efficient water use, a volumetric pricing of irrigation water, to replace area-based pricing, was experimentally introduced in two surface irrigation systems in Northern Luzon, Philippines under a strong initiative of the World Bank. An impact assessment survey, which was conducted in 2012 (baseline) and in 2013 (after the treatment), revealed supportive outcomes; there were some contributions in reducing total discharge (water saving), providing more water for lower stream (equitable water distribution), and implementing stricter water management (corresponds to M2a in Figure 16) (Kajisa et al. 2018). At the same time, however, the study finds three obstacles. First, it emphasizes the tremendous difficulty in accurate volume measurement in the current

surface irrigation systems where many parts are still earthen canals. Second, the system must be sophisticated enough to supply water on demand. Otherwise, the users would not agree to pay the fee based on the amount they use. Third, in surface irrigation system for paddy, it is difficult to control underground water flow from upstream to downstream fields. Hence, downstream paddy fields can buy less water to fulfill their irrigation, which may be regarded as unfair by the upstream farmers. By nature, the third problem cannot be solved. Regarding the first two problems, a possible solution is to upgrade the irrigation infrastructure for accurate volume measurement, ideally to the level of similar to a domestic water supply system. Hence, a practical issue is whether such an expensive system pays off.

D. India: Tank and Groundwater Irrigation

The traditional irrigation system in Tamil Nadu is a tank system, which is a kind of small-scale surface irrigation system consisting of a water storage area (a tank), sluices, and canals. This is a communal infrastructure which has been collectively managed by informal local bodies. Recently, two factors have accelerated the exit of the farmers from tank systems since the early 1990s: (i) migration to urban and foreign nonagricultural sectors; and (ii) switch to private electric pumps for groundwater irrigation which has been accelerated mainly by the state's free electricity power policy in rural area (M1 in Figure 16).

Kajisa (2012) and Kajisa et al. (2007) investigate the impact of these changes and find the following results. The exit of farmers led to the decline of collective tank management by the remaining farmers (corresponds to C1 in Figure 16), and the remaining farmers suffer water shortage and a decrease in rice productivity. In addition, some negative effects were also experienced by well users because of the overexploitation of groundwater beyond a socially

optimal level, and thus, eventually, well users became unable to earn as much profit for rice as they had previously (M1 in Figure 16). Further, the depletion of groundwater aquifer was aggravated through the decline in tank irrigation management because the functioning tanks could have recharged the aquifer. In this manner, the exit of farmers from tank irrigation to groundwater irrigation resulted in a double tragedy: tank water shortage and groundwater shortage.

We can draw three lessons from Tamil Nadu's experience. First, regarding private groundwater irrigation, in order to circumvent the situation of "the tragedy of commons" in groundwater aquifer, policies discouraging investment in groundwater irrigation facilities are needed. In addition, the termination of the free electricity policy is needed to discourage overuse, although it seems to be politically difficult. Moreover, the negative externality associated with the extraction of groundwater must be controlled. For this end, economists usually prefer Pigouvian tax or subsidies together with a metered charge, rather than a flat charge, for socially efficient outcome.[11]

At the same time, it is worth considering equity issues, first, between large-scale and small-scale well-owners and, second, between owners and non-owners. A resent empirical study in India indicates that rationing or quota, vis-à-vis Pigouvian tax/subsidy, could improve equity between the first groups (Ryan and Sudarshan 2020). This is because large well-users (who are usually wealthy) have to shrink their farming more disproportionately than small well-users under fixed amount of electricity rationing. Regarding the equity issue between the second groups, restricting the groundwater extraction could shrink water markets, resulting in limited irrigation access and declining productivity among the non-owners who are usually not wealthy. It is worth taking into

[11] A major obstacle for the introduction of metered tariff is a very high administrative cost for metering and record keeping of power used by pumps, which are scattered widely over the country. An introduction of labor-saving technologies such as smart meters with cellphone devices could be a solution (Sidhu et al. 2020).

account of these equity issues in designing appropriate policies.

Designing the appropriate policies for groundwater use can vary, depending on agro-ecological and socioeconomic conditions of the area where the policies are implemented. Reviewing the case of Tamil Nadu is not sufficient to draw comprehensive lessons. Box 2 shows more comprehensive options taken from the review of entire India by Sidhu et al. (2020).

Now we turn to the second lesson. Regarding tank irrigation, since the root of the problem is the negative externalities associated with increasing labor shortage, similar to the cases of Japan and the PRC, support by the government for the substitution of capital for labor is a possible solution. Needless to say, however, we have to be aware of government failures when we increase the public support.

Third, coordination between private and public irrigation systems is crucially important also in Tamil Nadu. The dissemination of private pumps has negative externality on tank management. At the same time, the malfunctioning tanks also have a negative externality to the groundwater aquifer through a weakened aquifer recharging function. Hence, the dissemination of private wells has negative effect on the well irrigation itself through the negative hydrological linkage. Given the aquifer recharging function of the tanks, there must be a socially optimal level of co-existence between private wells and surface tank irrigation for sustainable irrigated farming.

V. CONCLUSION

Much of the modern irrigation infrastructure in Asia was constructed in the 1970s and 1980s with a huge financial and technical assistance from the international organizations, donor countries, and local governments for the achievement of the Green Revolution. The basic structure of Asian

irrigation systems was established in that period. Since then, however, Asian economies have experienced structural changes dramatically in some countries and, if not, moderately in others. It is, therefore, obvious that the existing irrigation systems, whose design was appropriate at the time of their establishment, have become obsolete and thus needs to be adjusted and upgraded to the current conditions for their sustainable use. This paper explored contemporary issues for upgrading and showed the lessons drown from the case studies. The issues and lessons are summarized as follows.

> **1. The existing irrigation systems, which are mostly in the form of surface water structure, having been constructed and managed by public (government) or semipublic (community) sectors, need to be upgraded toward a labor-saving direction for their sustainable maintenance under increasing rural labor scarcity, more diversified occupations, and aging of remaining farmers.** For this, an introduction of labor saving infrastructure (e.g., lined canals) and technologies (e.g., remote water-sensing and controlling facilities) are needed. However, because of the existence of negative externalities in the exit of the farmers from the surface irrigation systems, this cannot occur automatically at socially optimal level.
>
> We can approach this problem either from the state or the market. First, through state intervention, it is effective to use a support by the government for the modernization of the systems to achieve the substitution of capital for labor. At the same time, however, we have to be aware of the possibility of government failures. As we learned from Japan's experience, we need some mechanism to circumvent excessive support on agriculture sector following the trend for increasing agricultural protectionism.
>
> A solution through the market is not explicitly discussed in the case studies because it remains at a conceptual level without much of empirical support. We briefly explain the concept herewith. Remember that a key reason for the decline in the collective irrigation management in the surface irrigation systems is the emergence of fallow plots after the exit of some farmers, resulting in the discontinuity among the irrigation users' farm plots. Agglomeration of farm plots through the activation of land rental or sales markets could contribute to solving this problem. Then, in the long-run, a new community which

consist of smaller number of large-scale farmers, where among them the continuity of farm plots is maintained, could revitalize the community for collective irrigation management. Related to this, the development of rental and sales markets for large-scale machines (e.g., a four-wheal tractor and a combine harvester) is needed to enhance the change toward this direction because large-scale mechanization makes large-scale farming more efficient. This direction of change is the change toward more capital-intensive farming, which is an appropriate direction under increasing labor scarcity. Therefore, through the development of markets for farm land and machines, irrigation maintenance could be revitalized under the new community's initiative.[12] To confirm this concept, we need more empirical supports.

2. It is important to recognize an increase in positive externalities in nonagricultural benefits in the public or semipublic surface irrigation facilities. As shown by the macro statistics review as well as in Japan's case, nonagricultural benefits such as disaster prevention, environmental service, and reciliation amenities increase along with economic development. This means that the stakeholders of the irrigation facilities expand beyond farmer users and that the characteristics of irrigation infrastructures become closer to pure public goods, leading us to emphasize again that the role of government is more important than before. Again, however, we have to be aware of the possibility of government failures.

3. We need to control the dissemination and the use of private wells for sustainable groundwater use in the area where groundwater resources are limited. As the private groundwater irrigation expands rapidly, the depletion of aquifer proceeds at an unsustainable speed. The root of this problem is the existence of negative externalities in groundwater use. As we have observed in our Indian case, the community cannot easily solve this problem internally. Herewith, we find the role of state again to control this negative externality. It is worth considering not only the use of Pigouvian taxes or subsidies but also the application of rationing or quota. The latter approach could be more attractive if the achievement of equity matters. Meanwhile, it is worth noting that

[12] In the course of reactivation of the community, the complementary role of the state can be found in supporting the local community's institutional change, which sometimes take time because of institutional inflexibility. Since the appropriate direction of change can vary, depending on the agro-ecological and socioeconomic background of the community as well as on its historical background, an important attitude of the state is that it should appreciate the direction chosen by the community, rather than imposing uniform policies over different communities.

depletion is not always the issue, as shown in the case of West Bengal, India. If the groundwater resources are abundant, it is better to encourage its use. By doing so, not only well owners but also non-owners could benefit through the development of water markets. Therefore, in order to choose the right policies, it is also important to utilize the local knowledge on water resource endowments.

4. Coordination between public (or semipublic) surface irrigation systems and private irrigation systems is needed to achieve a socially optimal co-existence of these two systems, if the interlinkage of these two systems is strong. Private irrigation systems such as pumps, wells, and ponds are becoming popular in Asian irrigation as we have observed in the PRC and Indian cases. In addition, as shown in the macro review, the expansion of high-value crops increases the use of other types of private irrigation systems such as sprinkler and drip irrigation systems. An important finding of the case studies is that the dissemination of private irrigation facilities in the area of surface irrigation system produces negative externalities sequentially. Initially, the exit of the farmers to private irrigation hastens the decline of the collective management of existing surface irrigation system, by which the remaining users of surface system suffer. Then, in the case of groundwater specifically, the decline in surface irrigation performance weakens its groundwater recharging function, by which groundwater users themselves suffer eventually. Therefore, if such interlinkages are strong, the coordination between public (or semipublic) surface irrigation systems and private irrigation systems is needed to achieve a socially optimal co-existence of these two systems. However, since the systems are interlinked through externalities, a socially optimal combination could not be realized easily. As we have explained in points 1 and 3 in this conclusion, we need to use skillfully the role of state, community, and market to control the maintenance and expansion of these two systems in order to achieve a socially optimal level of co-existence. Further, for designing the optimal co-existence, we need further accumulation of localized hydrological and civil engineering knowledge on the degree of interlinkage which can vary over different locations.

5. We need better understandings on the factors underlying effective implementation of volumetric pricing. Facing increasing water scarcities for farming in many Asian countries, the achievement of water savings through the introduction of volumetric water pricing sounds attractive. However, our case studies indicate that it is not a panacea. It is very costly to effectively implement volumetric pricing for surface irrigation systems unless infrastructure is highly sophisticated to the extent that accurate

volume measurement and on-demand water supply are possible. We need more investigation under what condition volumetric pricing effectively implemented at reasonable costs.

Last, we would like to close this section by pointing out an important issue which is not explicitly discussed in this report: a water right issue at an international level. Currently, the water rights disputes along international rivers have been arising in such a way that construction of a dam in the upstream country affect water access in the downstream countries. A typical example can be found in Mekong River, where there is a conflict between upstream (the PRC) and downstream (Lao People's Democratic Republic, Thailand, and Cambodia) countries. We need an international platform for the solutions of this problem.

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BOX ARTICLES

Box 1: The Green Revolution, Human Capital Accumulation, and Demographic Changes in a Rice Bowl in the Philippines

Background. Box 1 assesses the impact of the rice Green Revolution on human capital and demographic changes, using the long-term panel data set in Central Luzon in the Philippines. The area is regarded as a "rice bowl" of the country and it is one of the first beneficiary areas of the Green Revolution. The International Rice Research Institute started survey in 1966, a year before the release of the so-called miracle rice—IR8—in order to explore the agronomic and socioeconomic conditions of the potential beneficially area. Since then, the survey has been conducted every 4–5 years for 13 rounds until 2015–2016, suitable to investigate the long-term changes after the Green Revolution. This article uses the data until the 2011–2012 round. More details are in Moya et al. (2015).

Irrigation development and farm productivity. This area has a distinct wet season and dry season, wherein the wet season is the main rice season traditionally. The irrigation development in this area follows a typical pattern observed in many Asian countries; initially with a large-scale surface irrigation system with public investment, followed by the dissemination of private pump irrigation systems.* This irrigation development has accelerated the adoption of modern varieties and made the double cropping possible as it enabled the dry season rice farming. Paddy yield increased from 2.3 t/ha in 1966 (before the Green Revolution) to 3.8 t/ha in 2011 during the wet season, 1.8 t/ha to 5.8 t/ha during the dry season. An average crop intensity, an index of double cropping taking value 2 if double cropped, increased from 1.1 to 1.8.

