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ABSTRACT OF DOCTORAL THESIS

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Title: Assessment of Agricultural Water Management at Branch and Tertiary Canal Levels in the North Nile Delta, Egypt

(エジプト・ナイルデルタにおける支線・三次水路レベルの農業用水管理評価)

Egypt's water sector faces enormous challenges that necessitated an integrated management of water resources. Thus, modernizing the irrigation system infrastructure and water allocation has become inevitable. Accordingly, the Ministry of Water Resources and Irrigation (MWRI) has set various goals and projects in its National Water Research Plan (NWRP) to secure future water resources management in lighting of water quantity and quality. Particularly, in the North Nile Delta, where it is located at the end of Egypt's irrigation system and paddy rice is allocated, the government has challenged to implement the Irrigation Improvement Project (IIP). In 1991, the MWRI implemented the Irrigation Improvement Project (IIP) to facilitate equitable water distribution and improve on-farm irrigation management by improving irrigation infrastructure. This can be achieved by replacing individual pumps with collectively operated pumps and renewing the old tertiary canals. Since the new irrigation system was operated through the single lift point, the operation and management were transferred to the water user associations (WUAs) established within the project. The target area of the IIP is 1.5 million hectares, of which approximately 70% is in the Nile delta.

The modernization of the irrigation infrastructure has motivated farmers to grow more paddy rice than what is originally planned by MWRI (40% to 50% of the total irrigated area). Paddy rice is the major summer crop for farmers due to its higher net profit, as well as, it is the subsistence crop for farmers. As a result of the increasing paddy rice area, several water shortages were occurred, particularly at the midstream and downstream. Therefore, this study aimed at (I) monitoring and evaluating the irrigation practices of farmers during summer and examined the extent of sufficient and equitable water distribution in a branch canal located in the North Nile Delta, (II) evaluating the performance of the irrigation system and quantifying the amount of water that could be saved for midstream and downstream in case farmers would follow the government's planned area, and (III) investigating farmers irrigation practices under the conditions of increasing paddy rice area through investigating timeously water delivery performance during daytime and nighttime. This is to suggest further actions and interventions to pursue an effective integrated framework for water management.

For the purpose of the study, a branch canal located in the North Nile Delta was chosen, where paddy rice cultivations are concentrated and where the MWRI has challenged the implementation of the (IIP). Along the canal, two, three, and one pumping stations were selected from the upstream, midstream, and downstream, respectively. In this study, data collection and analysis were conducted during the mid-irrigation season of June, July, and August because the water demand peaks and water shortage usually occurs. The first and last months of the summer irrigation seasons (i.e., May and September) were not included in the analysis to prevent errors from factors such as the uncertainty of the seeding period for each crop. For the study, the branch canal water level, pump operation hours, water supply, requirements, crop areas, and yield were collected and calculated during the two summer seasons of 2013 and 2014. The canal water levels were monitored at 30-minute intervals by installing water level sensors (SOLINST LEVEL LOGGER) in front of the intake of each tertiary canal. The operation time of each pump was recorded at 10-minute intervals using THERMO sensors, and the pump discharge was measured using a portable ultrasonic flow meter (MAXIFLO, MU-PO-CM).

Water supply was estimated by multiplying the operation hours with each pump's discharge. The irrigation water requirement for each crop was estimated using the Penman-Monteith method. Water requirement was calculated based on a 10-day interval using the ET_0 calculator software developed by the Land and Water Division of the Food and Agriculture Organization. Cropping patterns were collected through field survey. Yield survey was conducted at different locations from upstream, midstream, and downstream. Water delivery performance was analyzed in terms of adequacy, equity, and dependability under both actual and planned paddy rice area. Based on the difference between the actual water supply and planned water demand, the amount of water that could have been saved for downstream uses was calculated. To assess farmers irrigation practices and how they differed between upstream, midstream, and downstream, daytime and nighttime irrigation practices among locations were analyzed. Canal water levels and pump operation hours were monitored. The period from 18:00 h to 06:00 h is considered nighttime and others are daytime.

Results showed that, paddy rice accounted for up to 80% and 71% of the total cultivated crops in 2013 and 2014, respectively, more than the government's planned range of 40% to 50%. As a result, midstream and downstream farmers, water reached their inlet gates one or two days after the branch canal had been turned on. The downstream tertiary canal received less water than required compared with upstream and midstream, and this insufficient supply affected rice yields downstream, where average yield downstream was 7.6 t ha^{-1}, while upstream yield was 10.5 t ha^{-1} in both years. Overall, the average adequacy was good at one location, fair at 2 locations, and poor at 3 locations in both years. Further, adequacy under both actual and planned paddy rice area was poor in late July at all locations. However, the planned adequacy and dependability downstream and equity among locations improved compared to the actual condition in both years. Under the condition that paddy rice area is the upper limit planned by the government, about 12.3 % and 9.6% of water could be potentially saved each year. The difference between actual and planned water delivery performance

is caused by the branch canal's low water level. As a result, both midstream and downstream farmers received in a range of 17% to 26% of the water supply during the nighttime in both years. Further, during the peak water demand of June and July, these values increased to 39%. On the other hand, the upstream farmers received a range of 6% to 17% of the water supply during the nighttime in both years. Due to increasing paddy rice areas, water intake during the daytime upstream becomes large, while the water level in the canal becomes low during the daytime, and pumping up a sufficient amount of water cannot be performed midstream and downstream. The limited amount of water supply during the daytime in the midstream and downstream resulted in the necessity to have additional irrigation during the nighttime from 18:00 h–06:00 h, especially during the late darkness from 24:00 h–03:00 h. Consequently, the numbers of nighttime irrigation days midstream and downstream increased more than upstream. In addition, even if water flowed at an insufficient amount in the canal during the daytime, upstream farmers could handle this by irrigating during the early night from 18:00 h–21:00 h. Contrary to midstream and downstream, during the period with insufficient canal water level, they irrigate during the late darkness (24:00 h to 03:00 h). This indicates that midstream and downstream are more heavily dependent on night irrigation than upstream.

Overall, the following points are recommended to mitigate water shortages and improve water delivery performance in the study area (I) coordination of cropping pattern (paddy rice areas) and water distribution among WUAs is inevitable for further improvement of water delivery performance and water-saving and (II) in the existing Irrigation Improvement Project, control upstream farmers' pump discharges could improve equity in terms of volume and timing.

Eventually, the coordination of cropping pattern and following the recommended area by the government (40% to 50% of the total irrigated area) should consider that farmers everywhere tend to increase their income. Thus, instead of imposing penalties, the government and industry need to create a system that encourages farmers to grow crops other than rice. This could be through, (I) improving the industrial structure to encourage increased demand for upland crops, such as cotton, (II) offering subsidies for farmers who maintain an appropriate permitted percentage of paddy rice area, and (III) introducing drip irrigation and other irrigation facilities to enhance farmers to grow upland crops, and then this would reduce irrigation water used for crops, and then the paddy area ratio could be higher than 40-50%.

* In addition, some of the figures, etc., have been omitted.