THE PADDY WATER DEMAND PARADOX: CAN WE SOLVE IT ?

LE PARADOXE DES BESOINS D'APPROVISONNEMENT EN EAU DESTINÉE AUX RIZIÉRES : SOMMES-NOUS CAPABLES DE LA RÉSOUDRE ?

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Abstracts

Paddy irrigation is accused of consuming too much water. At the irrigation scheme level, the ratios of water demand for rice to water demand for wheat are 2.1 times (Cai), 1.8 times (Oki) and 2.6 times (Chapagain). On the other hand, at the plot level, Brouwer reports that the ratios of water demand for rice to water demand for wheat range from 1.0 to 1.15 times.

Is this a paradox? What is the cause of the difference between these two values?

The authors applied a meta-analysis of irrigation water demand to the scheme levels in the Mekong River basin.

The first is irrigation demand of **swamp area paddies** on low lying land. The irrigation return flow flows into canals. The net consumption almost equals the evapotranspiration. The second is irrigation demand **of hill slope paddies** on hill slope areas. The water demand of schemes is, in the case of Thailand, approximately 2,000mm per season. The third is irrigation demand of **terrace paddies** in the plot to plot irrigation system. If the inflow to paddies is defined as water demand, the value sometimes reaches more than 100,000mm in one season.

Because of difficulty of measurement, almost all measured paddy irrigation water demand data are at the scheme level at hill slope area. This is the reason for the paradox. It is possible to decrease paddy irrigation demand, by improving the efficiency of paddy irrigation through the introduction of swamp area paddy technology in the pond and return flow system.

Résumé et conclusion

L'irrigation des rizières est toujours la cible d’accusations mettant en cause une consommation excessive d’eau. Au niveau du système d'irrigation, on a constaté que les besoins(intrants) en eau d'irrigation pour produire une récolte d’un kg de riz étaient de 2.128 litres (Cai), de 3.600 litres (Oki) et de 3.419 litres (Chapagain).

Mais les besoins pour le blé sont de 1.000 litres (Cai), de 2.000 litres (Oki) et de 1.334 litres (Chapagain). La quantité d’eau nécessaire pour le riz est 2,1 fois (Cai), 1,8 fois (Oki) et 2,6 fois (Chapagain) supérieure à celle nécessaire pour le blé. Ces données indiquent que l'irrigation des rizières consomme beaucoup plus d'eau que l'irrigation pour la culture du blé.

D'autre part, au niveau des parcelles de terrain, Brower signale que les besoins d'approvisionnement en eau destinée au riz s'étendent sur une plage allant de 450 à 700 millimètres et de ceux destines au blé, sur une plage allant de 450 à 650 millimètres. Au niveau des parcelles de terrain, les besoins en eau d'irrigation pour les rizières sont presque identiques aux besoins d’eau pour l'irrigation du blé.

Est-ce qu’il y a là un paradoxe ? Quelle est la cause de la différence entre ces deux valeurs ?

Les auteurs ont appliqué une méta-analyse des besoins d'approvisionnement en eau d'irrigation au niveau du système d'irrigation dans le bassin du Mékong.

Le premier type de besoins est la demande en eau d'irrigation destinée aux rizières dans les zones marécageuses. Ce type de rizières se trouve sur les étendues de basses terres à proximité des embouchures des rivières. Les canaux d'irrigation et de drainage ne peuvent pas être séparés. L'écoulement en retour de l’eau d'irrigation s’écoule dans les canaux d'irrigation et de drainage. Cet effet indique que la consommation nette de l'eau d'irrigation est pratiquement identique à la valeur de l'evapotranspiration. Le manque d'eau destinée à l’irrigation est rare à l’exception des problèmes causes par la qualité de l'eau tels que la salinité, etc.

Le deuxième type de besoins en eau d'irrigation concerne les rizières situées sur les versants des collines. Les besoins d'approvisionnement en eau destinée aux rizières dans ces systèmes sont approximativement, dans le cas de la Thaïlande, de 2.000 mm par saison. La composante principale de la perte de transport de l'eau destinée à l'irrigation est la mauvaise gestion des équipements et installations d'irrigation.

