WORKING PAPER 31

Assessment of Performance and Impact of Irrigation and Water Resources Systems in Taiwan and Sri Lanka

Final Report

R. Sakthivadivel, Noel Aloysius and Yutaka Matsuno

International Water Management Institute

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AGRICULTURAL ENGINEERING RESEARCH CENTER, TAIWAN

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Cover photograph by Yutaka Matsuno shows the diversion structure in the Kaohsing irrigation system, Taiwan.

Contents

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Preamble

The International Water Management Institute (IWMI), Sri Lanka, and the Agricultural Engineering Research Center (AERC), Taiwan, both recognize the increasing importance of developing a reliable methodology to assess the performance of irrigation and water resource systems. For mutual benefit, the Council of Agriculture (COA), Taoyan Irrigation Research and Development Foundation, Tsao-Jiin Memorial Foundation for Research and Development for Agriculture and Irrigation, Environmental Greening Foundation, and Chi-Seng Water Management and Development Foundation are supporting research on this issue as part of an on-going research project being carried out by IWMI in collaboration with other national and international research centers.

Studies by IWMI indicate that by the year 2025, approximately 1.4 billion people or one-third of the population of developing countries will be living in areas of chronic water scarcity. People living in these areas will not have sufficient water resources to maintain even their 1990 average levels of per capita water consumption in the agricultural, industrial and environmental sectors, and much less avenue to increase these levels to acceptable standards. Since agriculture consumes over 80 percent of all the water in developing countries, there will be intense pressure to transfer water out of agriculture to meet the needs of the other sectors and to increase efficiencies of irrigation water use at both system and field levels.

Consequently, there is a need to develop a reliable tool to measure and assess the performance of water uses in river basins. This work would lead to better water allocation and better decision making for water management authorities. Water for irrigation is essential for the security of food supplies. We also recognize the importance of irrigation water for non-agricultural uses, which lack a systematic approach which could be described within the context of irrigation and water resource systems by taking these different perspectives into account.

The collaborative research program has implemented projects aimed at supporting IWMI's research program in performance assessment:

- Interpreting performance and sustainability of irrigation systems in Taiwan and Sri Lanka and comparing the systems of the two countries.

- Studying on-farm irrigation management in Taiwan and Sri Lanka.

Support from Taiwan and the Irrigation Associations of Taiwan contribute to research activities in countries such as Sri Lanka (Uda Walawe Irrigation System) and Taiwan (Taoyuan and Kaohsung Irrigation Systems) where IWMI is currently initiating research projects.

As a part of this year's collaborative study, two IWMI staff members visited Taiwan, from 25 September to 4 October 2000, to familiarize themeselves with Taiwan's irrigation systems. The first part of this report gives a brief introduction to the Taiwan irrigation systems and describes the two irrigation systems visited. Based on the visit and discussions with the Association Managers, staff of the Agricultural Engineering Research Centre (AERC) and staff of the Council of Agriculture (COA), certain issues were identified in the two systems, which are detailed. In the second part, the results of analyses of the performance and a comparison of the three irrigation systems are described.

Taiwan Irrigation Systems

In Taiwan, the COA oversees the administration of agriculture, including irrigated agriculture, forestry, fisheries, animal industry, and food and grains. At the same time, it is also responsible for advising and supervising the administration and management affairs of the provincial and municipal governments, including Irrigation Associations (IAs).

The history of irrigated agricultural development in Taiwan shows how development has evolved from the earliest stage when efforts were concentrated on increasing crop production by raising productivity, to the present stage of modern agriculture that seeks to strike a balance in productivity, livelihood, and the environment.

Taiwan is a small island and crowded. A full two thirds of the island's land area is occupied by mountains and hills, leaving only about 870,000 ha suitable for farming and livestock production. Today, there are approximately 790,000 farming households, each with an average of just over 1 ha of land for cultivation. Of this total, only 13 percent are full-time farming households.

In recent years, the annual value of agricultural production in Taiwan (crops, animal production, and fisheries) has exceeded NT$400 billion. It accounts for 3.3 percent of Taiwan's gross domestic product.

The warm climate of Taiwan provides for a long growing season and permits diversified cropping. Wherever water is available, two or more crops can be grown in a year. The average annual rainfall of 2,515 mm is unevenly distributed in space and time necessitating irrigation for crop production. The total area of Taiwan is about 36,000 km^2 of which 8,760 km^2 (24%) is cultivable, with 60 percent of it irrigated while the remainder is rainfed. In 1996, the total water diverted for use was 18.1 billion m^3 of which about 10.2 billion m^3 was for irrigation (WRB 1997). River offtake, reservoir/pond storage water, and groundwater are the major supplies used either singly or conjunctively for irrigation along with rainfall. The total irrigated area was about 456,000 ha in 1997 of which 381,000 ha (76%) were under the jurisdiction of 17 IAs and the rest were managed by individual farmers and Taiwan's farmer's sugar corporations. These irrigation areas were served by 1,797 irrigation canal systems, 2,000 shallow and deep irrigation wells and 18 reservoirs (TJIA 1998).

In Taiwan, irrigation was essentially developed for rice cultivation since rice is the staple food. The early development of the irrigation systems was small scale, and the systems were essentially built and managed by the farmers themselves without any assistance from the government. By about 1895, a total area of 350,000 ha had been developed for farmland and of this about 200,000 ha were under irrigation. During the Japanese colonization from 1896 to 1947, 181 irrigation cooperatives were founded to take charge of the operation and management of these canals. During this period, the irrigated area was increased to 560,000 ha. Following World War II, some large-scale irrigation projects were constructed by the government and by 1962, the irrigated area was increased to 676,384 ha, which is the highest recorded irrigated area. During this period, rotational irrigation, canal lining and land consolidation were implemented.

As of 1998, the total irrigated area managed by 17 IAs was 381,000 ha. Of the total service area, the double rice-crop area was 261,000 ha; the single rice-crop area 24,000 ha, the two-and-three-year rotational area 83,000 ha and the upland crop area 13,000 ha (TJIA 1998).

Irrigation Practices

During the early stages of land development and rice growing, paddy fields were continuously supplied with water, 50 to 60 mm in depth, throughout the period of rice growth except during weeding, fertilizer application and harvesting. Such practices resulted in high water use with a water rate as low as 330 ha/m^3/s. After World War II, the use of cultivable lands and existing water resources for irrigation and other purposes reached a limit due to rapid growth of population and industrialization; an attempt was made to change the conventional continuous irrigation method to a rotational irrigation method by adopting three different types of rotation (Ko and Lavine 1972):

A. Rotation of sections of main canal.

B. Continuous flow in main canal but rotations of laterals/sub-laterals.

C. Continuous flow in main and lateral canals but rotation of farm ditches.

Cases A and B are mostly used in drought periods while Case C is used in normal irrigation periods. By rotational irrigation, water supply rate has increased to 800 ha/m^3/s with a water saving of 20 to 30 percent from continuous irrigation supply. Furthermore, it was found that rotational irrigation favors plant growth, reduces fertilizer application and minimizes conflicts among farmers. With land consolidation, water flows continuously through the turnout gate, controlled by flow adjusting devices, and irrigation is rotated among rotation units. A block area of about 10 to 14 ha served by a field channel regarded as a rotation unit is subdivided into several plots with areas of 0.2 to 0.4 ha (100–120 m long and 20–40 m wide). Irrigation water is delivered to each plot from the supply ditch directly, while the drainage water is collected at the far end of the supply ditch. Up to 1998, the total area developed for rotational water supply was about 380,000 ha.

Irrigation Associations

The major functions of IAs are construction, improvement and maintenance of irrigation and drainage facilities as well as water management. The IAs have a management division at the head office to handle irrigation management policy, water planning and scheduling, and irrigation supervision. A typical IA has local regional offices called “working stations.” The irrigation working station operates and maintains the irrigation system. Besides, some IAs have a water source and canal working station to control and supply the water.

Field water distribution planning and execution are the main responsibilities of an irrigation working station. The station supervises and assists five to ten irrigation groups to carry out the water distribution and maintenance work of an irrigation system at the farm-level. The irrigation groups are organized by the IA members themselves on the basis of farm level irrigation systems without salary from the association. A group consists of an area of 50 to 150 ha and several irrigation teams, each with 10 to 15 members. The main work of an irrigation group is to maintain irrigation and drainage ditches and to distribute irrigation water.