Socioeconomic impacts. What have been the socioeconomic impacts of the Green Revolution? First, the first generation of Green Revolution farmers increased educational investments to their children. Figure B1, which shows the changes in educational attainment over time, indicate that, before the Green Revolution, about 80 % of people in the survey area had merely elementary

* The completion of the Pantabagan Dam in 1975 and the establishment of the Upper Pampanga Integrated Irrigation System represented the first major irrigation project in the region. The Casecnan Irrigation and Hydroelectric Plant, which commenced in 2002, diverts water from the Casecnan and Taan rivers of Nueva Vizcaya to the Pantabangan Reservoir through a 25-kilometer long tunnel in Nueva Ecija, and this further enhanced the expansion of irrigated area in the region. In the past two decades, the adoption of low-lift pumps and shallow tube wells has been the major source of irrigation expansion, particularly during the dry season.

school or less. A proportion of high school level education increased by the mid-1990s and further to collage level by 2011. Such progress in human capital accumulation has encouraged the occupational shift of educated children from agricultural to nonagricultural jobs. Figure B2 shows that the proportion of rice income increased once in 1970s because of the success of the Green Revolution, but then decreased after that as the younger generations started engaging more in nonagricultural opportunities such as off-farm employment and overseas works. The significant number of younger generations have moved out of the original villages for nonagricultural opportunity, resulting in the aging of remaining farmers. This feature is clearly depicted in the changing shapes of population pyramid from a triangle shape to a bell shape, and further to a rectangular shape in Figure B3.

Reference:

Moya, P., K. Kajisa, R. Barker, S. Mohanty, F. Gascon, and M. R. San Valentin. 2015. *Changes in rice farming in the Philippines: Insights from five decades of household-level survey*. Los Baños (Philippines): International Rice Research Institute. 145p.

Box 2: An Overview of Power Tariffs and Expected Outcomes for Groundwater Irrigation in India

Sidhu et al. (2020) summarizes the differential effects of two major power tariff policies in India, namely (i) flat tariffs, fixed according to the power rating of a farmer's groundwater pump; and (ii) metered tariffs, based on the amount of electricity consumed, the performance of electricity administration, livelihood of small and marginal farmers, and farmers' pumping behaviors, and comprehensive review of different policies over the Indian states. Their article also proposes the reformed policies not only for groundwater scarce states but also for abundant states. Tables B1 and B2, copied from the original article, summarized their arguments, which are useful to understand what are the features of groundwater issues and what kind of policy options are available.

Reference:

Sidhu, B. S., M. Kandlikar, and N. Ramankutty. 2020. Power tariffs for groundwater irrigation in India: a comparative analysis of the environmental, equity, and economic tradeoffs. *World Development*, 128, 101836.

Table 1: Area equipped for irrigation by continent and region

Continent Regions	Equipped area (million ha)		As % of cultivated land		Of which groundwater irrigation (2006)	
	1961	2006	1961	2006	Area equipped (million ha)	As %of total irrigated area
Africa	**7.4**	**13.6**	**4.4**	**5.4**	**2.5**	**18.5**
Northern Africa	3.9	6.4	17.1	22.7	2.1	32.8
Sub-Saharan Africa	3.5	7.2	2.4	3.2	0.4	5.8
Americas	**22.6**	**48.9**	**6.7**	**12.4**	**21.6**	**44.1**
Northern America	17.4	35.5	6.7	14.0	19.1	54.0
Central America and Caribbean	0.6	1.9	5.5	12.5	0.7	36.3
Southern America	4.7	11.6	6.8	9.1	1.7	14.9
Asia	**95.6**	**211.8**	**19.6**	**39.1**	**80.6**	**38.0**
Western Asia	9.6	23.6	16.2	36.6	10.8	46.0
Central Asia	7.2	14.7	13.4	37.2	1.1	7.8
South Asia	36.3	85.1	19.1	41.7	48.3	56.7
East Asia	34.5	67.6	29.7	51	19.3	28.6
Southeast Asia	8.0	20.8	11.7	22.5	1.0	4.7
Europe	**12.3**	**22.7**	**3.6**	**7.7**	**7.3**	**32.4**
Western and Central Europe	8.7	17.8	5.8	14.2	6.9	38.6
Eastern Europe and Russian Federation	3.6	4.9	1.9	2.9	0.5	10.1
Oceania	**1.1**	**4.0**	**3.2**	**8.7**	**0.9**	**23.9**
Australia and New Zealand	1.1	4.0	3.2	8.8	0.9	24
Pacific Islands	0.001	0.004	0.6	0	0	18.7
World	**139**	**300.9**	**19.7**	**112.9**	**112.9**	**37.5**
High-income	26.7	54.0	6.9	14.7	26.5	49.1
Middle-income	66.6	137.9	10.5	19.3	36.1	26.1
Low-income	45.8	108.9	13.2	24.5	50.3	46.2
Low-income food deficit	**82.5**	**187.6**	**16.6**	**29.2**	**71.9**	**38.3**
Least-developed	**6.1**	**17.5**	**5.2**	**10.1**	**5.0**	**28.8**

ha = hectare.

Note: Country groupings follow the definitions and standards used in FAOSTAT.

Source: Adopted from FAO. 2011. *The state of the world's land and water resources for food and agriculture (SOLAW) – Managing systems at risk*. Rome: Food and Agriculture Organization of the United Nations and Earthscan, (table 1.8).

Table 2: Area Equipped for Irrigation Projection to 2050 by Continent and Region

Continent Regions	Area equipped for irrigation				
	Area (million ha)			Annual Growth	
	1961	2006	2050	1961-2006	2006-2050
Africa	**7.4**	**13.6**	**17**	**1.3**	**0.5**
Northern Africa	3.9	6.4	7.6	1	0.4
Sub-Saharan Africa	3.5	7.2	9.4	1.5	0.6
Americas	**22.6**	**48.9**	**46.5**	**1.6**	**-0.1**
Northern America	17.4	35.5	30	1.5	-0.4
Central America and Caribbean	0.6	1.9	2.4	2.5	0.5
Southern America	4.7	11.6	14.1	1.9	0.5
Asia	**95.6**	**211.8**	**227.6**	**1.7**	**0.2**
Western Asia	9.6	23.6	26.9	1.9	0.3
Central Asia	7.2	14.7	15	1.5	0
South Asia	36.3	85.1	85.6	1.8	0
East Asia	34.5	67.6	76.2	1.4	0.3
Southeast Asia	8	20.8	23.9	2	0.3
Europe	**12.3**	**22.7**	**24.6**	**1.3**	**0.2**
Western and Central Europe	8.7	17.8	17.4	1.5	0
Eastern Europe and Russian Federation	3.6	4.9	7.2	0.6	0.9
Oceania	**1.1**	**4**	**2.8**	**2.7**	**-0.8**
Australia and New Zealand	1.1	4	2.8	2.7	-0.8
Pacific Islands	0.001	0.004	-	2.9	-
World	***139***	***300.9***	***318.4***	***1.6***	***0.1***
High-income	26.7	54	45.1	1.5	-0.4
Middle-income	66.6	137.9	159.4	1.5	0.4
Low-income	45.8	108.9	113.8	1.8	0.1
Low-income food-deficit	**82.5**	**187.6**	**201.9**	**1.7**	**0.2**
Least-developed	**6.1**	**17.5**	**18.4**	**2.2**	**0.1**

ha = hectare.

Note: Country groupings follow the definitions and standards used in FAOSTAT.

Source: Adopted from FAO. 2011. *The state of the world's land and water resources for food and agriculture (SOLAW) – Managing systems at risk*. Rome: Food and Agriculture Organization of the United Nations and Earthscan, (table 1.14).

Table 3: Area Equipped for Pump Irrigation (Surface Water or Groundwater) (1000 ha)*

	1973-1977	1978-1982	1983-1987	1988-1992	1993-1997	1998-2002	2003-2007	2008-2012
Kazakhstan					600			40
Kyrgyz Republic					60		53	
Tajikistan					318			297
Turkmenistan					284			
Uzbekistan					1,173			
Bangladesh					3,120			4,887
Bhutan					1			
India					26,538	51,543		
Sri Lanka					171			
People’s Republic of China	24,188	26,555	26,540	28,608	29,288		36,066	
Republic of Korea					175			
Lao People's Democratic Republic					23			
Myanmar					55			
Thailand				200	319		460	
Viet Nam					792		2,148	
Malaysia			34					
Philippines					169		265	

ha = hectare.

* Area equipped for irrigation where pumps are used for water supply from the source to the scheme. It also includes areas where water is drained out with human- or animal-driven water lifting devices. It does NOT refer to pumping required for the technology used within the field (such as sprinkler irrigation or localized irrigation, which require pressure and thus pumping).

Source: FAO. AQUASTAT Database. http://www.fao.org/aquastat/en/ (accessed 24 December 2020).

Table 4: Area Equipped for Irrigation by Source of Water (1000 ha)

		1958-1962	1963-1967	1968-1972	1973-1977	1978-1982	1983-1987	1988-1992	1993-1997	1998-2002	2003-2007	2008-2012
Afghanistan	S		2,297							2,631		
	G		418							577		
Kazakhstan	S								3,334			2,064
	G								178			2
Kyrgyz Republic	S								1,070			
	G								7			
Tajikistan	S								626			697
	G								68			33
Turkmenistan	S								1,700		1,981	
	G								44		10	
Uzbekistan	S								4,007			
	G								274			
Bangladesh	S						1,217	1,280	1,159			1,062
	G						982	1,805	2,592			3,988
Bhutan	S								27			
India	S	17,400		19,200		21,100	21,400		20,327	22,482		
	G	7,300		11,900		17,700	20,600		26,538	39,426		
Maldives	S											
	G											
Nepal	S								838	929		
	G								140	224		
Pakistan	S							10,948				7,630
	G							4,871				4,130
Sri Lanka	S								569	563		
	G								1	7		
PRC	S						38,541				43,569	
	G						8,894				19,369	
DPR of Korea	S							1,220				
	G							200				
Japan	S								2,628			
	G											
Mongolia	S								48			
	G								36			
Republic of Korea	S								844			761
	G								45			45
Cambodia	S								270			
Lao PDR	S								155		310	
	G								0		0	
Myanmar	S								1,527		2,010	
	G								55		100	
Thailand	S								4,992		5,831	
	G							7	12		584	
Viet Nam	S										4,539	
	G										46	
Brunei Darussalam	S								1			
Indonesia	S								4,384		6,655	
	G								44		67	
Malaysia	S								335			
	G								27			
Philippines	S								1,398		1,478	
	G								152		107	
Timor-Leste	S									34		
	G									1		

DPR of Korea = Democratic People's Republic of Korea, G = groundwater, ha = hectare, Lao PDR = Lao People's Democratic Republic, PRC = People's Republic of China, S = surface water.

Source: FAO. AQUASTAT Database. http://www.fao.org/aquastat/en/ (accessed 23 December 2020).

Table 5: Rural and Urban Population Growth

		Growth rate 1998-2008	Growth rate 2008-2018			Growth rate 1998-2008	Growth rate 2008-2018
Armenia	Rural	-0.2	0.2	Malaysia	Rural	-0.7	-0.8
	Urban	-0.9	0.0		Urban	3.6	2.6
Azerbaijan	Rural	0.6	0.6	Maldives	Rural	1.2	1.9
	Urban	1.3	1.7		Urban	5.3	3.6
Bahrain	Rural	5.8	2.7	Mongolia	Rural	-1.2	0.9
	Urban	6.0	3.5		Urban	2.6	2.1
Bangladesh	Rural	0.8	0.0	Myanmar	Rural	0.7	0.6
	Urban	4.0	3.5		Urban	1.6	1.5
Bhutan	Rural	1.2	0.3	Nepal	Rural	1.0	0.7
	Urban	6.1	3.6		Urban	4.1	3.2
Brunei Darussalam	Rural	0.3	-0.1	Oman	Rural	1.1	0.4
	Urban	2.3	1.8		Urban	2.4	6.9
Cambodia	Rural	1.6	1.1	Pakistan	Rural	1.8	1.7
	Urban	2.4	3.4		Urban	2.7	2.6
Hong Kong, China	Rural			Palestine	Rural	1.7	1.7
	Urban	0.7	0.7		Urban	2.8	3.0
People's Republic of China	Rural	-1.5	-2.2	Philippines	Rural	2.1	1.3
	Urban	3.8	2.9		Urban	1.8	1.9
Cyprus	Rural	1.9	1.3	Qatar	Rural	1.3	-1.0
	Urban	1.7	0.8		Urban	9.5	6.7
DPR of Korea	Rural	0.6	0.0	Republic of Korea	Rural	-0.8	0.5
	Urban	0.9	0.8		Urban	0.9	0.4
Georgia	Rural	-1.4	-1.9	Saudi Arabia	Rural	1.5	1.3
	Urban	-0.8	-0.4		Urban	2.9	2.8
India	Rural	1.2	0.7	Singapore	Rural		
	Urban	2.7	2.4		Urban	2.6	1.8
Indonesia	Rural	-0.2	-0.2	Sri Lanka	Rural	0.7	0.5
	Urban	3.4	2.6		Urban	0.6	0.6
Iran (Islamic Republic of)	Rural	-0.7	-0.8	Syrian Arab Republic	Rural	1.9	-0.9
	Urban	2.4	1.9		Urban	3.3	-1.2
Iraq	Rural	2.5	2.5	Tajikistan	Rural	2.0	2.1
	Urban	2.8	3.2		Urban	1.7	2.4
Israel	Rural	1.3	0.8	Thailand	Rural	-0.9	-1.2
	Urban	2.1	1.8		Urban	3.7	2.3
Japan	Rural	-6.7	-2.7	Timor-Leste	Rural	1.7	1.6
	Urban	1.4	0.2		Urban	3.6	3.3
Jordan	Rural	-0.1	-1.7	Turkey	Rural	-0.4	-0.5
	Urban	3.4	5.1		Urban	2.3	2.3
Kazakhstan	Rural	0.3	1.2	Turkmenistan	Rural	0.7	1.0
	Urban	0.5	1.5		Urban	1.6	2.5
Kuwait	Rural			United Arab Emirates	Rural	6.7	1.2
	Urban	3.8	4.6		Urban	9.4	3.6
Kyrgyz Republic	Rural	1.0	1.4	Uzbekistan	Rural	0.5	1.5
	Urban	0.9	1.8		Urban	2.4	1.6
Lao PDR	Rural	0.4	0.5	Viet Nam	Rural	0.2	0.1
	Urban	5.3	3.3		Urban	3.2	3.2
Lebanon	Rural	1.8	2.7	Yemen	Rural	2.1	1.7
	Urban	2.9	4.1		Urban	4.7	4.4

DPR of Korea = Democratic People's Republic of Korea, Lao PDR = Lao People's Democratic Republic.