Le troisième type concerne les besoins en eau destinée à l'irrigation des rizières en terrasses. Plus de 50%, parfois plus de 90%, de l'apport en eau s'écoule vers les rizières situées en aval. Si l'apport en eau destinée aux rizières est défini comme les besoins d'approvisionnement en eau d'irrigation pour les rizières, la valeur est parfois supérieure à 1.000 mm/jour ou 100.000 mm pour une saison.

Si les données concernant les rizières situées dans des zones marécageuses sont utilisées pour faire une comparaison, il n'y a aucun paradoxe. Parmi ces trois types de besoins d'irrigation en eau destinée aux rizières, uniquement les besoins d'approvisionnement en eau pour les rizières situées sur les versants des collines sont faciles à déterminer et à mesurer. La plupart des données concernant les besoins d'approvisionnement en eau pour les rizières au niveau du système d'irrigation sont constituées par des données portant sur les secteurs des versants de collines. C'est la raison principale du paradoxe.

Si on introduit la technologie utilisée pour les rizières situées en zone marécageuse, à savoir le système d'étangs et d'écoulement en retour, afin de réduire les besoins d'approvisionnement en eau destinées aux rizières, on pourra améliorer l'efficacité de l'irrigation des rizières.

Introduction

Water use efficiency is one of the most important water problems as pointed out by the United Nations (2009) and IWMI (Molden, 1997). The basic concept of adequate irrigation consumption is given by Allen *et. al.* (1998). Paddy irrigation is constantly accused of consuming too much water. **Table 1** shows past studies of paddy irrigation water by Cai(2003), Oki and Chapagain(2004). Irrigation water inputs are evaluated as input water to produce a 1kg crop of rice at the irrigation scheme level. For rice, Cai, Oki, and Chapagain estimated 2,128L, 3,600L and 3,419L respectively. But the inputs for wheat are 1,000L , 2,000L and 1,334L . The ratios of water for rice to water for wheat by Cai, Oki and Chapagain are 2.1 times, 1.8 times and 2.6 times respectively. These results show that paddy irrigation consumes much more water than wheat field irrigation.

On the other hand, at the plot level, Brouwer (1986) reports that water demand by rice ranges from 450 to 700 mm and that by wheat, from 450 to 650 mm. The maximum value for rice is larger than that for wheat, while the ranges and the minimum are almost identical. At the plot level, paddy irrigation demand is almost the same as wheat irrigation demand.

What is the cause of the difference between these two values? Is this a paradox? The aim of this paper shows the reason for this gap, "Paddy Water Demand Paradox" by using meta-analysis with reference to the paddy irrigation situation in Japan and in the Mekong River Basin.

Table 1 Irrigation water consumption as virtual water (L/kg)

C.: countries

Crop	Cai Under Devloping C.	Cai Developed C.	Oki	Chapagain
Rice	2,564	2,128	3,600	3,419
Wheat	1,786	1,000	2,000	1,334

Study Method

Characteristics of Paddy irrigation

Table 2 shows correlation factors between evapotranspiration and crop yield per area by Zwart *et. al.* (2004). This table shows that the yields of wheat and maze are related to evapotranspiration. But rice is almost unrelated. Our knowledge of plant physiology, tells us that evapotranspiration is related to the yield of all plants. The results of **Table 2** can be interpreted as the results of the following tendencies.

1) Rice yield responds very sharply to a shortage of water. A small water shortage seriously damages yields.

2) Rice yield responds very gently to excess water supply. Excess water supply causes no damage to yields except deeply inundating rice plants in water.

If these two remarks are correct, rice irrigation in project schemes has some rooms for operation. And avoidance of drought is the most important objective of water management. Normally, for paddy irrigation, there is enough water to grow rice. Measurement of the actual irrigated volume of water is only a rough index of water demand. In the following chapter, the authors discuss actual water demand in irrigation schemes. But these values represent not only water demand but also rooms for operation.

