Multi-functionality as a Key to Enhance Water Use Efficiency and Sustainable PIM in Paddy Rice Agriculture

Kazumi Yamaoka
kyamaoka@nkk.affrc.go.jp
Chief, Laboratory of Agricultural Water Management
National Institute for Rural Engineering (NIRE, Japan)
Contents

- Characteristics and Water Use Efficiency in Paddy Rice Farming in the Asian Monsoon Region
  - Natural condition
  - Economic rationality of rice farming with ample water use
  - Triangular substitutability and farmers’ good governance

- Basin Scale Contribution to Enhancing Ecosystem Services both Outside and Inside the River
  - Hydrologic feature – water use co-existent with ecosystems
  - Stabilizing downstream river flow through constant return flow to rivers
  - Creating a secondary natural environment with wetlands and water networks
  - Recharging groundwater with water used in paddy fields

- Multifunctionality and Social Capital as Vital Keystones for Sustainable Irrigation Management
  - Significance and development of multifunctionality across Asian countries
  - Sustainable irrigation management supported by social capital

- Conclusions and Recommendations
Monthly precipitation in cities in Asia and western countries

Note: Mean in 1971-2000    Source: WMO
Steep terrain causes rapid river stream into the sea and results in low usability of river flow. Paddy field irrigation system works as retardant reservoir in a basin and increases the usability. 

- Steep terrain causes rapid river stream into the sea and results in low usability of river flow.
- Paddy field irrigation system works as retardant reservoir in a basin and increases the usability.
Steep terrain with river basins that are influenced by tectonic zones

Global tectonic zones

- **Alpine-Himalayan Zone:**
  - Alps – Mediterranean Coast – Middle and Near East – Himalaya – Sumatra – Java

- **Circum-Pacific Zone:**
  - New Zealand – New Guinea – Philippines – South-western fringe of Asian continent – Japan Archipelago – Aleutian Islands – West Coasts of both North and South America

- Asia accounts for about 90% of the world's paddy rice production
- Rice supplies 31% of total food calories to people in Asia which has about 60% of the world’s population while it does only 3% of that in other areas in the world
- Of the world's annual water usage, about 70% or 2,504 km³ is used by agriculture, and of this about 70% is used in Asia alone

Source: FAOSTAT, Oxford Economic Atlas
### Advantages of Paddy with Ample Water

<table>
<thead>
<tr>
<th>Labor Force and Investment Reductions</th>
<th>Water Use Efficiency and Management Enhancements</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Reducing labor force for water management off farm: water distribution in canal network</td>
<td>Preventing a fall in yield from repeated cropping through the mechanism of alternation of anaerobic and aerobic microbes</td>
</tr>
<tr>
<td>b) Reducing labor force for water management on farm: e.g., fixed depth of water through plot irrigation</td>
<td>Preventing soil erosion against heavy rainfall by means of surrounded levees and standing pool of water</td>
</tr>
<tr>
<td>c) Reducing labor for weed control with preventing growth of weeds on submerged soil</td>
<td>Reducing labor and materials for fertilization with improving utilization of nutrients under reduced condition of submerged soil</td>
</tr>
<tr>
<td>d) Preventing soil erosion against heavy rainfall by means of surrounded levees and standing pool of water</td>
<td>Reducing labor for plowing and accelerating soil leaching against saline accumulation</td>
</tr>
<tr>
<td>e) Reducing labor and materials for fertilization with improving utilization of nutrients under reduced condition of submerged soil</td>
<td>Reducing labor force for plowing and accelerating soil leaching against saline accumulation</td>
</tr>
<tr>
<td>f) Reducing labor for plowing and accelerating soil leaching against saline accumulation</td>
<td>Reducing labor and materials for fertilization with improving utilization of nutrients under reduced condition of submerged soil</td>
</tr>
<tr>
<td>g) Preventing a fall in yield from repeated cropping through the mechanism of alternation of anaerobic and aerobic microbes</td>
<td>Preventing soil erosion against heavy rainfall by means of surrounded levees and standing pool of water</td>
</tr>
</tbody>
</table>