Source: FAO. FAOSTAT Database. http://www.fao.org/faostat/en/#home/ (accessed 23 December 2020).

Table 6: Employment in Agriculture (% point change in total employment) (modelled ILO estimate)

	1998-2008	2008-2018
Australia	-2	0
Brunei Darussalam	0	0
Cambodia	-19	-24
People's Republic of China	-10	-14
Fiji	-7	-7
French Polynesia	-3	-2
Guam	-1	0
Indonesia	-4	-11
Japan	-1	-1
Korea, Democratic People's Republic of	-3	-3
Korea, Republic of	-5	-2
Lao People's Democratic Republic	-9	-11
Malaysia	-5	-3
Mongolia	-9	-13
Myanmar	-8	-5
New Caledonia	-3	-1
New Zealand	-2	-1
Papua New Guinea	-4	-10
Philippines	-4	-10
Samoa	-9	-4
Singapore	0	0
Solomon Islands	-6	-8
Thailand	-11	-8
Timor-Leste	-9	-7
Tonga	-6	-5
Vanuatu	-6	-5
Viet Nam	-16	-10
Afghanistan	-6	-16
Bangladesh	-17	-9
Bhutan	-5	-6
India	-8	-10
Maldives	-6	-5
Nepal	-7	-5
Pakistan	1	-8
Sri Lanka	-9	-9

ILO = International Labour Organization.

Source: World Bank. World Development Indicators. https://databank.worldbank.org/source/world-development-indicators (accessed 16 December 2020).

Table 7: Growth of Area Harvested, Vegetable Primary (ha)*

	1988-1998	1998-2008	2008-2018
Afghanistan	6.8	0.2	0.0
Armenia		2.3	-1.7
Azerbaijan		9.2	-1.8
Bahrain	1.9	-4.2	-6.0
Bangladesh	2.1	6.4	2.8
Bhutan	5.7	3.4	-1.6
Brunei Darussalam	3.7	-3.3	-10.8
Cambodia	-1.9	1.2	2.7
People's Republic of China	7.1	4.4	2.1
Cyprus	0.1	-1.9	-1.7
Democratic People's Republic of Korea	1.8	0.6	-1.1
Georgia		-6.6	-4.6
India	0.9	2.5	2.2
Indonesia	0.4	0.7	1.5
Iran (Islamic Republic of)	5.4	2.2	-2.9
Iraq	2.3	0.7	-11.9
Israel	2.4	4.5	4.8
Japan	-1.5	-1.1	-0.2
Jordan	1.5	2.4	-0.7
Kazakhstan		1.4	3.7
Kuwait	1.0	4.6	-1.7
Kyrgyz Republic		1.2	2.2
Lao People's Democratic Republic	12.6	9.7	7.2
Lebanon	-3.1	-0.8	2.0
Malaysia	4.0	3.6	3.5
Maldives	-16.8	3.9	21.2
Mongolia	2.8	2.3	2.1
Myanmar	3.6	2.5	1.4
Nepal	3.2	4.2	2.3
Oman	2.7	2.1	6.6
Pakistan	4.1	3.0	0.4
Palestine		1.0	-3.5
Philippines	1.5	1.7	1.7
Qatar	7.4	-2.2	0.6
Republic of Korea	-0.5	-2.1	-1.2
Saudi Arabia	2.9	-5.2	-4.7
Singapore	-1.6	5.7	3.4
Sri Lanka	-1.0	0.4	-0.8
Syrian Arab Republic	-3.5	1.4	0.1
Tajikistan		3.7	5.8
Thailand	4.9	-2.1	-2.7
Timor-Leste	-0.7	2.8	2.2
Turkey	2.0	-0.3	0.9
Turkmenistan		3.0	-0.2
United Arab Emirates	12.3	-10.2	2.0
Uzbekistan		2.5	2.2
Viet Nam	4.8	1.3	6.0
Yemen	6.2	2.8	-2.1

* Vegetables, as classified in this group, are mainly annual plants cultivated as field and garden crops in the open and under glass, and used almost exclusively for food. Vegetables grown principally for animal feed or seed should be excluded. Certain plants, normally classified as cereals and pulses, belong to this group when harvested green, such as green maize, green peas, etc. This group differs from international trade classifications for vegetables because it includes melons and watermelons, which are normally considered to be fruit crops. But, whereas fruit crops are virtually all permanent crops, melons and watermelons are similar to vegetables because they are temporary crops. Chillies and green peppers are included in this grouping when they are harvested for consumption as vegetables and not processed into spices. FAOSTAT production data for green peas and green beans refer to the total weight including pods, although some countries report on a shelled weight basis. The weight of the pods ranges from 40% to 50% for peas to up to 70% for broad beans. Area data on small vegetable gardens are often omitted in agricultural surveys, although production estimates may be reported. Trade data for fresh vegetables also include chilled vegetables, meaning the temperature of the products has been reduced to around 0°C without the products being frozen. Vegetables contain principally water, accounting for between 70% and 95% of their weight. They are low in nutrients, but contain minerals and vitamins. FAOSTAT covers 27 primary vegetable products. Each is listed along with its code, botanical name, or names, and a short description. Products derived from vegetables refer to processed products. Apart from a few main products, international trade classifications do not permit a sufficiently detailed classification of processed products according to the primary commodity used in the preparation. A similar situation prevails for frozen vegetables.

Source: FAO. FAOSTAT Database. http://www.fao.org/faostat/en/#home/ (accessed 23 December 2020).

Table 8: Area Equipped with Sprinkler and Localized Irrigation in India, PRC, and Japan

		Area equipped with sprinkler and localized irrigation (1000 ha)							Growth of vegetable harvest area		
		1978-1982	**1983-1987**	**1988-1992**	**1993-1997**	**1998-2002**	**2003-2007**	**2008-2012**	**1988-1998**	**1998-2008**	**2008-2018**
India	sprinkler*				700	1,446	1,446		0.8	2.5	2.2
	localized irrigation**	0.02	1	71	71	578	578				
PRC	sprinkler	599	543	534	616		2,841		6.6	4.4	2.1
	localized irrigation						760				
Japan	sprinkler			117	243			430	-1.4	-1.1	-0.2
	localized irrigation		1	57	55			60			

ha = hectare, PRC = People's Republic of China.

*A sprinkler irrigation system consists of a pipe network, through which water moves under pressure before being delivered to the crop via sprinkler nozzles. The system basically simulates rainfall because water is applied through overhead spraying. These systems are also known as overhead irrigation systems.

**Localized irrigation is a system where the water is distributed under low pressure through a piped network, in a pre-determined pattern, and applied water as a small discharge to each plant or adjacent to it. There are three main categories: 1) drip irrigation (where drip emitters are used to apply water slowly to the soil surface); 2) spray or micro-sprinkler irrigation (where water is sprayed to the soil near individual plants or trees); and 3) and bubbler irrigation (where a small stream is applied to flood small basins or the soil adjacent to individual trees). The following other terms are also sometimes used to refer to localized irrigation: micro-irrigation, trickle irrigation, daily flow irrigation, drop-irrigation, sip irrigation, diurnal irrigation.

Source: FAO. AQUASTAT Database. http://www.fao.org/aquastat/en/ (accessed 28 December 2020).

Table 9: Number of Natural Disasters by Type of Triggering Hazards, Regional Distribution 1995-2004

	Hydrometeorological disasters						**Geological disasters**		**Biological disasters**	
Region	**Floods**	**Wind storms**	**Droughts and related disasters**	**Landslides**	**Avalanches**	**Waves and surges**	**Earthquakes and tsunamis**	**Volcanic eruptions**	**Epidemics**	**Insect infestations**
Africa	277	70	123	11	0	0	18	4	346	14
America	269	269	205	43	1	1	51	23	48	2
Asia	444	326	229	97	16	6	193	13	154	3
Europe	180	86	156	7	10	0	28	2	37	1
Oceania	35	68	37	8	0	0	9	6	10	3
World	1205	848	750	166	27	7	299	48	595	23

Source: Adopted from Y. Sawada. 2007. The impact of natural and manmade disasters on household welfare, *Agricultural Economics,* 37(s1), 59-73, (table 1).

Table 10: Top 50 Countries on Flood Occurrence

	Region	Flood occurrence Indicator (2013)*
Bangladesh	Asia	4.9
Bhutan	Asia	4.7
Nepal	Asia	4.5
Philippines	Asia	4
Haiti	Americas	3.9
India	Asia	3.9
Pakistan	Asia	3.9
Cambodia	Asia	3.9
Lao People’s Democratic Republic	Asia	3.9
Somalia	Africa	3.8
Kenya	Africa	3.8
El Salvador	Americas	3.8
Viet Nam	Asia	3.8
Slovakia	Europe	3.8
Republic of Moldova	Europe	3.8
Dominican Republic	Americas	3.7
Colombia	Americas	3.7
Afghanistan	Asia	3.7
Tajikistan	Asia	3.7
Sri Lanka	Asia	3.7
Thailand	Asia	3.7
Romania	Europe	3.7
Benin	Africa	3.6
Rwanda	Africa	3.6
Uganda	Africa	3.6
Honduras	Americas	3.6
Nicaragua	Americas	3.6
Antigua and Barbuda	Americas	3.6
Barbados	Americas	3.6
Dominica	Americas	3.6
Saint Lucia	Americas	3.6
Saint Vincent and the Grenadines	Americas	3.6
Georgia	Asia	3.6
Bosnia and Herzegovina	Europe	3.6
Guatemala	Americas	3.5
Jamaica	Americas	3.5
People’s Republic of China	Asia	3.5
Republic of Korea	Asia	3.5
Hungary	Europe	3.5
Montenegro	Europe	3.5
Serbia	Europe	3.5
Slovenia	Europe	3.5
Niger	Africa	3.4
United Kingdom	Europe	3.4
Burkina Faso	Africa	3.3
Sudan	Africa	3.3
Burundi	Africa	3.3
Lesotho	Africa	3.3

*A normalized indicator of the number of floods recorded from 1985 to 2011, using the total number of floods observed in that period. The indicator was created by the World Resources Institute (WRI) and ranges from 0-5, where 0 is lowest and 5 is highest. Values represent the "All-sector" indicator, and have been rounded to the nearest tenth by AQUASTAT. This was a one-time exercise and will be updated by WRI when new data is made available.

Source: FAO. AQUASTAT Database. http://www.fao.org/aquastat/en/ (accessed 28 December 2020).

Table 11: Functions, Limitations, and Complementary Roles of Community, State, and Market

	Functions	Limitations	Complementary roles
Community	• Internalize the externality in the community. • Resolve asymmetric info in the community. • Achieve equity in the community.	• Local optimal • Inflexibility in institutional change	
State	• Internalize the externality in the state. • Achieve equity in the state.	• Misallocation of resources due to asymmetric information between the state and citizens. • Misallocation of resources due to rent seeking.	• Establishment of judicial system and laws for functioning market systems.
Market	• Efficient resource allocation of private goods in a broad area covered by the market.	• Market failures • Achievement of equity	• Provision of price signal and competition for efficient resource allocation by the state and community.

Source: Author.

Table B1: Summary of the impact of the different power tariffs in India

Summary of the comparative analysis between flat and metered tariffs in terms of their impact on electricity administration, livelihood of small and marginal farmers, and farmers' pumping behavior. Bold, regular, and italicized text denotes positive, mixed, and negative influence, respectively.