Field inspection by IWMI team

Irrigation Planning and Operation

Before the start of the irrigation season, a tentative water distribution plan is worked out by the management division at the head office according to government policy, production goals, the existing reservoir/pond storage and water release, water flows at diversion weirs, other available water sources, past records of irrigation requirements, canal conveyance losses, rotational irrigation intervals, time of irrigation, etc. The prepared plan is handed to the working stations for further study and discussion with irrigation groups and finalization.

The finalized water distribution plan is implemented by the working stations. The canal operators of stations are in charge of regulating and controlling water flows along the main canal, laterals and sub-laterals. The irrigation supervisors are in charge of water control and measurement at turnout gates of laterals and sub-laterals, and inspection at farm-level distribution is undertaken by irrigation groups in their individual irrigation areas.

Irrigation-Related Problems

Paddy is grown widely in Taiwan. The paddy harvested area was 502,018 ha with an annual brown rice production of 639,000 tonnes in 1945, which increased to a record high of 786,343 ha with a maximum production of 2,712,000 tonnes in 1976 (COA 1994). Moreover, consumption patterns are changing with increasing wealth and the average consumption of rice per year per person has fallen from 134 kg in 1974 to 59 kg in 1996 (DF 1998). In addition, there was no steady export market for Taiwan rice. In order to balance paddy production to demand, a crop diversification program was initiated in 1984 to divert the use of paddy fields from the production of rice to alternative crops.

From 43,700 ha in 1984, the total area of diversified paddy fields increased to 260,000 ha in 1997 (DF 1998). Under this program, theoretically, a large amount of water should have been saved for other uses. However, 76 percent of the irrigation water is provided through river diversion structures, which have been seriously polluted and cannot be used by other users. Besides, the diversified field crops that are not contiguous are not likely to save much water due to conveyance and seepage losses. As a consequence, irrigation management has become more complicated. With the current economic growth in Taiwan, water demand has been increasing and the creation of additional new water sources has become more costly. No new irrigation project can be implemented for rice production due to economic feasibility factors. However, to maintain food self-sufficiency and food security, and to raise farmers' income and narrow the income gap between farmers and non-farm workers, about 350,000 ha of paddy fields have to be maintained and managed by providing irrigation.

Irrigation water resources are essential not only for agricultural production but also for maintaining the ecological functions.

Some of the questions for which we need answers are the following:

- In order to implement the dry and wet crops rotation plan, investigation of existing irrigation water use is needed. Raising the water-use efficiency for first paddy in the dry season is necessary.

- Strengthening improvements in irrigation management and operation techniques, repairing and improving the existing old irrigation system facilities, adopting water-saving techniques are measures for raising the effective use of water resources.

- Strengthening irrigation water quality control, implementing management of water quality measures in the heavily polluted areas and studying the degradation tendency of soil and groundwater in polluted areas are essential.

- Further observation of drainage water effluent from industries and monitoring of its quality are needed.

- The functions and achievements of paddy yields on production, living organisms and ecology are to be investigated and evaluated.

- The use of remote sensing coupled with GIS and modeling are to be used for real time operation of irrigation systems.

Irrigation development and management are no longer merely problems of engineering. They encompass social, economic and institutional aspects of improving land and water productivity, minimizing soil and water degradation and maintaining ecological functions. As a result, a great effort should be made to ensure efficient utilization of the limited irrigation water through the improvement of existing irrigation systems and intensive management.

Taoyuan Irrigation System

The Taoyuan irrigation system lies in the area of Taoyuan, Hukou, Tahsi and Hsinhai located in the northern part of Taiwan, which includes Taipei, Taoyuan and Hsinchu counties. The total irrigation area is 25,967 ha. The main sources of irrigation water are Taoyuan and Kuanfu canals drawing water from the Shihmen reservoir and subcanals in the Tahan river basin and storage ponds.

The climate is sub-tropical with an annual average temperature of 21°C. The average summer temperature is 27.6°C while the winter average is 15°C. The annual average rainfall is 2,000 mm.

Of the total rainfall, 25 percent to 30 percent contributes to irrigation. The main crop occupying 95 percent of farmlands in the irrigation area is rice, which can be grown twice a year while the remaining 5 percent of the area is planted with sweet potatoes, vegetables, etc. The soil of the command is clay loam with low permeability.

The Taoyuan Irrigation Association (TIA) was established and became operational in 1924. The irrigation infrastructure of the Association consists of 2,762 km of canals (including 2,200 km of farm ditches), 285 storage ponds, 346 weirs along the river (average capacity of 4.28 m^3/s), and 17 headworks along the canal.

In 1919, the TIA Canal Cooperative of the Public Canal was founded, and it constructed 231 storage ponds with a total surface area of 2,218 ha and a volume capacity of 66 million m^3. In 1956, it was reorganized as the TIA, a combination of 3 associations. Due to this, the irrigated area increased from 23,000 ha to 27,000 ha.

In 1970, the TIA combined with the neighbouring Hsinhai Irrigation Association and its irrigation area increased to 34,568 ha. Since then, the irrigation area has decreased due to urban expansion and development of industries. It decreased to 28,241 ha in 1984, to 26,365 ha in 1989 and to 25,967 ha in 1999.

The members of this association are:

- Representatives of the agency that manages or uses public farmland.
- The landowner or mortgagee of the private farmland.
- The temporary or permanent tenancy of the public or private farmland.
- Other beneficiaries.

In 1999, there were 57,660 members in the Association.

During the early period, the Cooperative Council was composed of members elected and appointed by the government. From 1956, the Commission (council) was reorganized as the

Assembly of Representatives, who were elected by the members. The representatives had the right to elect and dismiss the Chairman of the Association.

After 1994, the Authority was changed to the Committee for the Affairs of the Association because of the government's policy to establish an organization of the irrigation associations. The committee members with a tenure of office of 4 years are elected by the government from among the well-qualified association members, scholars, experts, and representatives of related institutions. The association members comprise of two-third of the committee members.

The mission of the Committee for the Affairs of the Association has broadened:

- to approve the working plan of the association and the budget,
- to examine the management of real estate including financial dealings,
- to examine applications for loans and donations,
- to take decisions on the proposals of the Chairman and the committee members for the affairs of the association,
- to take decisions on the petitions of members, and
- to exercise other rights within limits prescribed by law.

Since 1994, the Chairman is appointed by the government from those who are qualified and register voluntarily. The tenure of the Chairman is 4 years, and one reappointment is allowed. In the executive office, there is one general manager, one chief engineer, several secretaries, and several specialists who together assist the Chairman.

The executive office is composed of 8 units: administration, financial, management, engineering, accounts, personnel, guidance, and computer section.

In addition, there are 13 operation stations that are in charge of the management of water conveyance and distribution, the maintenance of irrigation facilities and the training of members of the association.

The irrigation group is established with a basic area of 51-150 ha. The group chief is elected by members and can be reelected consecutively. Several teams are set up in a group. The duty of the team leader, appointed by the group chief, is to assist the chief in the management of irrigation and is expected to achieve this independent of the management. The association (in 1999) has 339 irrigation groups and 2,137 teams.

The responsibilities of the irrigation groups are as follows:

- maintenance, management and repair of the supply ditches and drainage ditches,
- management of water distribution in the group area,
- assistance in the affairs of land acquisition for construction,
- construction of supply ditches in the owned group area, and
- irrigation affairs that are entrusted or assigned by the association.