**Substitutable items for efficient irrigation management in paddy fields**

- High substitutability between water and labor

- Ample water use can reduce various labor force and investment for facility on the normal basis
- Conversely, temporary labor investment reduces use of scarce water during abnormal dry spells

**Characteristics and Water Use Efficiency in Paddy Rice Farming in the Asian Monsoon Region**

**Available amount of water use**

**Substitutable**

- Investment for developing facility
- Labor investment for operation & maintenance

**Source:** Yamaoka K, Horikawa N and Tomosho T (2004)
Terraced Rice Paddies
Japan “Foggy morning”
Japan

“Transplanting in water”

“Drying rice in the sun”
Japan

“Thousand plots of terraced paddies on a mountainside”
Philippines
“Reaching up to the very sky”

Japan
“Oriental Arcadia in mountain”
Viet Num

“Ethnic minority’s preparation - seedlings for transplanting”
China - Yunnan

“Dizzy sculpture on the Earth”
Indonesia - Bali

“Worshipped water from the kingdom of God”
Japan

“Live pyramid succeeded by local farmers”
Japan

“Fantastic twilight over the water world”
**Diverting water in harmony with downstream ecosystems**

- Major part of water taken from a river to paddy is not consumed
- The unconsumed water in paddy fields contributes to enhancing ecosystem services in two ways:
  
  a) Inside the river: Reinforcing the ecosystems in the downstream river and related marsh with water drained from paddies and returning into the river
  
  b) Outside the river: Serving as a network of wetlands and water ways, and creating another excellent secondary natural environment with an enriched flora and fauna

*Water balance in a paddy plot: a case in Japan*

Source: Maruyama, T., R. Nakamura et al. (1998)
Diverting water in harmony with downstream ecosystems – continued

- Contrasting the contribution system in humid regions with the competitive nature of water use in arid and semi-arid regions

**Contribution of paddy field irrigation to ecosystem services in humid regions**

- Minimum release obligation
- Co-existent

- Abundant River Flow
- Diverted water
- Agricultural Water Use

- Ecosystems / Bio-diversity in downstream rivers, marsh and swamps
- Return flow

- Moisture necessarily consumed by crops to grow up
- Remained water in paddies, canals and ponds serves as a network of wetlands and water ways
- Creating another excellent secondary natural environment outside the river

Diverted water and return flow gives positive impact on the environment

**Competitive nature of water use in arid regions where water is constantly scarce**

- Limited River Flow
- Diverted water

- Agricultural Water Use

- Ecosystems / Bio-diversity in downstream rivers, marsh and swamps

- Moisture necessarily consumed by crops to grow up

Diversion of water is prone to give negative impact on the environment

Most of water is evapo-transpired
Model analysis: Inside the river
Quantifying return flow from paddy fields to the river

The Kino River Basin – Plan and points for calibration and simulation

- Catchment area: 1750 km² (farmland area: 15%)
- Annual precipitation: 1350 mm in the long and narrow plain, 3000 mm in the upper mountainous area
- Irrigation water use: 80% of the total water use
- Methodology: Complex Tank Model (CTM) with dividing into 25 sub-basin

Calibration: Annual mean relative errors of simulated daily river flow to the observed one (%)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Shimobuchi</td>
<td>30.2</td>
<td>24.2</td>
<td>20.1</td>
<td>15.9</td>
<td>24.5</td>
<td>17.1</td>
<td>18.3</td>
<td>25.1</td>
<td>21.9</td>
</tr>
<tr>
<td>Suda</td>
<td>23.2</td>
<td>29.1</td>
<td>21.3</td>
<td>24.3</td>
<td>25.0</td>
<td>24.5</td>
<td>24.1</td>
<td>27.0</td>
<td>24.8</td>
</tr>
<tr>
<td>Funato</td>
<td>43.9</td>
<td>40.0</td>
<td>34.4</td>
<td>28.8</td>
<td>33.3</td>
<td>22.4</td>
<td>27.4</td>
<td>43.8</td>
<td>34.3</td>
</tr>
</tbody>
</table>

Source: Nakagiri et al. (1998, 2000)
Model analysis: Inside the river
Quantifying return flow from paddy fields to the river