Influence on	Flat tariffs	Metered tariffs
Electricity administration	**No metering or regular monitoring cost since farmers operate unmetered pumps and pay fixed tariffs (Shah et al., 2004)**	*High cost of metering and regular monitoring of millions of electric pumps distributed over a wide area (Shah et al., 2004).*
	No incentive to farmers for pilferage or underreporting of consumption (Shah et al., 2004).	*Prone to power theft, and erroneous reporting through collusion between farmers and meter readers (Shah et al., 2004).*
	Utilities can overreport agricultural power consumption to hide transmission losses and collect higher subsidy compensations from the government (Prayas (Energy Group), 2018a; Sant and Dixit, 1996).	**Regular collection of comparatively reliable power consumption data, although it is still vulnerable to accuracies arising from pilferage and erroneous reporting by meter readers (Prayas (Energy Group), 2018b).**
Livelihood of small and marginal farmers	**Due to a fixed monthly cost, tube well owners try to sell water to as many customers as possible. This competition creates buyers' water markets where poor farmers benefit from low-priced groundwater (Shah et al., 2017a).**	*As tube well owners are under no obligation of a fixed cost through water sales, water markets operate as sellers' markets and the price of water is higher (Mukherjee et al., 2009; Shah and Chowdhury, 2017; Shah and Verma, 2008).*
Farmers' pumping behavior	*Farmers have no incentive to consume groundwater judiciously (Scott and Shah, 2004). When supply is irregular or discontinuous, they sometimes keep their pumps running continuously (Sarkar, 2012).*	Capacity to promote groundwater conservation depends on a region's social, agricultural, and economic conditions. For example, metered farmers in Gujarat consume less groundwater than their flat-rated peers in some areas (Kumar et al., 2011), while there is no significant difference in other regions (Kishore and Verma, 2004).

Source: Adopted from B. S. Sidhu, M. Kandlikar, and N. Ramankutty. 2020. Power tariffs for groundwater irrigation in India: a comparative analysis of the environmental, equity, and economic tradeoffs. *World Development*, 128, (table 1).

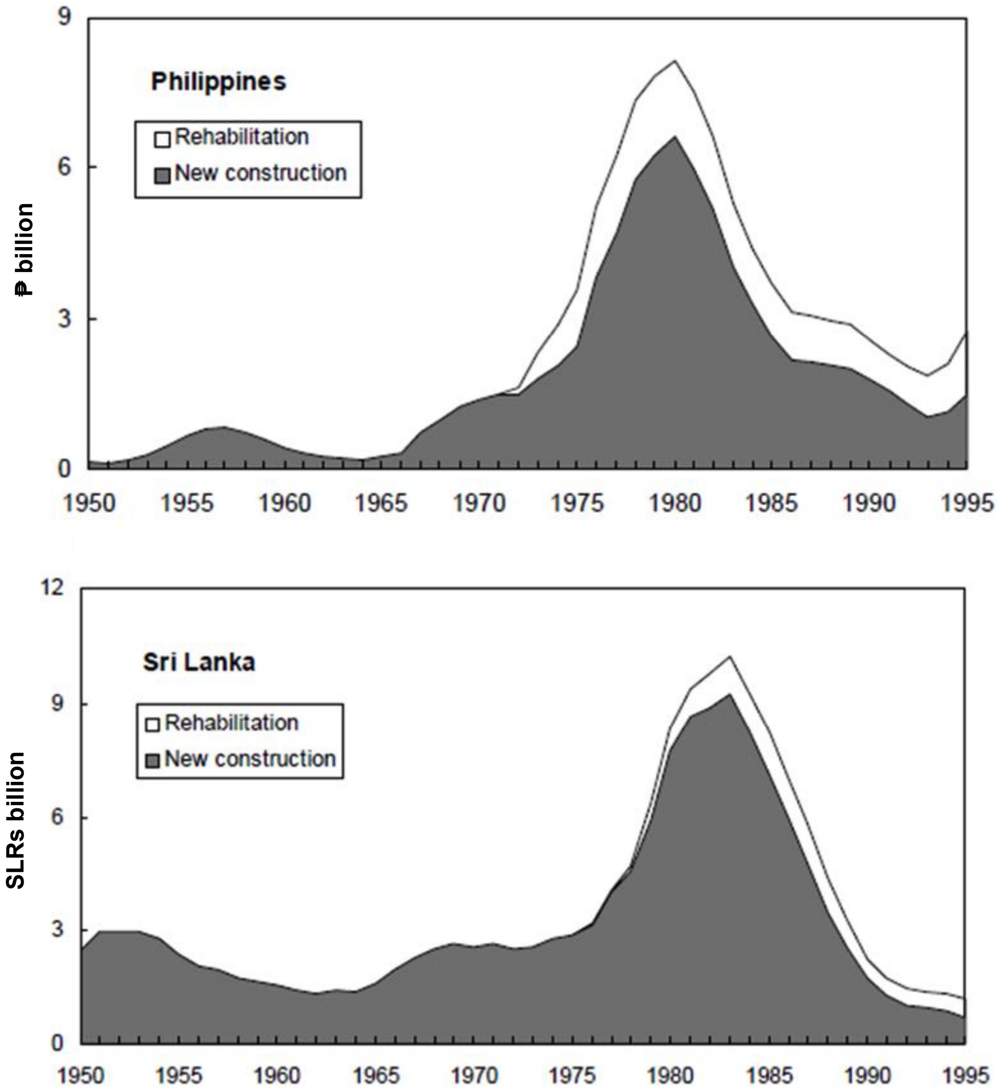
Table B2: Possible Impact of Different Tariff Rationalization Strategies in India

Impact of proposed tariff rationalization strategies on the three criteria of comparison between flat and metered tariffs. Bold, regular, and italicized text denote positive, mixed, and negative outcomes, respectively.

Strategy	Regional Suitability	Outcome		
		Electricity administration	Livelihood of small and marginal farmers	Farmers' pumping behavior
Intelligent rationing of flat tariffs	Western and northwestern regions with rapidly depleting aquifers due to overexploitation	**Does not require metering, so it is easily implementable in flat-tariffed systems. Utilities can cater to varying demand by splitting consumers into zones and supplying power cyclically (Shah, et al. 2004)**	*Reducing supply hours will penalize water buyers disproportionately as pump owners usually sell water after their own demand is met (Sarkar, 2012; Shah and Verma 2008)*	**Prioritizing power supply during periods of peak demand and rationing power at other times will discourage wasteful groundwater extraction (Shah et al., 2004)**
Payment for groundwater conservation	"	All three schemes require metering of individual consumers which can be costly (Shah, 1993). Potential solutions exists in the form of tamper-proof smart meters that do not require manual meter reading (Mukherji et al., 2009; Zekri et al., 2017). Metering will lead to the collection of reliable consumption data which can assist in future policy decisions.	*Compensating pump owners for forsaking profit from water sales is expected to increase water buyers, thereby affecting water buyers adversely.*	**Monetary compensation for reducing groundwater consumption is expected to discourage overexploitation (Fishman et al., 2016; Gulati and Pahuja, 2015).**
Restructuring subsidies as a minimum quantity of electricity supply	"	"	Distributing subsidized power according to farm size will lead to greater equity between large and small pump owners (Gulati and Pahuja, 2015). Water buyers may face higher water prices as pump owners reduce their groundwater extraction.	"
Combination of flat and metered tariffs	Eastern regions with abundant groundwater	"	**Flat portion of the tariff will encourage water sales (Shah et al, 2017a).**	**Metered portion of the tariff will discourage wasteful consumption (Shah et al., 2017a)**

Source: Adopted from B. S. Sidhu, M. Kandlikar, and N. Ramankutty. 2020. Power tariffs for groundwater irrigation in India: a comparative analysis of the environmental, equity, and economic tradeoffs. *World Development*, 128, (table 2).

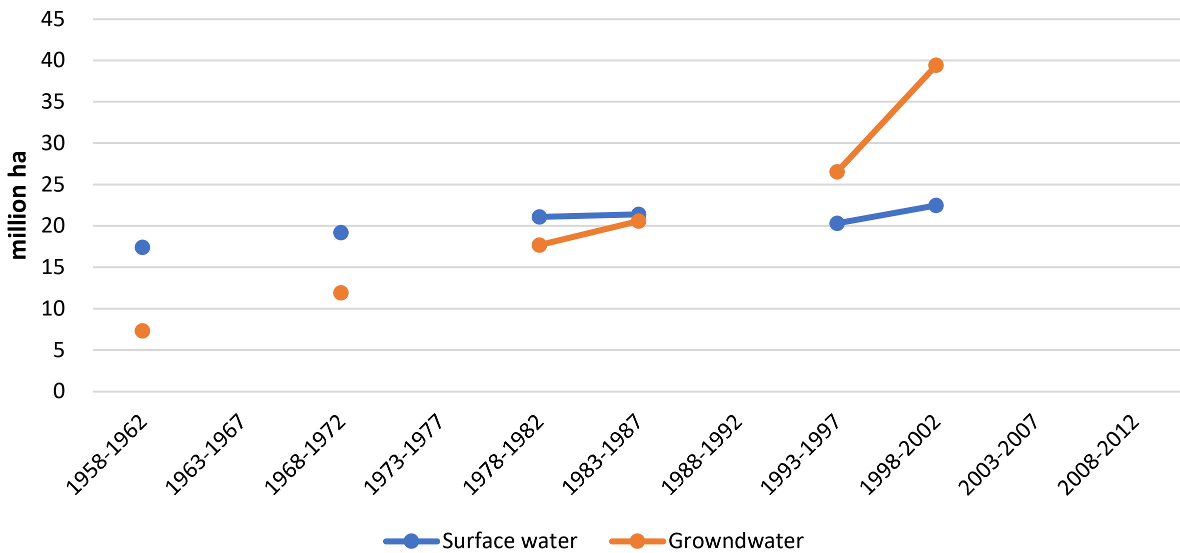
Figure 1: Irrigation investment in the Philippines and Sri Lanka, 1950-1995



Note: 1955 prices, five year moving averages.

Source: Adopted from M. Kikuchi, A. Maruyama, and Y. Hayami. 2001. *Investment inducements to public infrastructure: Irrigation in the Philippines and Sri Lanka since independence*. Manila and Colombo: International Rice Research Institute and International Water Management Institute (IWMI).

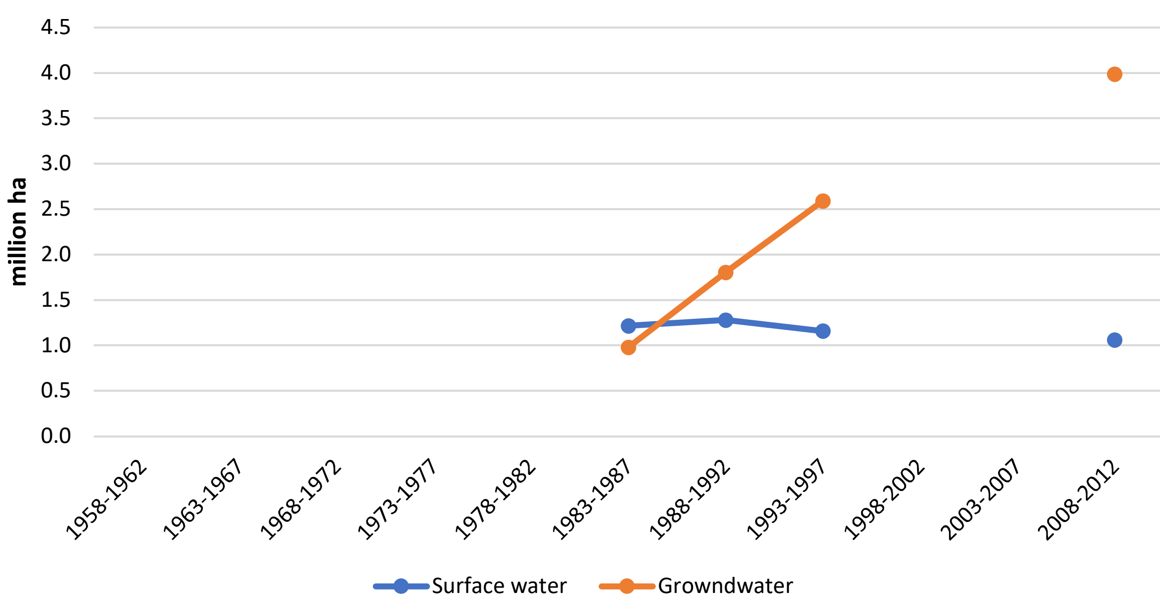
Figure 2: India, Area Irrigated by Source



ha = hectare.

Source: FAO. AQUASTAT Database. http://www.fao.org/aquastat/en/ (accessed 23 December 2020).