Characteristics of the Irrigation System

With the discharge limited to 16.7 m^3/s in the Taoyuan irrigation canal, which is only 50 percent of the irrigation requirement of the area, the balance water is supplied from 285 storage ponds and 346 scattered diversion weirs on various creeks. Due to its complexity, rules for operation are:

> The storage ponds that receive water both from the diversion weirs and the Shihmen reservoir shall use stream water as much as possible in order to save the water released from the Shihmen reservoir, which will be used for irrigating other areas.
>
> The storage ponds, each with a large catchment, shall also collect surface runoff as much as possible from their respective catchment areas.
>
> When the Shihmen reservoir has ample water supply, the storage ponds that do not take water from streams will have first priority to receive reservoir water. This, in turn, will make sure the success of paddy irrigation from solely reservoir-fed ponds.
>
> In case of water shortage, reservoir water is supplied to irrigation area direct from canals. Furthermore, if water shortage is acute, the water distribution plan may be revised to adopt an emergency irrigation rate and scheduled temporarily according to the total amount of water.
>
> When the rice irrigation season is over, canals shall continuously convey the water from the reservoir and diversion weirs to fill all storage ponds as much as possible, except those to be repaired.
>
> All possible measures must be taken to achieve the maximum storage by collecting runoff due to rainfall in the catchment area.
>
> Water used for land preparation and transplanted rice must be so scheduled that the peak use of water is minimized.

Water Management

Before the irrigation season starts, a tentative water distribution is worked out at the head office and sent to the operation station. The operation stations and irrigation group then discuss and finalize the operational plan.

The finalized water distribution plan is implemented by the officials of IAs. The canal managers are mainly responsible for the regulation and control of water along the main canals, laterals and sub-laterals, from diversion weirs and storage ponds.

The irrigation managers are responsible for water control and measurement at operating gates on laterals and sub-laterals and make inspections of farm-level water distributions that are to be carried out by irrigation groups in their individual rotation blocks.

The first crop of rice is raised from February 01 to July 29, a long-duration variety with a growing period of 120 days. The second crop is from July 09 to December 10, a short-duration variety of a 110 day growing period.

Field water requirement is worked out for each rotation block by classifying the soil of the block into four categories: light clay soil, clay loam, sandy clay loam and sandy loam. The seasonal water requirement varies from 968 mm to 1,271 mm for these soils. Two rotation intervals of water supply during the crop growth period are adopted. During the first 30 days, after transplanting, a 3-day interval is adopted while for the remaining period a 6-day interval is adopted.

Rotational irrigation is practiced in this system from 1955. Rotational irrigation is the application of irrigation water in proper amount at the proper time and in proper order, so that all farmers may get enough water to irrigate their fields. The irrigation distribution is designed according to the existing system layout and actual topographic conditions, so that irrigation water can be simultaneously delivered into each rotation block of about 50 ha. Each rotation block is sub-divided into four or five rotation units, each of 10 ha size. Every rotation block is provided with a turnout gate and measuring device and several division boxes. Water flowing continuously through the turnout gate and measuring device will be properly rotated among the rotation units according to the planned schedule.

Rotational irrigation has increased rice production to 2-5 percent and water saving to 25-50 percent compared to those of continuous irrigation.

Towards Improvement of Irrigation System Performance

Presently the association uses a certain criterion for irrigation water requirements; this criterion can be critically reviewed in the present context of changed cropping practices, including rice varieties, growing seasons, soil types, irrigation techniques and effective use of rainfall. Also, water requirement for eco-environmental preservation can also be included.

One of the best indicators of efficient water use in an irrigation system is the amount of return flow getting out of the system; monitoring the return flow at critical points is an important aspect for better managing an irrigation system. This is not being practiced in TIA.

The irrigation association now monitors the water quality at different selected locations within the irrigation system and informs the government to take effective action to curb or minimize the pollution to these water sources. In addition to water quality monitoring, water quantity monitoring at the critical points of flow need to be attempted to study the salt balance within the system. Moreover, attempts must also be made to integrate the water quality data in the real time operation of the system. For example, scientific methods should be established to divert the polluted water from the rivers and creeks to the ponds.

Since 65 percent of the irrigation requirement of TIA comes from the Shihmen reservoir, forecasting the inflow to the Shihmen reservoir and increasing the inflow to the reservoir, especially during the dry year, through catchment treatment are important areas of research and study.

Efficient and effective use of rainfall is an important source of irrigation water. Presently, less than 25 percent of rainfall is effectively used. Operational procedures are to be identified to increase this use so that water from reservoirs and ponds could be conserved. Raising the field bunds to capture more rain water is the method used in a number of counties.

In the operation of the TIA, the association does not record the discharges passing through the respective regulatory structures in the lateral and sub-lateral canals and tertiary canals. These data are very important to evaluate the water delivery performance of various canals.

In the TIA irrigation system, groundwater is used by industry while surface water is used by the irrigation association. Due to these uses, there is point and non-point pollution of TIA's water. Both groundwater and surface water are two sides of the same coin and they are inter-related. A fair amount of surface water is recharged to the groundwater from the paddy fields. Also, pollution of TIA's water affect both surface water and groundwater. In the long run, both industry and TIA have to work in close cooperation to maintain the quantity and quality of surface water and groundwater. Therefore, there is a need to systematically monitor the water within the TIA system to study the impact of irrigation on groundwater quantity and quality, and vice versa. A comprehensive study through detailed water accounting for quantity and quality needs to be undertaken.

Kaohsung Irrigation System

The Kaohsing Irrigation System is situated in the southern part of the island and has a command area of 18,414 ha. It is a peri-urban association. In the early stages of IA (1956-64), it had an area of 32,237 ha. Now (1994-97) it is left with only 18,461 ha, the remaining area having been converted into urban and industrial areas. Historically the average yield of paddy has risen from 4.25 t/ha in 1974 to 5.5 t/ha in 1994. However, the total paddy production during this period has dropped from 198,235 t to 78,565 t.

The upland crop planted area has decreased from 23,000 ha to 16,300 ha and the paddy area from 27,000 ha to 14,400 ha. However, the total water used for irrigation during this period had not changed much from 46,152 million m^3 in 1981 to 46,761 million m^3 in 1994. In fact water used per hectare of paddy area has risen from 22,594 m^3 in 1981 to 32,479 m^3 in 1994. The farm size per family has come down from 0.50 ha to 0.37 ha during a period of 20 years.

The Kaohsing Irrigation Association (KIA) has 228 staff, 16 working stations, 49,300 members, 150 water groups and about 400 sub-water groups.

Its total annual revenue is NT$1.51 billion while expenditure is NT$1.19 million.

Most of its surface water supply is from river lifts through large scale pumping or from the tail race of hydropower generating units. In addition, there are more than 40 large scale pumps (15 to 20 hp) located along the canals which pump underground water and use lined canals for conveyance. A fair amount of drainage water is recirculated. Consequently, a conjunctive management of all types of water including rainfall is practiced in this IA. However, data such as reuse of drainage water, groundwater level and groundwater use is not readily available with KIA.

In the Kaohsing IA, two areas, Niasong and Meinong, were visited. These two areas have different developmental changes in terms of land use. Area Niaosong is a peri-urban area undergoing dynamic changes while the Meinong area is rural where relative changes of land use of the region are not much.

In KIA, Chao Kung pumping station with 9 pumps (4 x 150 hp + 5 x 300 hp) is capable of discharging 23 m^3/second. However, in normal times, it operates with 1,800 hp and 16.84 m^3/s.

This association grows a large amount of upland crops such as banana, arecunut, guava, etc. for export. The association is concerned with pollution from domestic wastes and its impact on export oriented crops.

The following are the issues that may need attention in this association:

- Tracing the flow paths of different water supply systems (canal water, wastewater, groundwater supply systems)
- Understanding the present operational pattern at the main system and within rotational unit levels
- Estimating the present wastewater use and its impact on productivity
- Analyzing the historical trend in water supply to different sectors (agriculture, drinking, industry, aquaculture, livestock, environment, etc.)
- Looking at point and non-point pollution within the system and identifying critical zones of pollution

- Carrying out water and salt accountings of the system
- Using remote sensing, GIS and modeling for developing water management strategies
- Evaluating the present performance of the system in terms of water productivity and sustainability of the system
- Improving the present method of formulating operational plans and carrying out monitoring of flow and drainage at critical points

Irrigation canal in the Kaohsing irrigation system, Taiwan

Concluding Remarks

Toyuan and Kaohsung irrigation associations are well organized and function effectively in the management of their irrigation systems. As the country developed and modernized, the associations have been able to bring in modern technologies and new ideas to its operation and management. However, at the same time, the irrigation associations have been facing new challenges. Striking a balance between resource conservation and development, specifically achieving industrial development without affecting crop productivity and the environment, is an important issue currently facing these associations.