- Results of simulation

Component ratio of return flow from agricultural land in the diverted flow discharge at each diversion work (by year, average for an irrigation period)

Irrigation water reuse ratio (%) at each diversion work (by year, average for an irrigation period)

- Component ratio of return flow from farmland reaches to 35% including both direct rainfall and irrigation water, and 25% including only irrigation water on average throughout irrigation period
- The year 1987 has the lowest precipitation of 617 mm during the irrigation period; that in 1988 was 1076 mm and that in 1989 was 1335 mm
- It predicts that the lower the annual precipitation, the higher the component ratio of return flow at the lower reaches in the basin

Source: Nakagiri et al. (1998, 2000)
Model analysis : Inside the river

Quantifying return flow from paddy fields to the river

- Calculating the $\rho_1$ and $\rho_2$ on average of every 5 days at Iwade D.W. from June to September in a dry year, 1987

Irrigation water reuse ratio (%) in intake water from D.W. in a dry year (1987, every 5 days average unit, Iwade D.W.)

Transition of river flow and its component corresponding to $\rho_1$ and $\rho_2$ at Iwade D. W. from June 20 to July 1 in 1987

- The left figure indicates that $\rho_1$ and $\rho_2$ fluctuate widely and reach 70% and 60% respectively after a dry spell
- The right figure indicates that return flows corresponding to $\rho_1$ and $\rho_2$ plays a very important role for stabilizing the river flow during the dry spells

Source: Nakagiri et al. (1998, 2000)
Outside the river: Creating an excellent secondary natural environment

- Figure below shows various creatures and their habitats on a typical bird’s-eye picture of a countryside paddy field area in Japan.

- Irrigation ponds connected with paddy fields through canals provide a habitat and place of refuge for aquatic creatures during the non-irrigation period.

- Scattered coppices and groves in the countryside also provide a habitat and place of refuge for terrestrial creatures during the non-irrigation period.
Outside the river: Creating an excellent secondary natural environment

- Paddy farming embraces varied on-farm water management such as for puddling, transplanting, temporary dry-up, intermittent irrigation and harvesting.
- This moderate human intervention provides an ideal habitat for creatures which used to inhabit flooded plains, marshes and swamps.

### Total number of species verified in paddy fields and canals in 14 areas in Japan

<table>
<thead>
<tr>
<th></th>
<th>Number of species verified in paddy A</th>
<th>Of which</th>
<th>Total number of species in Japan</th>
<th>A/B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mammals</td>
<td>28</td>
<td>(5)</td>
<td>Approx. 200</td>
<td>14</td>
</tr>
<tr>
<td>Birds</td>
<td>136</td>
<td>(37)</td>
<td>Approx. 700</td>
<td>19</td>
</tr>
<tr>
<td>Reptiles and amphibians</td>
<td>38</td>
<td>(17)</td>
<td>161</td>
<td>24</td>
</tr>
<tr>
<td>Fish (sweet water)</td>
<td>101</td>
<td>(36)</td>
<td>Approx. 300</td>
<td>34</td>
</tr>
<tr>
<td>Benthos</td>
<td>182</td>
<td>(24)</td>
<td>Approx. 5,200</td>
<td>4</td>
</tr>
<tr>
<td>Dragonflies</td>
<td>61</td>
<td>(9)</td>
<td>204</td>
<td>30</td>
</tr>
<tr>
<td>Plants</td>
<td>1,379</td>
<td>(67)</td>
<td>Approx. 7,000</td>
<td>20</td>
</tr>
</tbody>
</table>

Source: Ministry of Agriculture, Forestry and Fisheries of Japan (2003)

- Rice paddy fields in Japan account for only about 7% of national land territory but they raise more than 30% of species of fish and dragonflies and more than 20% of species of reptiles, amphibians and plants in the national territory.
Ichikawa (2002) observed the amount of flowing water at nearly 300 monitoring points in the middle-stream basin of the Shira river in Kumamoto prefecture in Japan.

- 16 municipalities with population of 960,000 depends on the groundwater spreading in the basin with area of about 1000 km² for the domestic water use.