Study Frames of Past Study

Paddy irrigation water demand is normally measured by a Parshall flume or a notch weir. The aim of the study is to determine the dam size or the capacities of irrigation canals. Past surveys for many irrigation projects show normalized ranges of paddy water demand of approximately 2,000mm for one crop season in cases in Thailand and Japan. Many researchers and engineers believe that there are some appropriate paddy water demand ranges even if there are differences of soil types, land conditions and varieties of rice. Normally, the main factor influencing paddy water demand is infiltration. In there a gap between these two views?

The main difference between 2,000mm and 450mm is the framework of the measurements. The former is aimed at the irrigation project scheme level and the latter at the paddy field level. The differences arise from the framework of their definitions of irrigation. These examples show two types of situations. But there are other contrasting situations. For example, at the irrigation scheme level, there are not only large irrigation schemes, but also small irrigation schemes, drainage schemes, and small scale terrace irrigation schemes. In past studies, among scheme level paddy water demands, large scale irrigation schemes were treated as typical conditions while small scale irrigation schemes and drainage schemes were ignored because of the difficulty of measuring their consumed water. But the authors insist that to solve the "Paddy Water Demand Paradox", the difference between types of irrigation should be considered. Even if their insistence is correct, difficulties with accurate measurement remain unresolved. The problem of the relation between measurement accuracy and extension of irrigation types is analogous to the question "which came first - the chicken or the egg".

High accuracy measurement is difficult under present technology except at large scale irrigation projects. In this paper, the authors propose a new approach. First, they discuss the order estimation of paddy water demand. Secondly, they discuss an outline of types of paddy irrigation which were ignored by past studies. This method basically pays attention to both paddy water demand and types of paddy irrigation. In this paper, this approach is called “meta-analysis” of irrigation water demand.

“Meta-analysis” collects the types of paddy irrigation data and estimate paddy water demand data using past measured data or other information. In this study, low accuracy measurements or lack of measurement data are covered by general information about irrigation conditions. Even after this correction, low accuracy problems will remain. Main point of concern of this study is not to estimate irrigation water demand but to classify irrigation water demand based on types of paddy irrigation.

Table 2 Correlation between water and yield

Crops	r2
Riec	0.09
Wheat	0.35
Maze	0.33

Results and Discussion

Unit Water Consumption of Paddy Rice in the Japanese Case

Based on the white book of water resources 2006, total paddy irrigation water use in 2000 was 53,900Mm^3. The total paddy area in 2000 was 2,641Kha. In the case of Japan, almost of 100% of paddy fields are irrigated. By using these two values, average paddy water demand is 2,041mm. Therefore, in the case of Japan, approximately 2,000mm for one paddy crop is the mean value of water consumption. If the growing period is 100 days, this value means 20mm/d.

Unit Water Consumption of Paddy Rice along the Mekong River

1) Mekong Delta

Paddy water demand in swamp areas is not clear. The authors conducted interviews at the Southern Institute for Water Resources Research of Vietnam, learning that the researchers of the institute did not study water consumption in the Mekong Delta Area. In the Mekong Delta Area, the main concerns of paddy irrigation are control of water levels under flooding and of water qualities under salinity intrusion and acid soil. If these conditions are fulfilled, there was never any lack of paddy irrigation water in the past. Except for the exchange of water for water quality control, the only consumption factor in paddy irrigation is evapotranspiration because all irrigation water return flow flows into irrigation and drainage canals and is reused for irrigation. The consumption value is assumed as 5 or 6 mm/d.

On the other hand, the Mekong River Commission (Hung *et. al.*, 2008) measured paddy water demand in a few paddy fields in the Mekong Delta using a laser water level meter. The paddy water demand for one crop season is 1,338mm. If the growing period is assumed to be 100 days, this means 13.4mm/d. Compared to the above-mentioned consideration and following measured data in Cambodia, this value seems too large. In the following description, the comparison of measure values in **Table 4** adopts 13.4mm/d and the discussion of irrigation types in **Table 5** adopts 5mm/d.