Due to the recent socioeconomic changes, the total water demand in Taiwan has increased with the expansion of industrialization and urbanization. The development of new water supplies for irrigated agriculture has become more difficult and costly. Besides, the existing irrigation water supplies face severe competition from other sectors and become polluted. As a result, great effort is needed to ensure efficient utilization and sustainable use of irrigation water through improved water management.

Some lessons and experiences of irrigation development in Taiwan can be useful to many developing countries. It is a good example of how irrigation has been undergoing transformation along with industrialization of a country.

In the remainder of this report we take a closer look at the performance of Toyuan and Kaohsung irrigation systems using the data available with the Taiwan authorities. As a comparison, performance of the Uda Walawe irrigation system in Sri Lanka was studied. Additionally, this year's program will analyze and describe the potential of the satellite remote sensing technique for application to irrigation management of the Taiwan systems.

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A COMPARATIVE ANALYSIS OF PERFORMANCE OF TAIWAN AND SRI LANKAN IRRIGATION SYSTEMS

Analysis of Rainfall Characteristics in Taiwan

Rain falls on an average for about 180 days in a year. Annual rainfall is approximately 2,900 mm. As far as rainfall distribution is concerned, light rains are common from October to March, while heavy rains are experienced from April to October. The greatest amount of rain falls in the summer and typhoons are responsible for particularly concentrated episodes of rainfall.

The annual rainfall of the Shihimen rainfall station in Taoyuan County for the period 1926-1997 is plotted in figure 1. The rainfall pattern during this period shows three distinct zones. The first zone is from 1925 to 1954, where the annual rainfall (average 2,870 mm over the period) had a decreasing trend. In the second zone (1954-1982), rainfall had an increasing trend and thereafter it decreased. These three zones represent a large scale periodicity of 25 to 30 years existing in the annual pattern of rainfall. Within these large cycles, there are intermediate mini/max occurrences of rainfall which repeat itself on an average of once in three years, i.e., a minimum rainfall followed by maximum rainfall occurs once in three years. These variations have important consequences for reservoir operation and irrigation scheduling.

The maximum monthly rainfall also has a similar trend (figure 2). Although the rainfall pattern and magnitude are always related to typhoon occurrence in Taiwan, there seems to be a definite pattern of repetition and trend in annual rainfall occurrences as seen from the above analysis. On the other hand, no such periodicity and perturbations are seen in the annual rainfall of the Uda Walawe system in Sri Lanka (figure 3).

Figure 1. Annual rainfall at Shihimen Rainfall Station, Taoyuan Irrigation Association, Taiwan from 1926-1997.

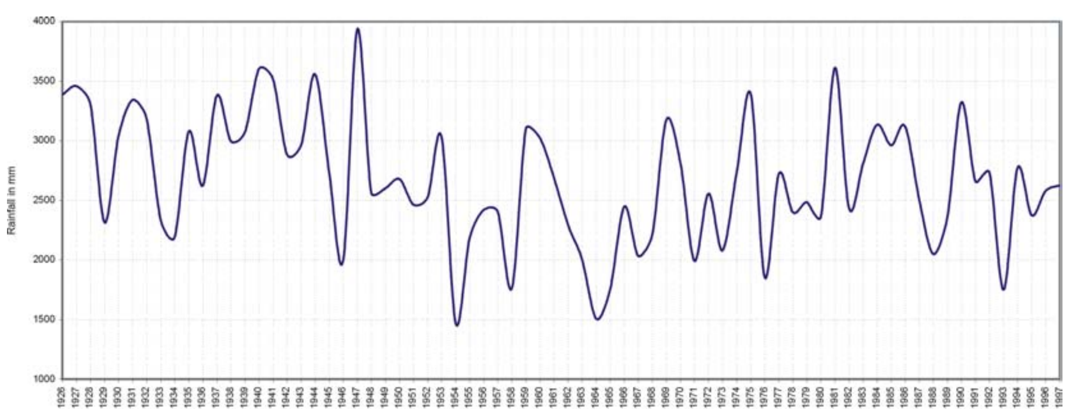


Figure 2. Maximum rainfall at Shihimen Rainfall Station, Taoyuan Irrigation ssociation, Taiwan from 1926-1997.

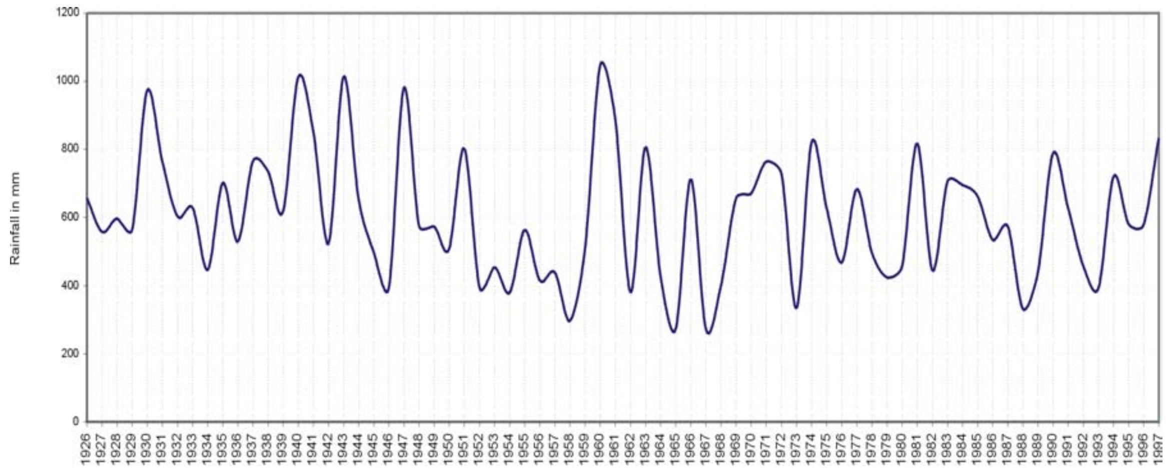
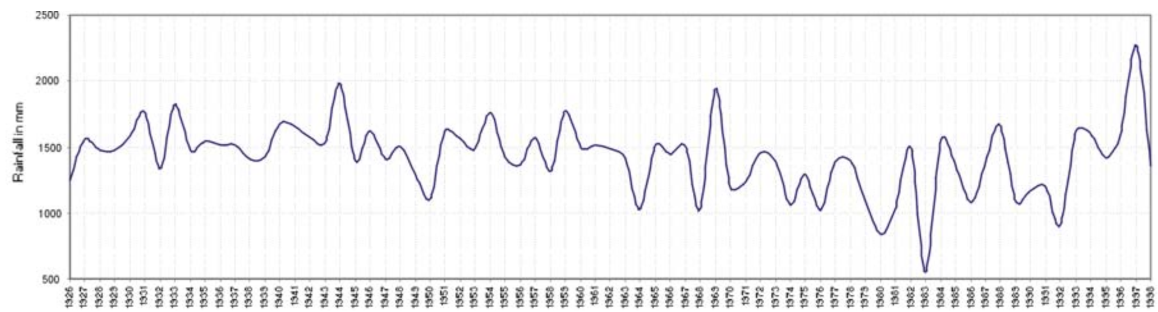


Figure 3. Annual rainfall at the Uda Walawe Rainfall Station, Walawe System, Sri Lanka, from 1926-1998.