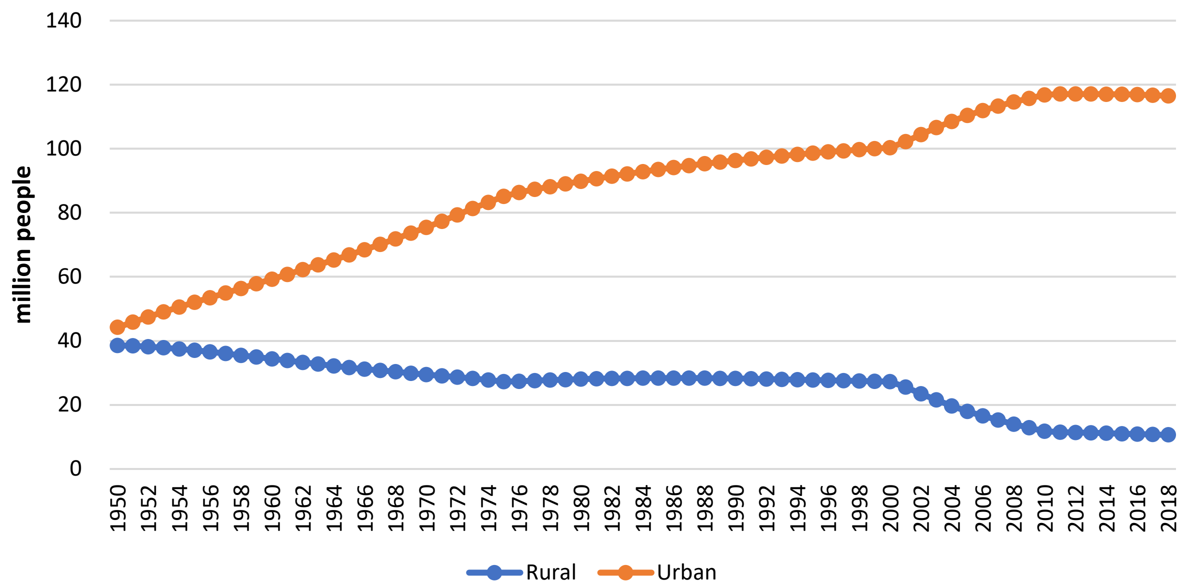
Figure 3: Bangladesh, Area Irrigated by Source



ha = hectare.

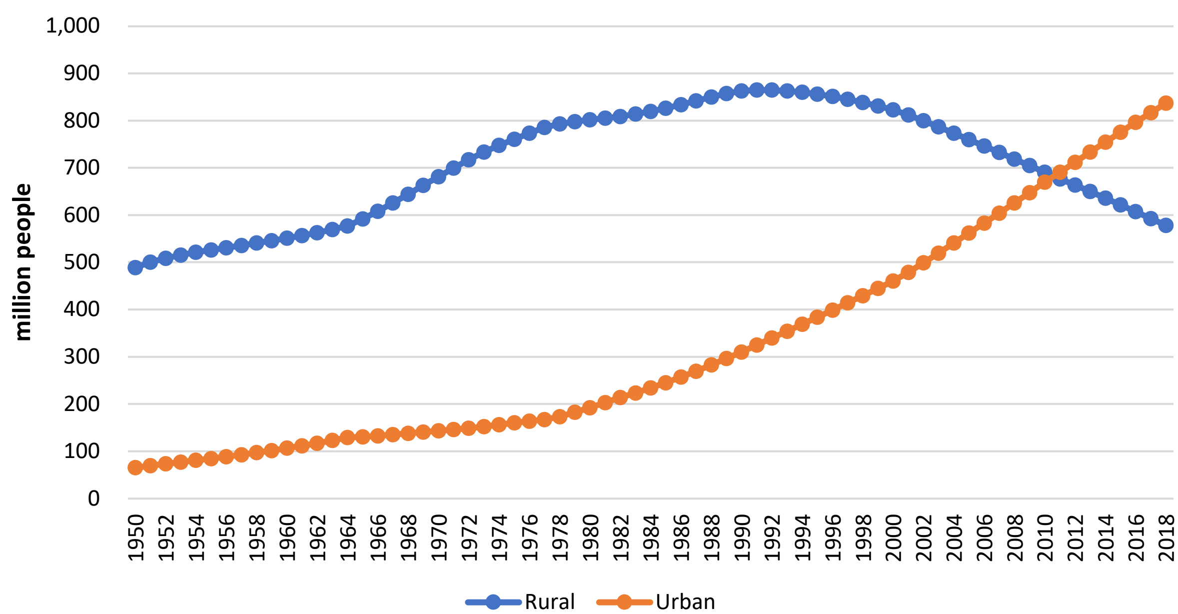
Source: FAO. AQUASTAT Database. http://www.fao.org/aquastat/en/ (accessed 23 December 2020).

Figure 4: Population by Sector in Japan



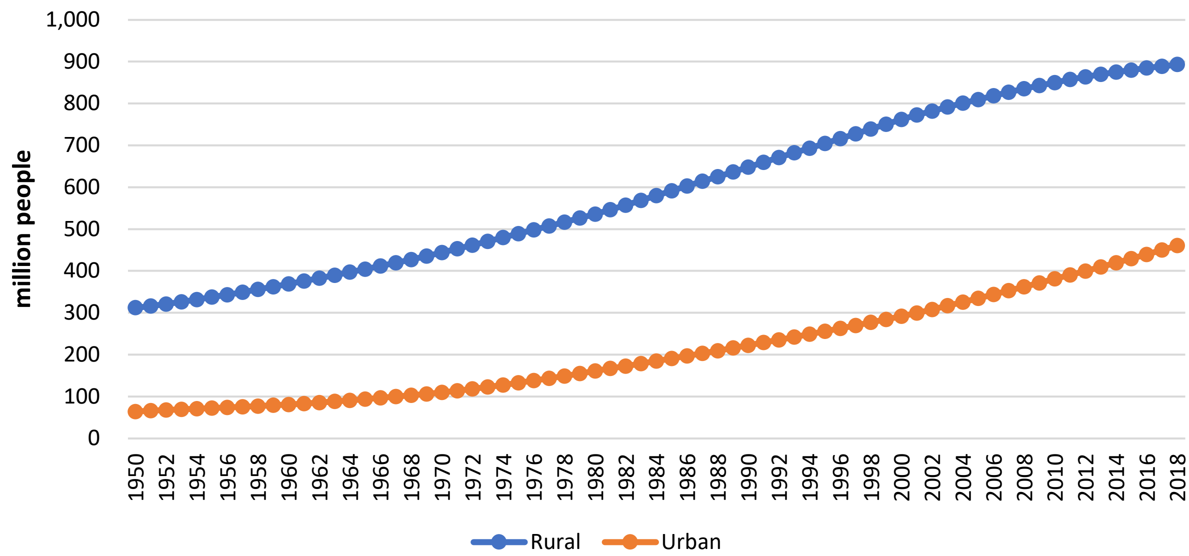
Source: FAO. FAOSTAT Database. http://www.fao.org/faostat/en/#home/ (accessed 23 December 2020).

Figure 5: Population by Sector in the People's Republic of China



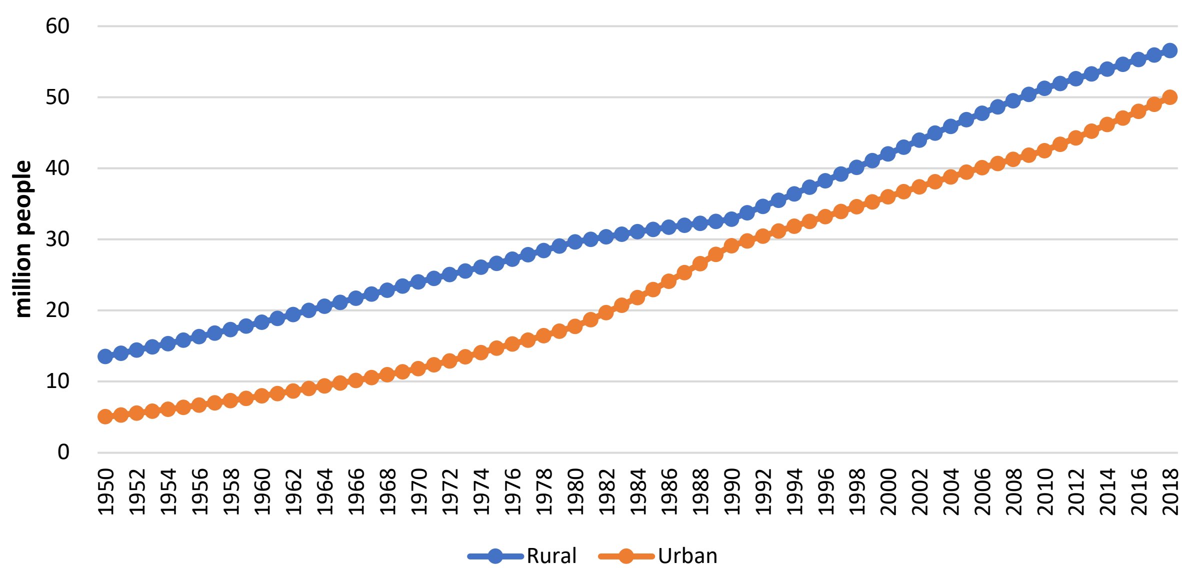
Source: FAO. FAOSTAT Database. http://www.fao.org/faostat/en/#home/ (accessed 23 December 2020).

Figure 6: Population by Sector in India



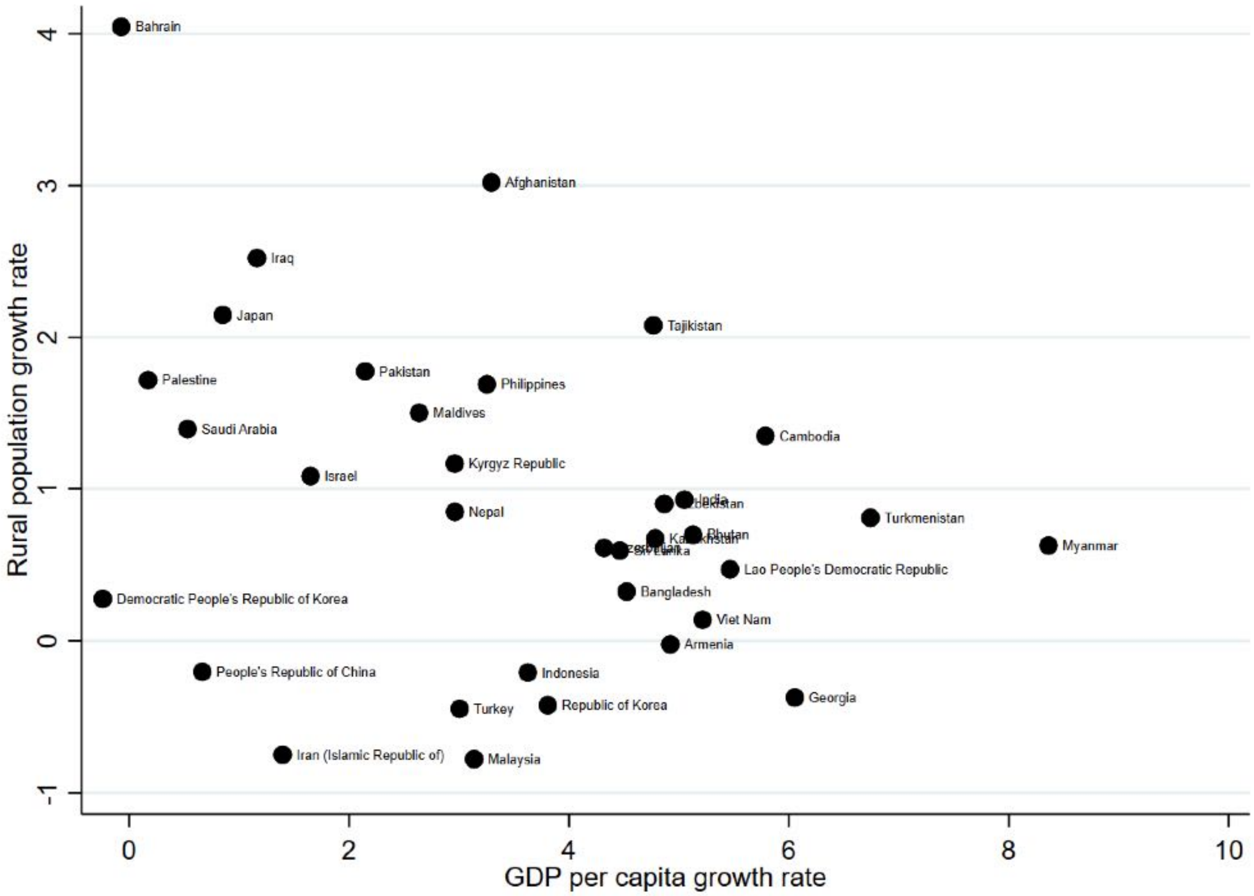
Source: FAO. FAOSTAT Database. http://www.fao.org/faostat/en/#home/ (accessed 23 December 2020).

Figure 7: Population by Sector in the Philippines



Source: FAO. FAOSTAT Database. http://www.fao.org/faostat/en/#home/ (accessed 23 December 2020).