2) Cambodian Ring Dike

The authors (Someth *et. al.*, 2009) measured paddy water demand in a ring dyke on a flood plain in Cambodia from 2006 to 2007. The results show 3.9mm/d in a dry season and 5.3mm/d in a wet season. These values are measured by the change of water volume in a ring dyke or the pass through discharge through intake gates. Though these values are smaller than the value by Brouwer *et. al.* (1986), the authors checked and confirmed the accuracy of measurement by checking data for 2006 and 2007.

3) Large Irrigation Schemes in North Eastern Thailand

There are many large scale irrigation schemes in North Eastern Thailand. Large scale irrigation schemes construct a dam and canals to supply irrigation water to hill slope paddies. In 2006, the authors visited several irrigation schemes in this area and had an interview about unit water demand for paddy about irrigation scheme levels. Normal value is 2,000mm and the value for one high infiltration scheme area was 3,000mm. If an irrigation period of 100 days is assumed, these mean 20 to 30mm/d.

4) Terrace Paddy in North Lao PDR

There are many terrace paddies in North Lao PDR. Defining water consumption of terrace paddies faces two difficulties. One is that irrigation is done by plot to plot water conveyance. Drainage from an upper paddy is used as irrigation in a lower paddy. Even large scale irrigation schemes in Thailand use plot-to-plot water conveyance, where there are many paddy cascades in terrace paddies. The other is that the infiltration value is strongly related to the location of a paddy on the hill. Normally infiltration at the top of the hill is large and small at its bottom. Under these two effects, paddy water demand is large at the top of the hill and small at the bottom of the hill.

In terrace areas, there are no unit water consumption data in Northern Lao PDR because irrigation projects schemes normally supply additional water to supplement water taken in from small rivers. The authors made a sample examination of paddy water demand at the top of the hill in 2007. For this examination, drainage outlets and irrigation intakes were closed. Change of the water stored in paddies was measured. The causes of water consumption in this examination were infiltration and evapotranspiration. The result of this examination is shown in **Table 3**. If pass through discharge is referred to as water demand, the value will be become larger than that examined. Photo 1 shows typical terrace paddies in Northern Lao PDR. Many pipes are used to pass through the discharge. Through these pipes, irrigation water is conveyed plot to plot.

Table 3 Infiltration on terrace paddies

Plot	Infiltration(mm/d)	Remarks
A	91	
B	215	
C	295+	Dry up
D	51	

Photo 1 Plot to plot irrigation on terrace paddies in Northern Lao PDR

Summary of Unit Paddy Water Demand in Mekong River Basin

Table 4 shows a summary of meta-analysis of paddy Water Demand in the Mekong river Basin. The range seems to be in the log-scale order. Generally the values decrease from upstream to downstream.

Table 4 Unit paddy water demand

Area	Irrigation(mm/d)
North LaoPDR	50-1,000
Nort East Thailand	20-30
Cambodia	4-5
Mekong Delta in Vietnam	14

Classification of Paddy Irrigation types

The authors propose a basic concept of the classification of paddy irrigation types: flow type (F type) and ponding type (P type).

In F type, irrigation water is used as flow. In P type, irrigation water is temporarily stored in and used from reservoirs. F type without reservoirs is classified as FF type. FF type is located in upstream (FF-U type) or middle stream (FF-M type) parts of the basin.

Even where there are reservoirs, water usage characteristics differ greatly according to the locations of reservoirs relative to irrigated areas. If the location is above the irrigated areas, water is conveyed a long distance and the usage of water are similar to F type. This type is classified as FP-M type. In this expression, "M" means that irrigated areas are located in the middle stream of the basin. If reservoirs are located near irrigated areas, this type is called P type. P type can be classified by ground water level (GWL). If GWL is high, P type is called PF-D type. "N" means non-drained and "D" means irrigated areas located in the downstream area of the basin. If GWL is low, P- type is called as PD-D type. These classification procedures are shown as **Figure 2**.