Trends in Irrigated Agriculture

Trends in Service Area

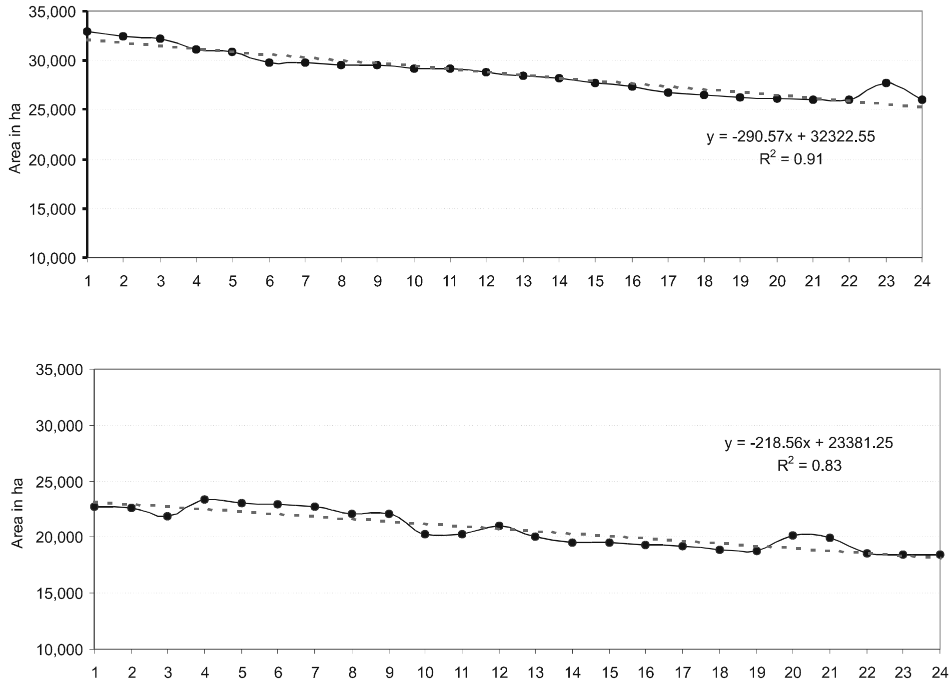
Beginning 1972 to date, both in Taoyuan and Kaoshiung, the service areas are going out of production in a linear fashion due to urban and industrial establishments. In Taoyuan, it is decreasing at the rate of 226 ha/year while in Kaoshiung, it is going down by 188 ha/year. Within the two decades (1972-1991) the service area decreased by 21 percent in Taoyuan and by 11 percent in Kaoshiung. Figure 4 shows the decreasing trend.

Trends in Planted Area

The annual planted area in Taoyuan over the last two decades had decreased from 65,000 ha to 50,000 ha (23%) while in Kaoshiung it decreased from 50,000 ha to 30,000 ha (40%). In Taoyuan most of the decrease was in the paddy planted area while planting of upland crops had increased slightly. In the case of Kaoshiung, both the paddy planted area and upland planting had decreased with paddy area decreasing from 27,000 ha to16,000 ha and upland crops from 23,000 ha to about 16,000 ha.

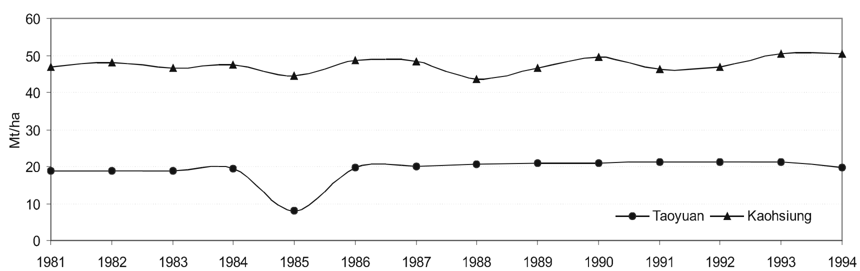
A similar trend in cultivated area can be seen in Uda Walawe. The cultivated area has reduced from 22,059 ha in 1987 to 16979 ha in 1998 (figure 5).

Figure 4. Service areas, Taoyuan and Kaohsiung Irrigation Associations, Taiwan, from 1972-1995.



[The dashed line is the linear regression line.]

Figure 5. Paddy cultivated area in Walawe Irrigation System, Sri Lanka, 1987-1998.



[The dashed line is the linear regression line.]

Trends in Paddy Yield

The variation of paddy yield from 1974 to 1994 for the two IAs is shown in figure 6. During the 1970s, Taoyuan produced only 3 t/ha while Kaoshiung produced 4 t/ha; but during the 1990s paddy yield had gone up both in Taoyuan and Kaoshiung to 4.5 t/ha and 5.5 t/ha, respectively. The annual rate of increase of paddy yield in both Taoyuan and Kaoshiung is almost the same at 50 kg/ha. The factors affecting the yield differences between the two IAs are discussed in a subsequent section. Paddy yield in Uda Walawe remained more or less the same at about 5 t/ha from 1987 to 1998.

Trends in Paddy Production

In spite of considerable reduction in the paddy planted area in Taoyuan (23%), paddy production remained more or less constant during the last two decades with paddy productivity increasing from 3 to 4 t/ha. In Kaoshiung, paddy production has come down by about 15 percent due to the large reduction in the planted area (40%) although the yield has gone up from 4 to 5 t/ha. Paddy production in the Uda Walawe is mainly affected by water availability in the reservoir and there appears to be no trend (figure 7).

Figure 6. Paddy yield in Taoyuan and Kaohsiung Irrigation Associations, Taiwan, 1981-1994.

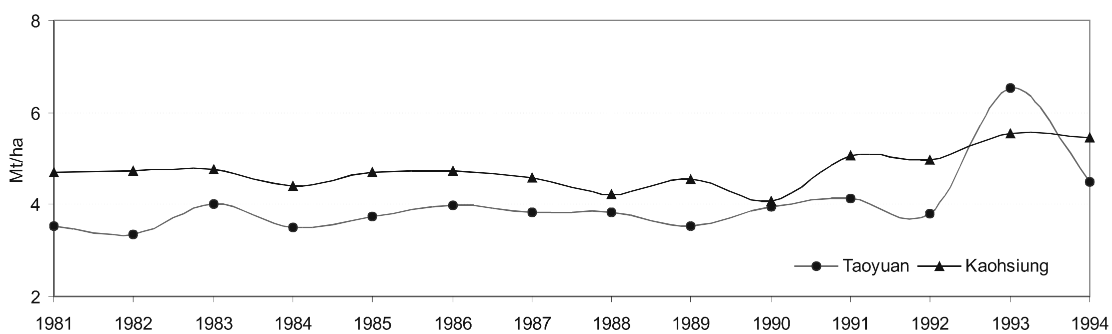
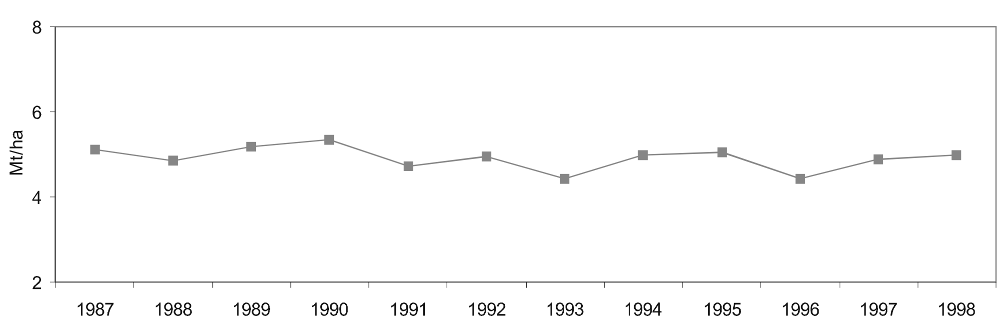


Figure 7. Paddy yield in Walawe Irrigation Area, Sri Lanka, 1987-1998.



Trends in Conveyance and Distribution System Canal Densities

Figure 8 shows the trend in conveyance system canal density (m/ha) for both Taoyuan and Kaoshiung. The trend of canal density development over the years for the two systems appear to be more or less similar. However, the magnitude of canal density is roughly 2.5 times higher for Kaoshiung compared to Taoyuan. This has implications for canal loss in conveyance systems and, consequently, the total water to be diverted/pumped from the source as well as the cost of maintenance and operation. On the other hand, the distribution system canal density in Taoyuan is slightly higher (about 84 m/ha) compared to Kaoshiung (60 m/ha). From 1970 to 1990, distribution canal density has increased by more than 100 percent in Kaoshiung compared to an increase of only about 30 percent in Taoyuan. The cost of operation and maintenance for transporting 1 m^3 of water is slightly higher for Kaoshiung compared to that of Taoyuan (1.1 against 1.2 yuan/m^3)

Sources of Water Supply

Releases from different sources as well as total releases for Taoyuan and Kaoshiung for the years 1992-1998 are shown in figure 9. In Taoyuan, except for 1996, in all other years, the total water supply had remained more or less constant while for Kaoshiung, there was reduction in total water supply in 1998.