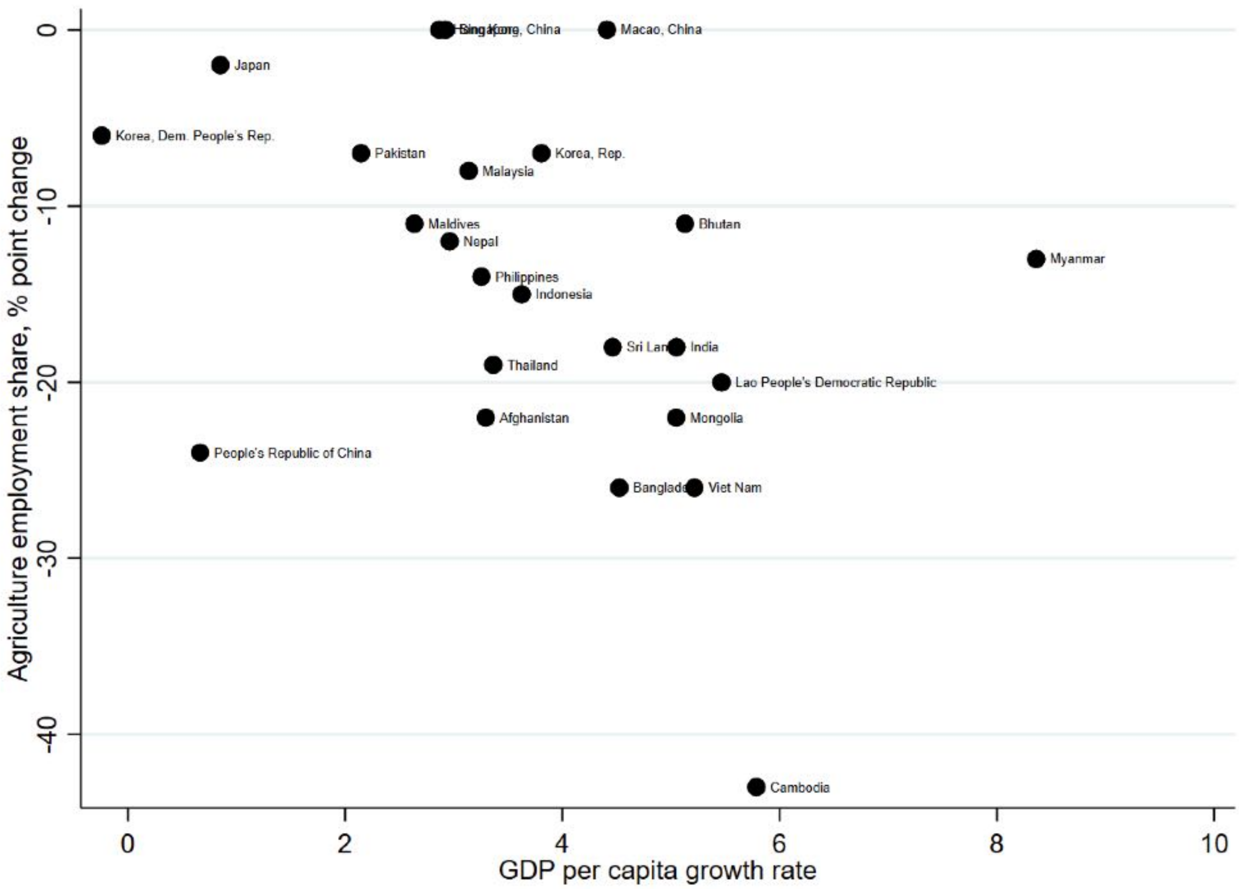
Figure 8: Growth of GDP per Capita and Rural Population, 1998–2018



GDP = gross domestic product.

Source: FAO. FAOSTAT Database. http://www.fao.org/faostat/en/#home/ (accessed 23 December 2020).

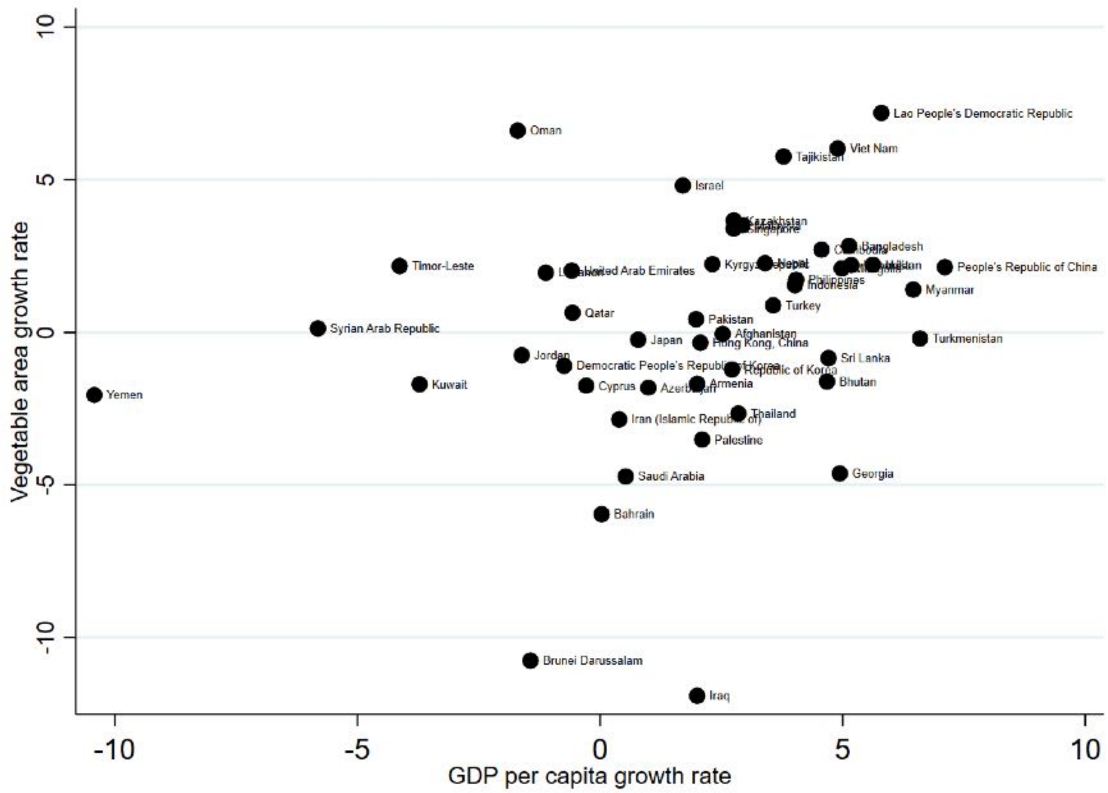
Figure 9: Growth of GDP per Capita and Change in Agricultural Employment Share, 1998–2018



GDP = gross domestic product.

Source: World Bank. World Development Indicators. https://databank.worldbank.org/source/world-development-indicators (accessed 16 December 2020).

Figure 10: Growth of GDP per Capita and Vegetable Area, 2008–2018

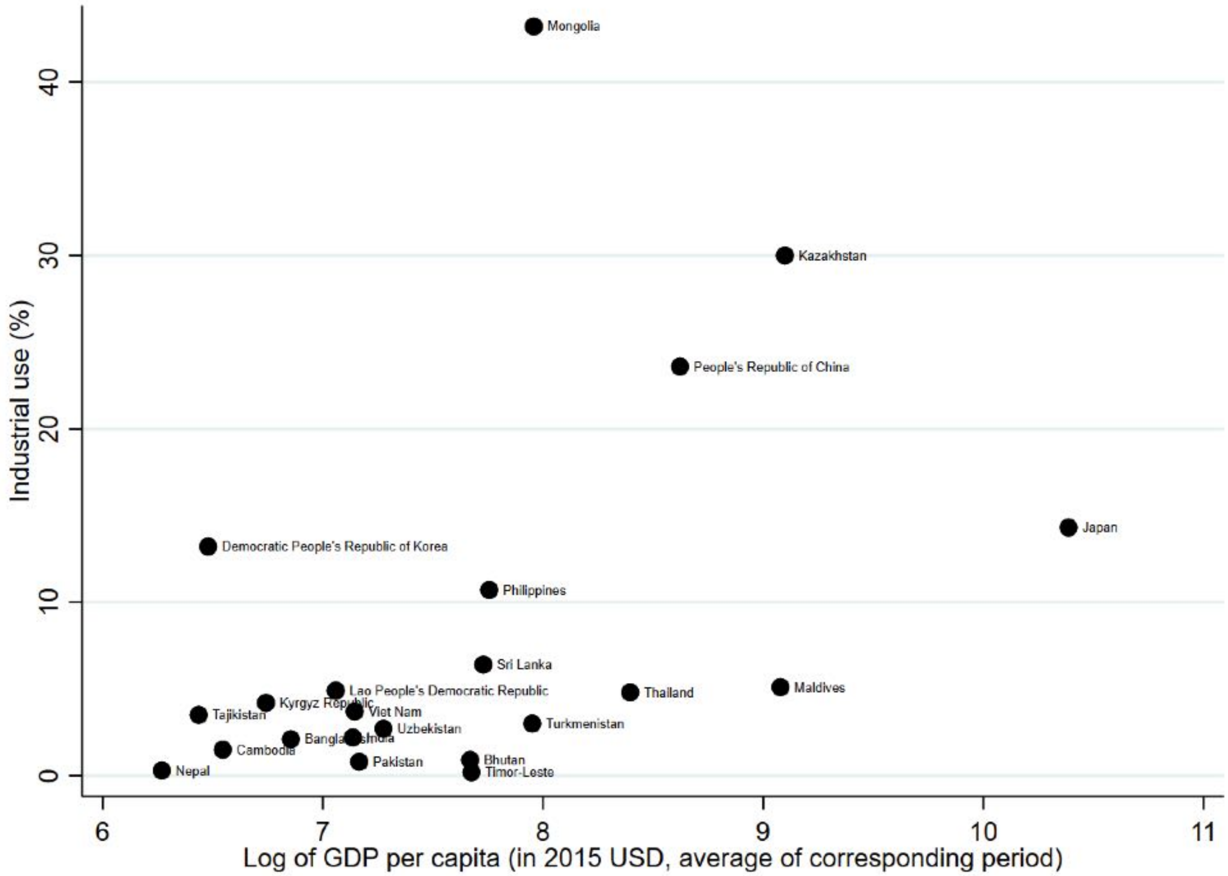


GDP = gross domestic product.

Note: Maldives is excluded as it shows extremely high (21%) growth in vegetable area.

Sources: FAO. FAOSTAT Database. http://www.fao.org/faostat/en/#home/ (accessed 23 December 2020); World Bank. World Development Indicators. https://databank.worldbank.org/source/world-development-indicators (accessed 16 December 2020).

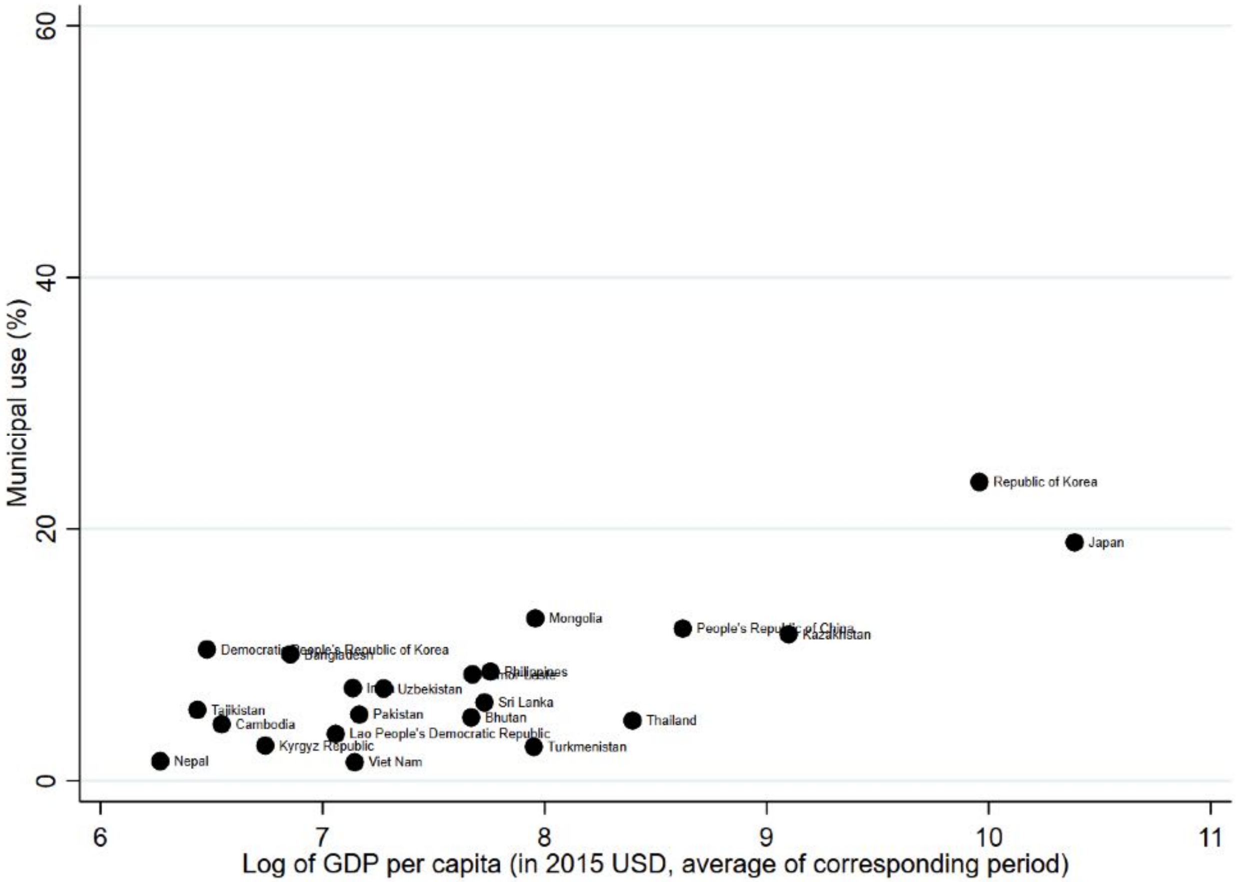
Figure 11: GDP per Capita and Industrial Water Use, 2003–2007 or 2008–2012



GDP = gross domestic product.