- Groundwater accumulation amounting to an average of around 90 mm/day and a maximum of 150 mm/day was observed (4000 mm annually while 2000 mm of annual precipitation).

- Paddy fields upstream of the Kumamoto city area supply 45% (282 million tons) of the total groundwater recharge while the city requires around 226 million tons of groundwater for drinking water, industrial water, and air conditioning for buildings.
Japan

“Network of wetland, water way, scattered coppices and groves in the countryside”
Japan

“Paddies blessed with land, water and people”
Viet Num

Thailand

“Life in water”
China and India

“Establishing Water Users Group”

“Collapse of groundwater”
Multi-functionality of water collectively managed for paddy rice agriculture

A. Benefits spread to public society through agricultural activity

A-1. Benefits spontaneously generated to the public
- Protect aqua-ecosystem, enhance water-related environment
- Form landscape, recharge groundwater aquifer, mitigate damage by flood
- Stabilize downstream river flow, etc.

A-2. Benefits intentionally provided to the public
- Provide water from agriculture for domestic use during severe dry spells
- Increase performance of paddy fields as outflow-retarding reservoirs during extreme floods
- Create winter sanctuaries for migratory birds
- Restore groundwater level for downstream city and industry, etc.

B. Benefits gained by farmers and local community

B-1. Multi-purpose use of water by farmers
- Aquaculture, duck raising, washing, cleaning, bathing, cooling, gardening, fire fighting, etc.

B-2. Supporting local cultural-religious activities
Socio-economic development in Asian countries and value of multifunctionality categorized into four characters

<table>
<thead>
<tr>
<th>GDP per capita</th>
<th>Low (Less than US$400)</th>
<th>(US$400–)</th>
<th>(US$600–)</th>
<th>(US$1500–)</th>
<th>(US$10000–)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation</td>
<td>Small scale traditional irrigation (natural river flow)</td>
<td>Large scale development in the plain area (water resources and main facility)</td>
<td>Improving water management and on-farm irrigation technology</td>
<td>Strong requirement for supplying water in cities and improving agricultural water use efficiency</td>
<td>Restoring facility and enhancing to provide benefits to the public</td>
</tr>
<tr>
<td>Socio-economic situation</td>
<td>Agriculture as a national key industry Expansion of population Poverty as a whole Fragile national finance</td>
<td>Agriculture as a national key industry Expansion of population Poverty in rural area Tight national finance</td>
<td>Socio-economic disparity between city and ruralOvercrowded city problems Promoting industrialization</td>
<td>Diminishing proportion of agriculture in GDP Rural development for good living environment</td>
<td>Diminishing proportion of agriculture in GDP Rural development for good living environment Preserving environment Providing payday</td>
</tr>
<tr>
<td>Typical countries</td>
<td>Laos, Cambodia</td>
<td>Viet-nam, Myanmar</td>
<td>China, Indonesia,</td>
<td>Thailand, Malaysia</td>
<td>Korea, Japan</td>
</tr>
</tbody>
</table>

A-1. Benefits automatically generated to the public

A-2. Benefits intentionally provided to the public

B-1. Multi-purpose use of water by farmers

B-2. Supporting local cultural-religious activities
Chain links of united front and confliction by multistage levels on dividing agricultural water
Water use efficiency during dry spells in the area of plot-to-plot irrigation

- Average paddy plot area: 0.126ha
- Average number of plots per farmer: 7
A mechanism for accumulating social capital, making sure of efficient and sustainable water use

Twin Spirals of Interaction between Governance and Social Capital

Experience on Governance

Accumulation of Social Capital

A : Spiral between governance on services for water distribution and social capital

B : Spiral between governance on maintenances for infrastructure and social capital
Japan

“Old bridge in which irrigation water goes through”
Thailand

“Planning, doing and reviewing together with village people”
India

“Communal farm orchestra with village people, cattle and tractor”
Thailand

“Questionnaire survey for measuring social capital in several village”
International Network for Water and Ecosystem in Paddy Fields

Thanks for your attention

http://www.maff.go.jp/inwepf/index.htm