The sources of water supply together with the percent of total water supplied by each source (averaged over 1992-98) are presented in figure 10. It is very interesting to note that in Taoyuan, reservoir supply followed by surface water supply constituted the bulk of water supply with very little water drawn from either groundwater or river diversion. Limited use of river diversion is mainly due to the pollution problem prevalent in the Taoyuan region while groundwater is used mainly for drinking and industries. On the other hand, Kaoshiung gets the bulk of its supply from river diversion (91%), followed by surface water and groundwater (4% each) and very little from storage reservoirs. Both large scale pumping and gravity diversion are used for river diversion.

Figure 8. Conveyance System Canal Density, Taoyuan and Kahsiung Irrigation Associations, Taiwan, 1981-1994.

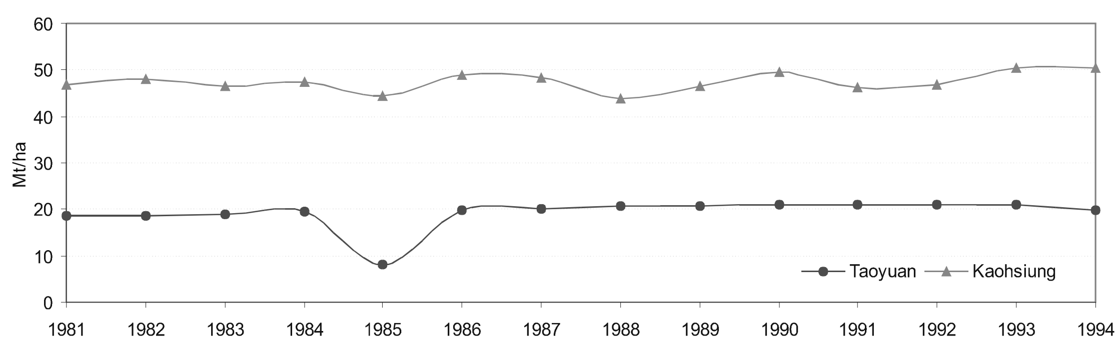
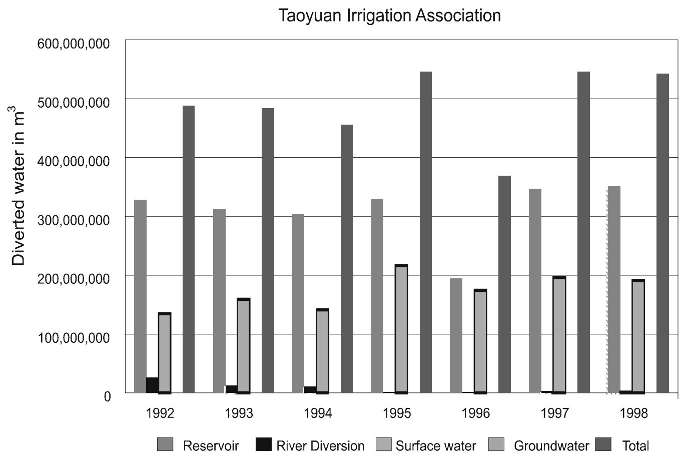


Figure 9. Water Releases from Different Sources for Taoyuan and Kaohsiung Irrigation Associations, Taiwan.



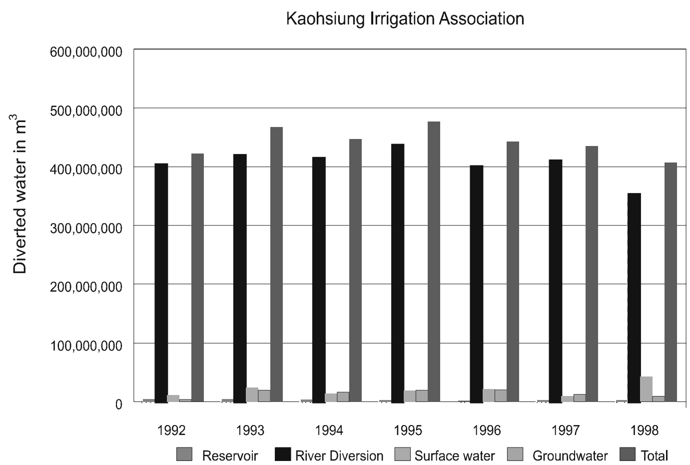
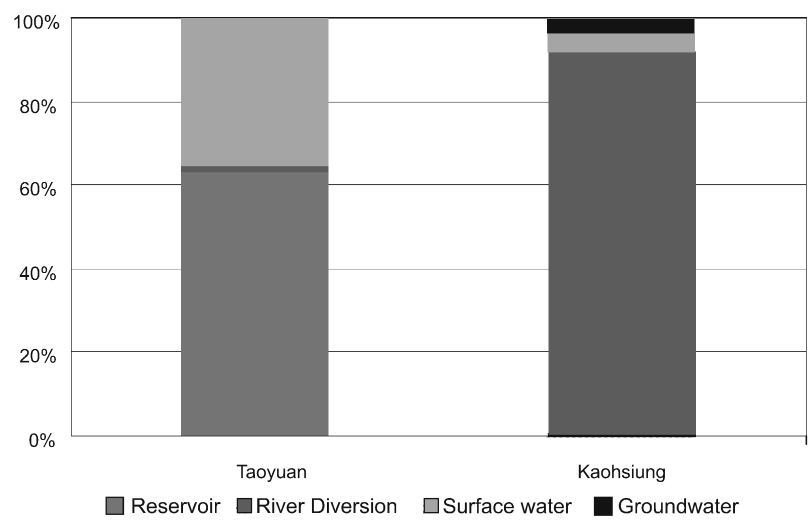


Figure 10. Water Supplied from Different Sources, Average for 1992-98, Taoyuan and Kaohsiung Irrigation Associations, Taiwan.



Dumping waste degrades irrigation water quality

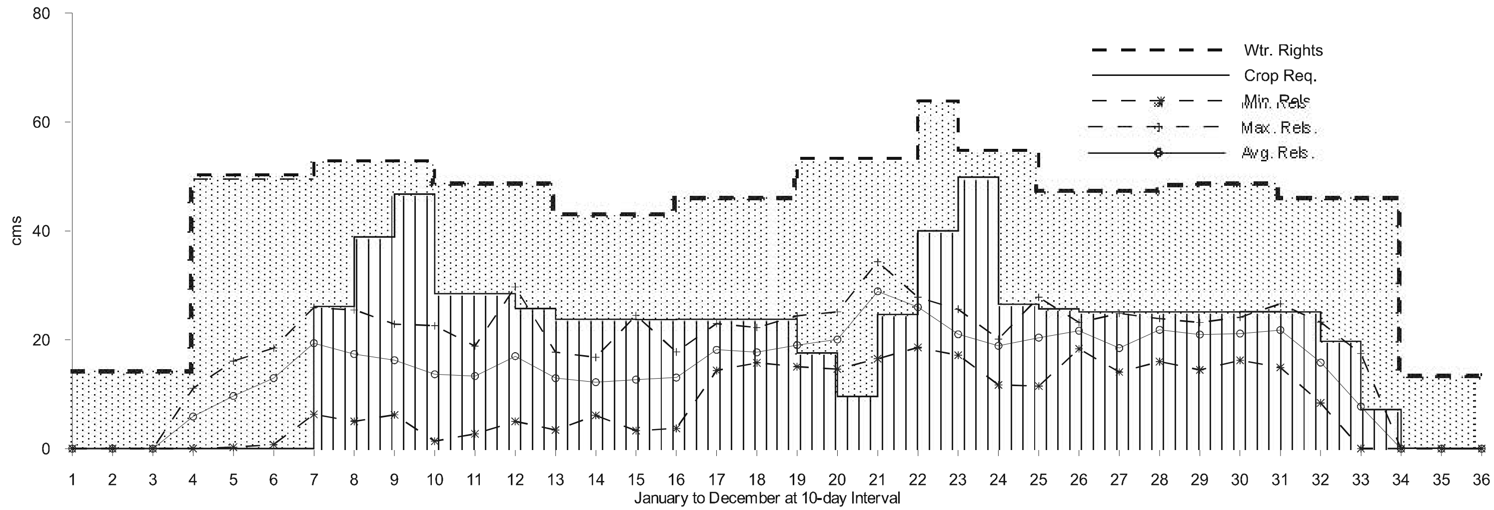
Adequacy and Distribution Pattern of Water Supply

Figures 11 and 12 show water rights, total system requirement and average, maximum and minimum water diverted from all sources on 10-day basis (averaged over a period 1992-98) for the two systems. From figure 11, the following can be observed regarding the Taoyuan system:

- The total water requirement for the system is always less than the stipulated water rights.
- The total diverted water was always less than the total water requirement, except for the month of July.
- Water diverted during the dry season (January to June) was much lower than the rainy season diversion. The average 10-day flow during the dry season was roughly 50 percent of the crop water requirement while in the rainy season, it was in the order of 80 percent.
- Ten-day releases for 1996 and 1997, representing maximum and minimum flow (figure 11), show that in the dry year of 1996, dry season crops could not be planted due to inadequacy of water.