Sources: FAO. AQUASTAT Database. http://www.fao.org/aquastat/en/ (accessed 23 December 2020); World Bank. World Development Indicators. https://databank.worldbank.org/source/world-development-indicators (accessed 16 December 2020).

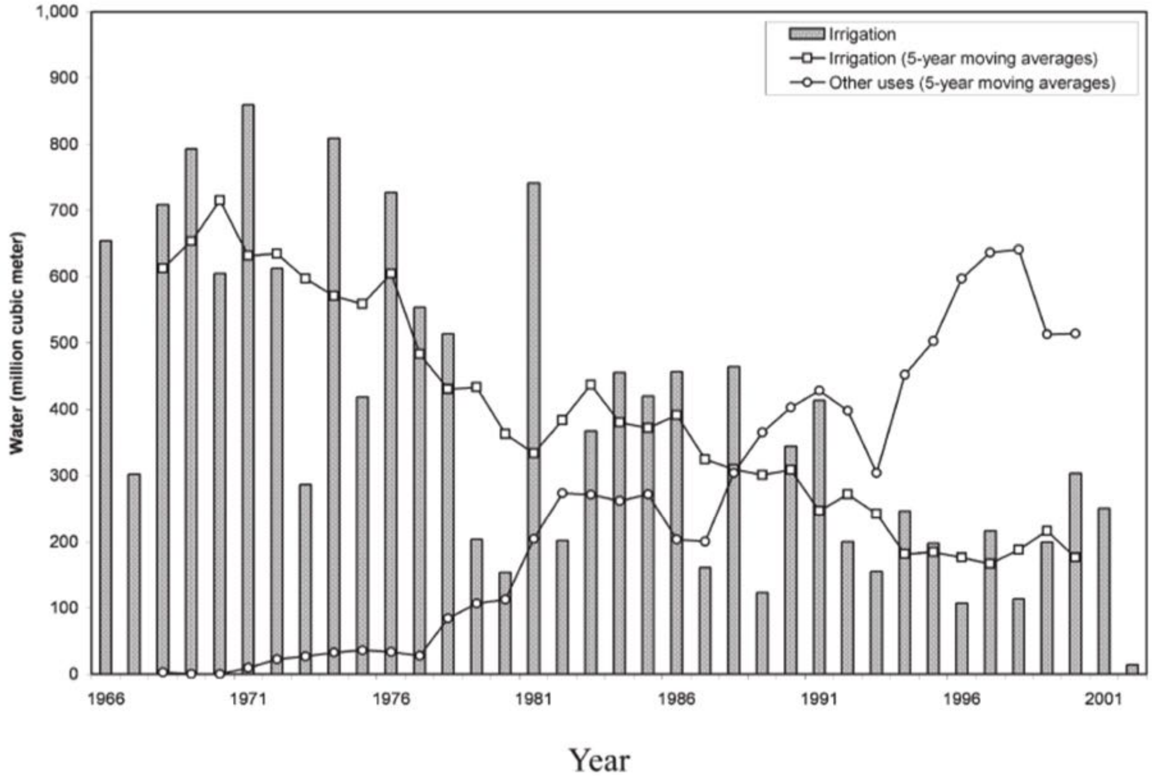
Figure 12: GDP per Capita and Municipal Water Use, 2003–2007 or 2008–2012



Note: Maldives is excluded.

Sources: FAO. AQUASTAT Database. http://www.fao.org/aquastat/en/ (accessed 23 December 2020); World Bank. World Development Indicators. https://databank.worldbank.org/source/world-development-indicators (accessed 16 December 2020).

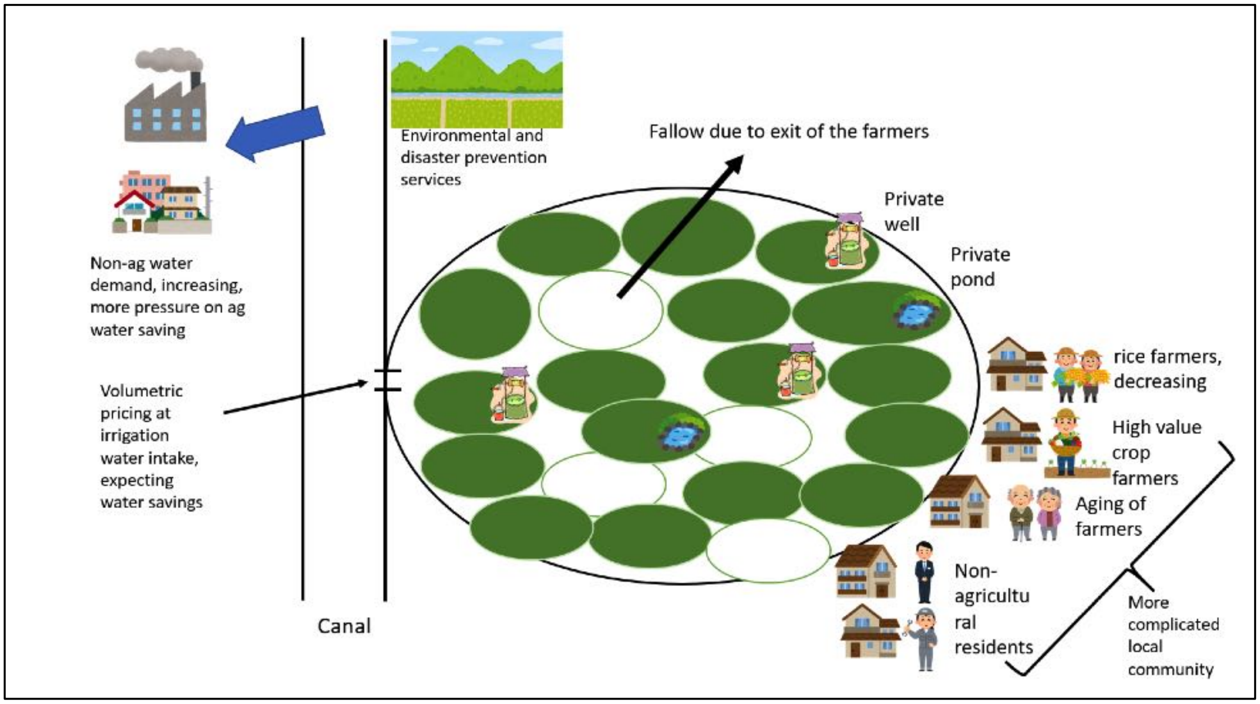
Figure 13: Allocation for Irrigation and Other Use, 1966–2002, Zhanghe Reservoir, Hubei, People's Republic of China



Note: Other use refers to municipal, industry, hydropower and flood release.

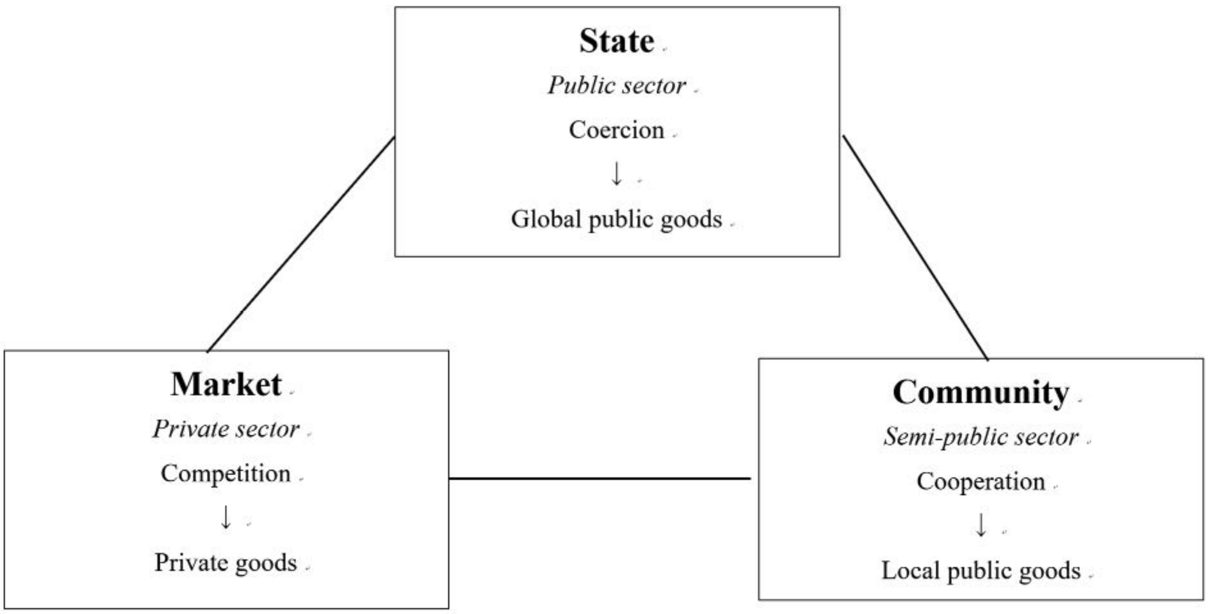
Source: Adopted from R. Loeve, L. Hong, B. Dong, Guo Mao, C. Chen, D. Dawe, and R. Barker. 2004. Long-term trends in intersectoral water allocation and crop water productivity in Zhanghe and Kaifeng, China, *Paddy and Water Environment*, 2(4), 237-245, (figure 2).

Figure 14: Summary Diagram of Contemporary Irrigation Issues in Asia



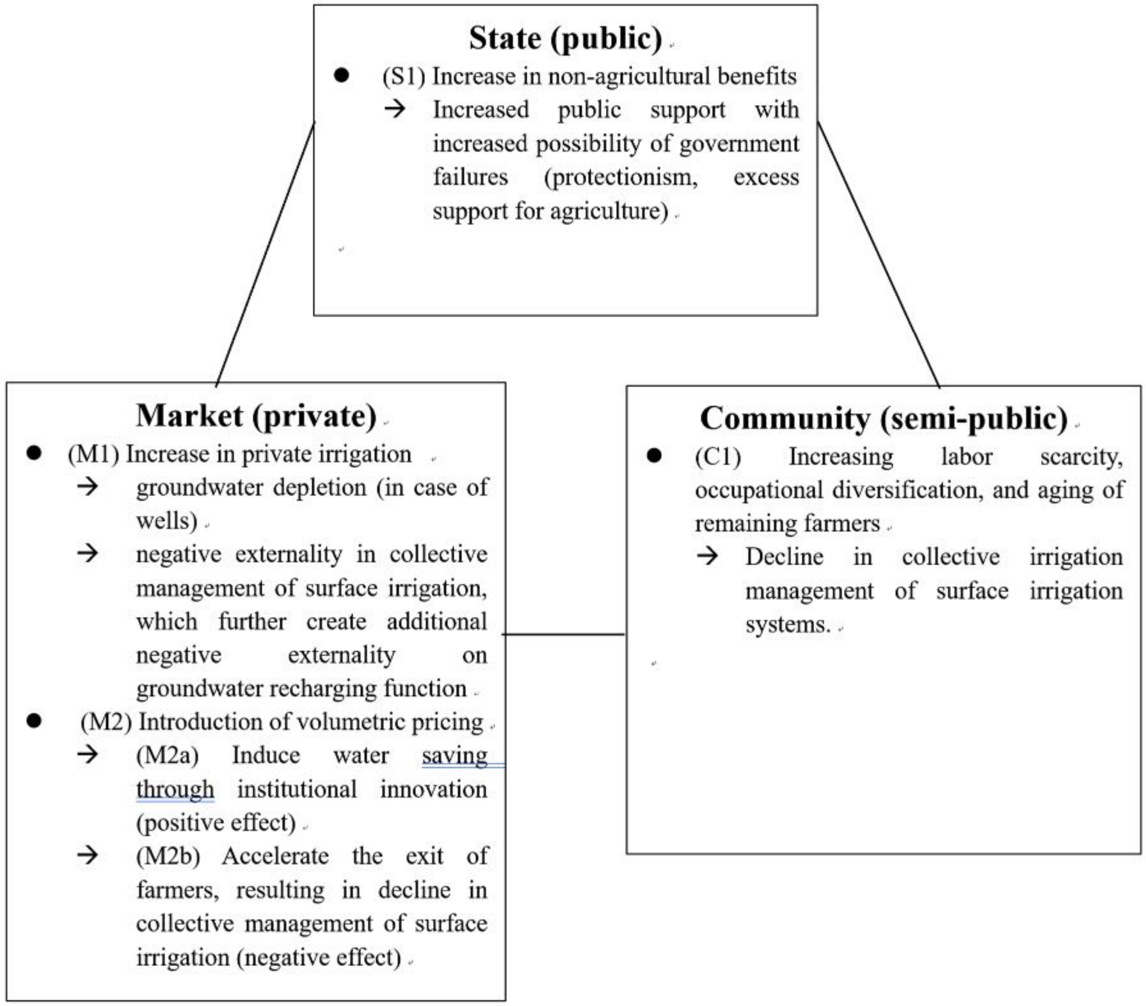
Source: Author.