Characteristics of irrigation types are shown as **Table 5**. "Drained water" means reuse of return flow. "Downstream" means return flow can be used downstream. "Recycle" means return flow can use at the same paddy field. "Power" means power irrigation. The symbol "-" means gravity irrigation and the symbol "+" means pumping irrigation. "GWL" means ground water level. "Low" means ground water level is low relative to the paddy surface level. Paddy with high GWL is usually called *ill drained* paddy where rice yield is low. "WQ" means water quality. The symbol "-" means that drained water easily causes water quality problems downstream. The symbol "+" means that there is small risk of water quality problems in downstream areas.

Of the five types, PN-D should be avoided to prevent a low yield. As irrigation water, PN-D and PD-D are effective. Overall, PN-D type is best in terms of both water efficiency and yield.

Actually, the most popular irrigation type is FP-M type because irrigation schemes are designed as gravitational irrigation.

If we prefer to discuss paddy water demand, the authors' opinion is that we should consider irrigation types. First, it is better to avoid comparing paddy water demands of different irrigation types. Second, as for FF-U and FF-M types, the concept of paddy water demand is doubtful. Third, the suffix of location, “U”, ”M” and ”D” are tentative. In the history of irrigation development in Japan, many irrigation of PN-M type were developed then changed into FP-M type to increase yields, resulting in the increase of both irrigation water and average paddy water demand.

Finally, the authors would like to answer the first question, “Paddy Water Demand Paradox”. In case of P type irrigation, there is no paradox. And in case of F type irrigation, there is a paradox.

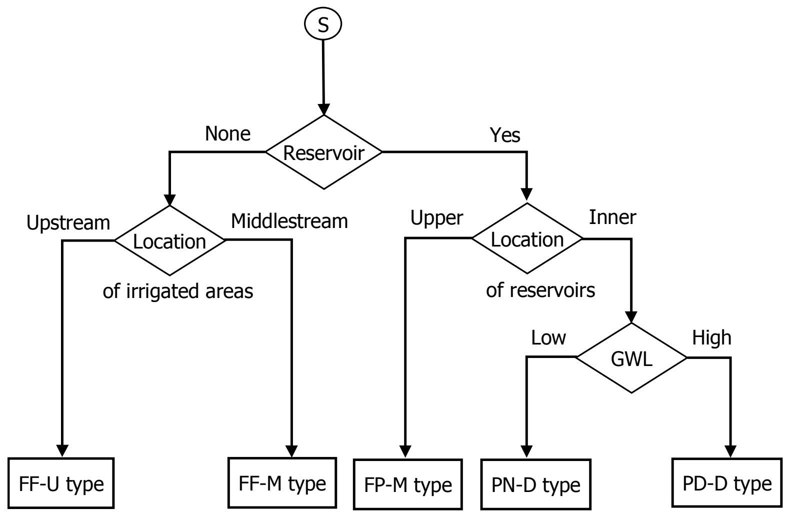

Figure 2 Paddy irrigation types

Table 5 Characteristics of irrigation types

Type	Resources	Location	Drained water	Power	Irrigation(mm/d)	GWL	WQ	Yield
FF-U	Flow	Upstream	Downstream	-	50	Low	-	High
FF-M	Flow	Middlestream	Downstream	-	20	Low	-	High
FP-M	F+P	Middlestream	Downstream	-	20	Low	-	High
PN-D	Pond	Downstream	Recycle	+	5	High	+	Low
PD-D	Pond	Downstream	Recycle	+	5	Low	+	High

Conclusion

Paddy water demand varies widely because of types and locations of irrigation. Without considering these parameters, there seems to be a paradox of paddy water demand. Concepts of irrigation types are proposed in this paper. Using these types will clarify the discussion of irrigation efficiency. In the PD-D type, the efficiency of water use is very high and rice yield is also high. But few middle stream irrigation schemes adopt the method because it creates a need for power irrigation. For gravitational irrigation, normally the FP-M type is adopted, causing a large water demand for paddy. But these gravitational irrigation schemes are not energy self-sufficient considering construction and management energy. The authors' recommendation is a new irrigation scheme of PD-D type with natural energy generation. New renewable energy generation systems will appear in near future because of recent advances in energy technology.

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