As opposed to the Taoyuan release, the diverted water in Kaoshiung presents an entirely different picture. Both the maximum and average releases during the dry season is higher than the total water requirement and water rights. Only minimum flow is within the stipulated water requirement. Even the minimum water releases during 1997 and 1998 were able to meet more or less the required total water requirement.

Figure 11. Distribution Pattern of Water Supply, Taoyuan Irrigation Association, Taiwan.



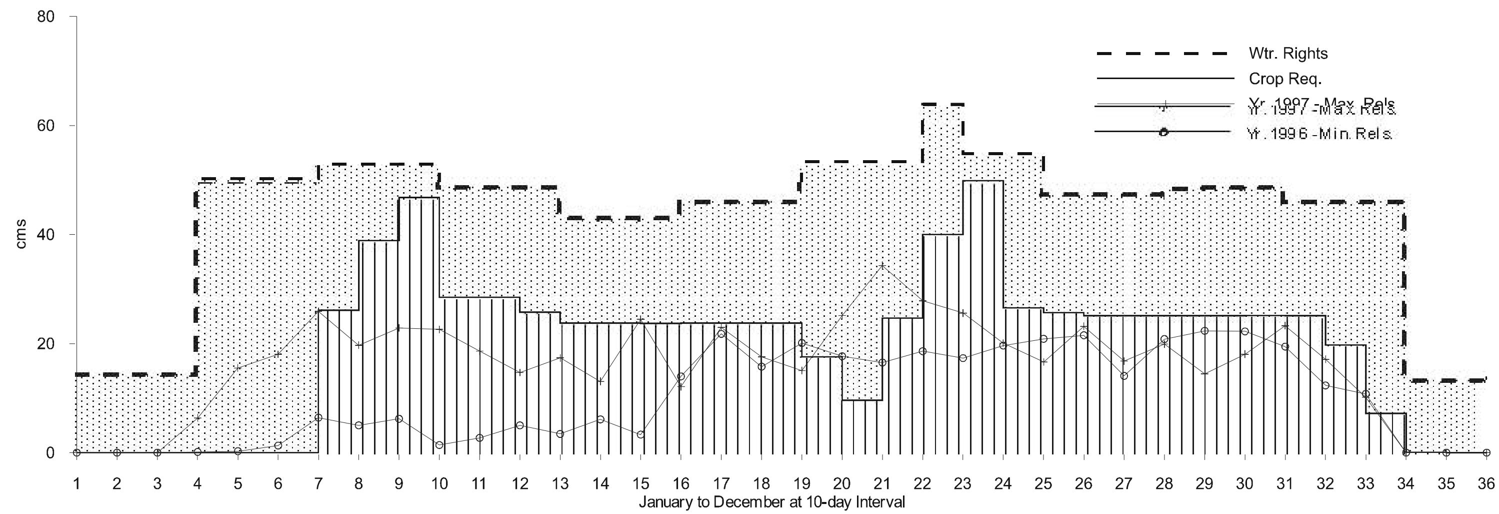
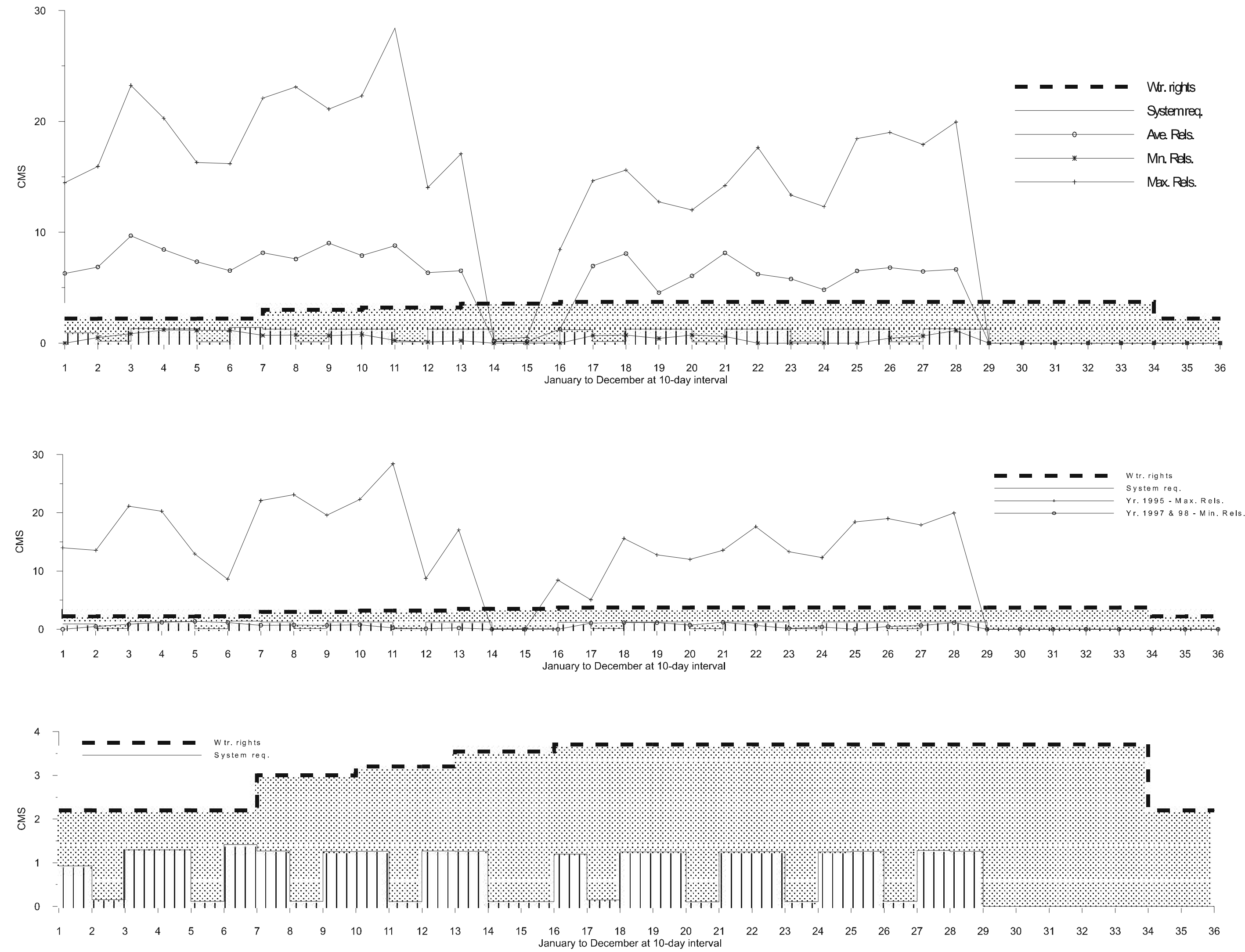


Figure 12. Distribution Pattern of Water Supply, Kaohsiung Irrigation Assiciation, Taiwan.