Figure 15: Functions of Community, State, and Market



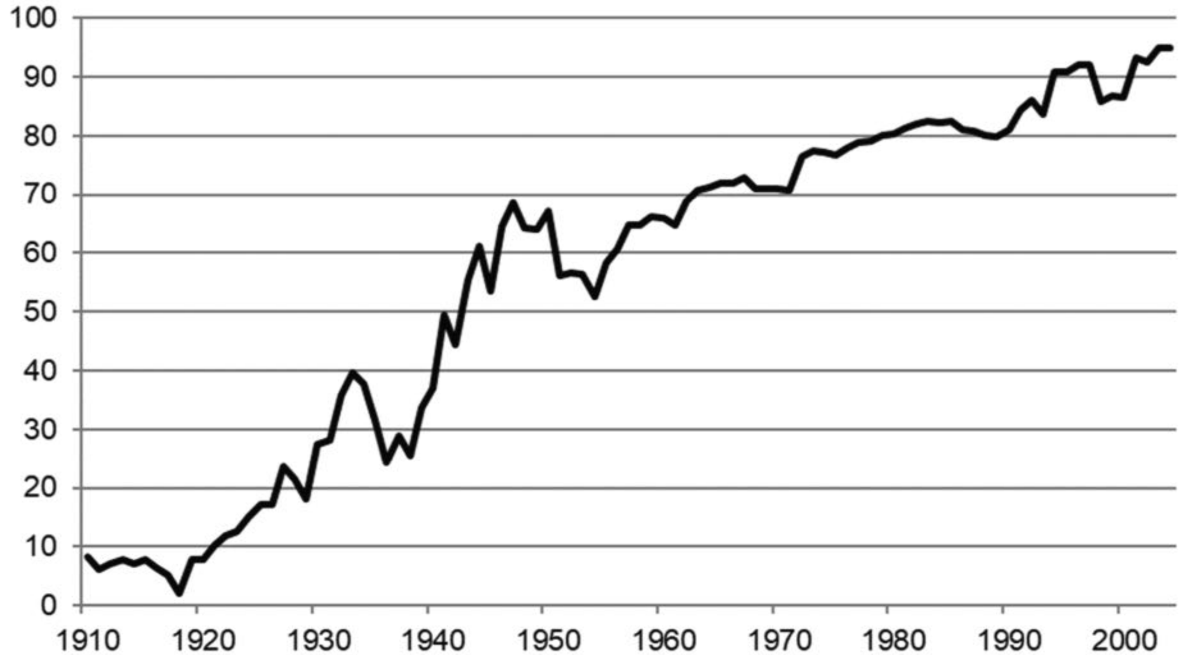
Source: Author.

Figure 16: Irrigation Issues in Community, State, and Market



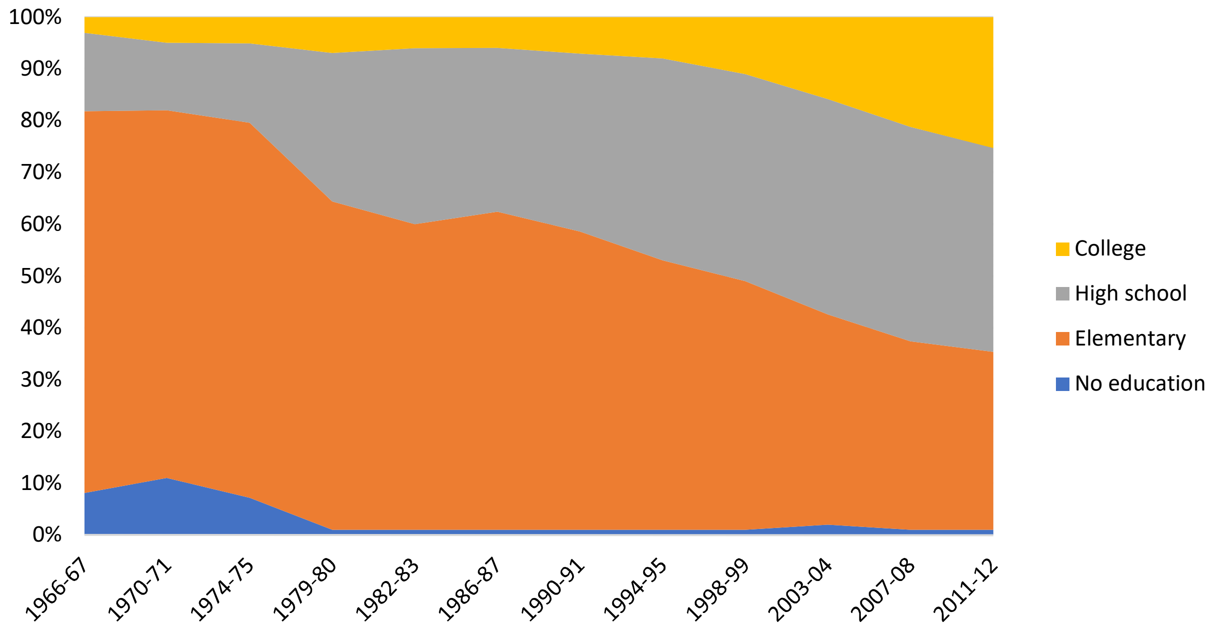
Source: Author.

Figure 17: Proportion of Financial Support for Land Improvement Investment by the Central and Local Government in Japan from 1910 to 2004



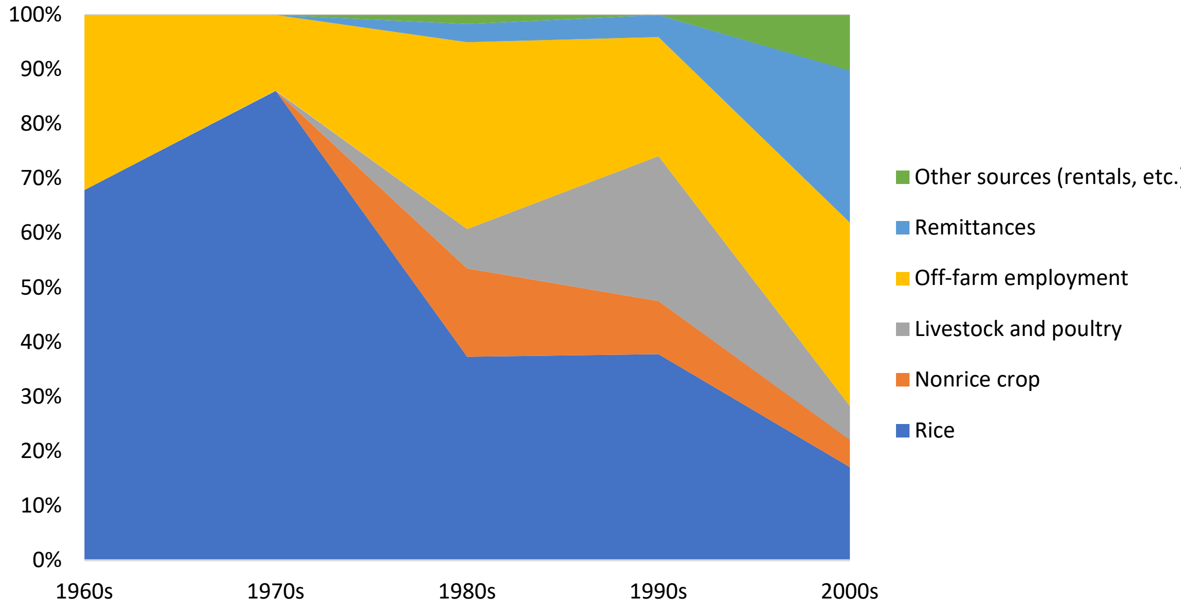
Sources: Ministry of Agriculture, Forestry and Fisheries. Various years. *Nougyou syuokuryou kannren sangyou no keizai keisan* (in Japanese) (Economic Accounting of Agricultural and Food Industries), Ministry of Agriculture, Forestry and Fisheries, Tokyo; National Research Institute of Agricultural Economics. 1967. *Nihon Nougyou no Tyouki Toukeisyuu* (I) (in Japanese) (*Long-term statistics of Japan's Agriculture*), National Research Institute of Agricultural Economics, Tokyo.

Figure B1: Educational Attainment Central Luzon, Philippines, 1966-2012



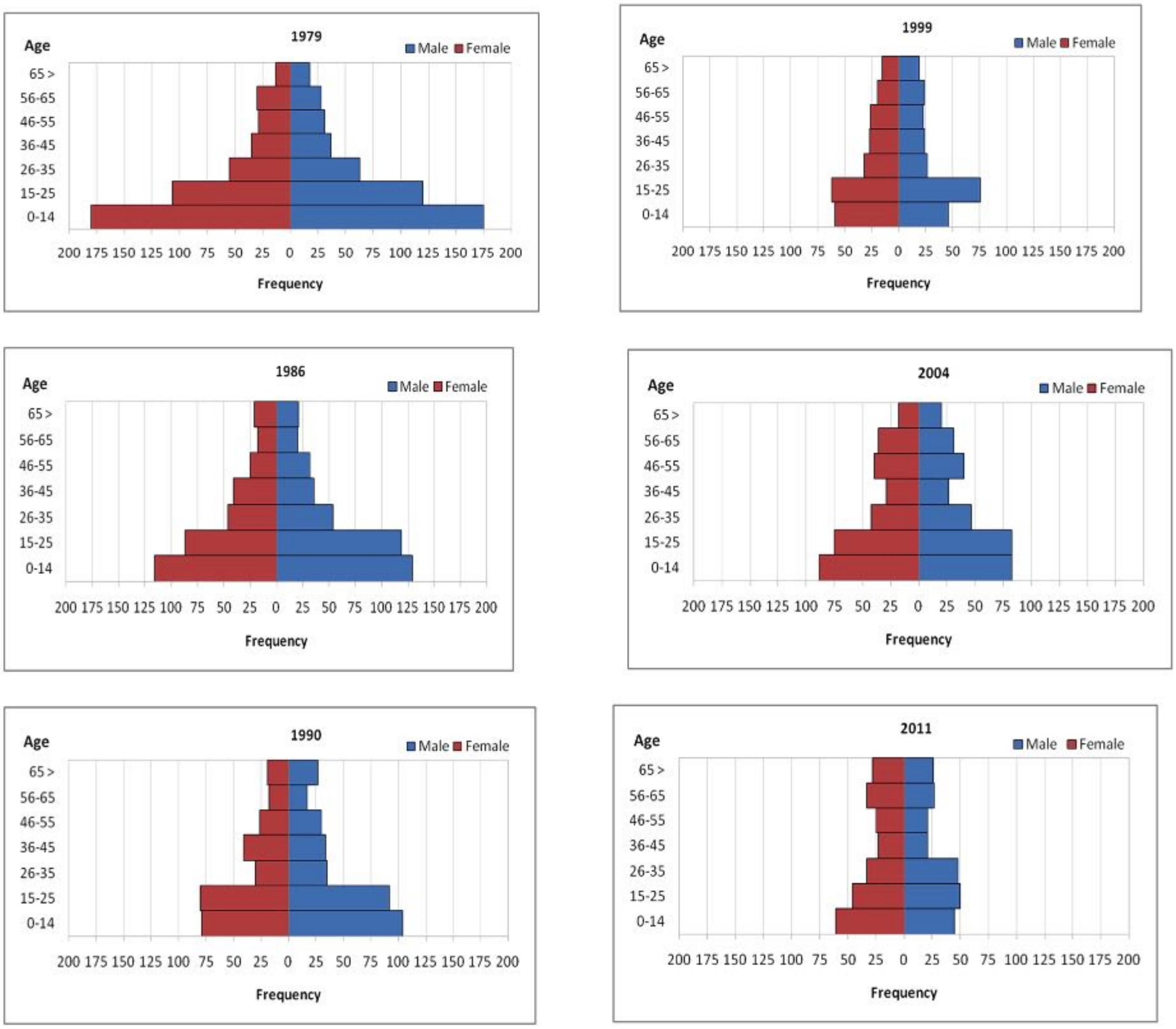
Source: P. Moya, K. Kajisa, R. Barker, S. Mohanty, F. Gascon, and M. R. San Valentin. 2015. *Changes in rice farming in the Philippines: Insights from five decades of household-level survey*. Los Baños (Philippines): International Rice Research Institute.

Figure B2: Income Source Central Luzon, Philippines, 1960s–2000s



Source: P. Moya, K. Kajisa, R. Barker, S. Mohanty, F. Gascon, and M. R. San Valentin. 2015. *Changes in rice farming in the Philippines: Insights from five decades of household-level survey*. Los Baños (Philippines): International Rice Research Institute.

Figure B3: Population Pyramid Central Luzon, Philippines, 1979- 2011



Source: P. Moya, K. Kajisa, R. Barker, S. Mohanty, F. Gascon, and M. R. San Valentin. 2015. *Changes in rice farming in the Philippines: Insights from five decades of household-level survey*. Los Baños (Philippines): International Rice Research Institute.