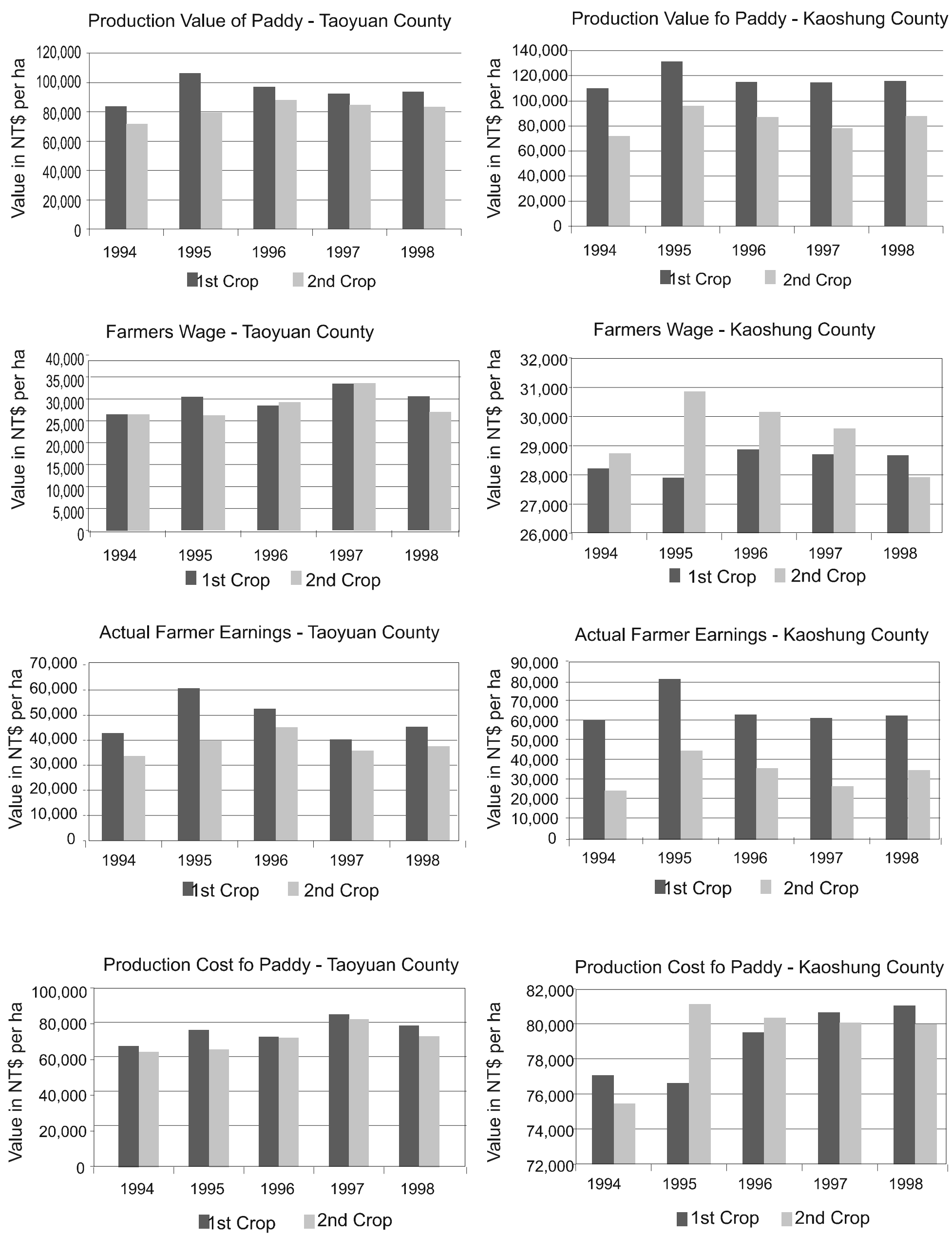


Trends in Production, Production Cost and Farmer's Earnings

Figure 13 indicates production value, production costs and actual farmer's earnings for 1994-1998 for the two counties, Taoyuan and Kaoshiung. As far as production value is concerned, there is no significant trend during 1994-98 in the two counties. In Taoyuan, the production value was nearly 80,000 yuan/ha/crop while it was nearly 110,000 yuan/ha/first crop and 80,000 yuan/ha/second crop in Kaoshiung. Production costs for both counties were more or less the same at 80,000 yuan/ha/crop, except in 1994 and 1995 for Kaoshiung county which were less. Farmer's income in Taoyuan county for each crop stood at roughly 40,000 yuan/ha while it was 60,000 yuan/ha for the first crop and 30,000 yuan/ha for the second crop in Kaoshiung county.

Water delivery through a field canal

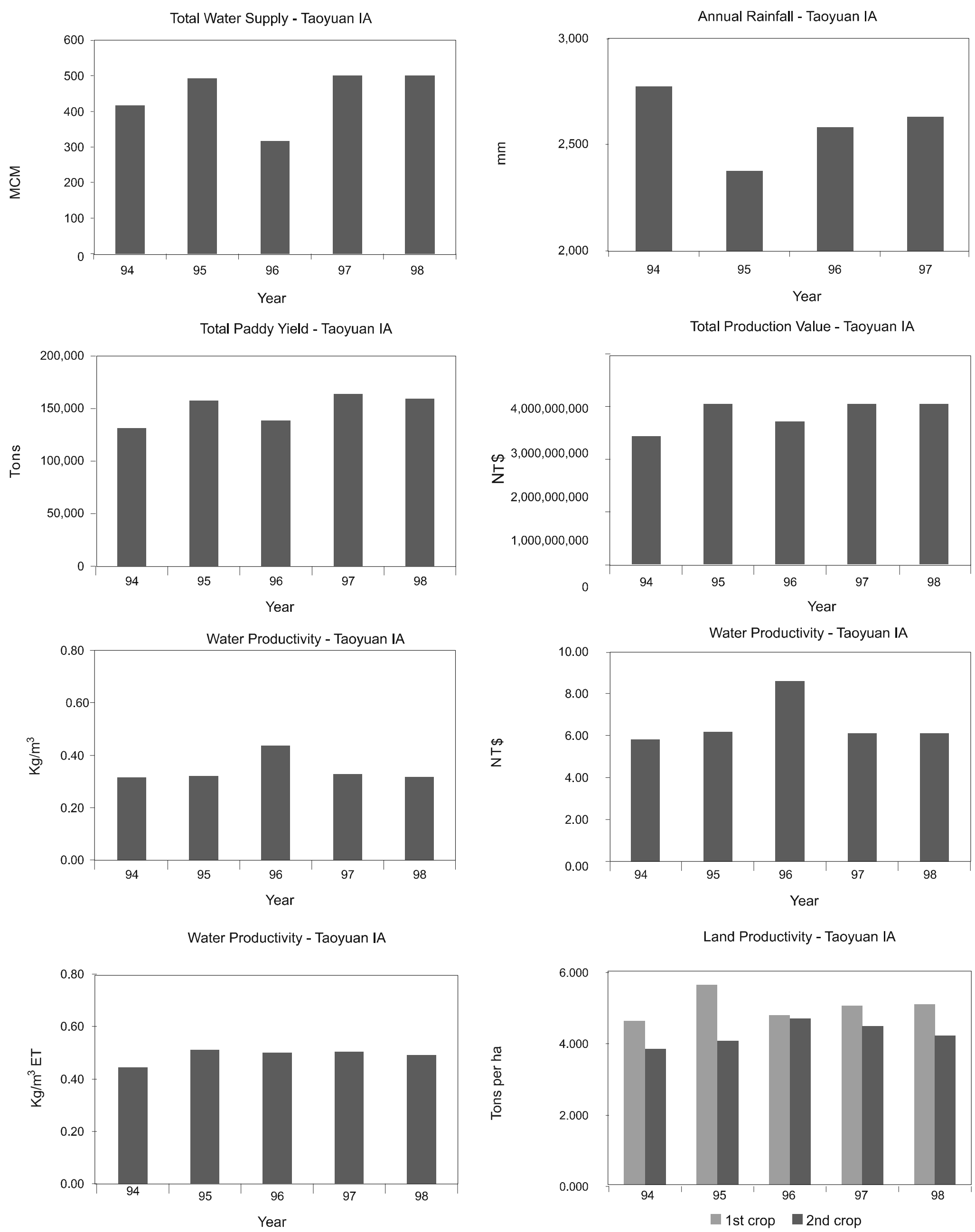
Figure 13. Production Value and Cost and Actual Farmer Earnings for 1994-1998, Taoyuan and Kaohsiung Irrigation Associations, Taiwan.



Land and Water Productivity

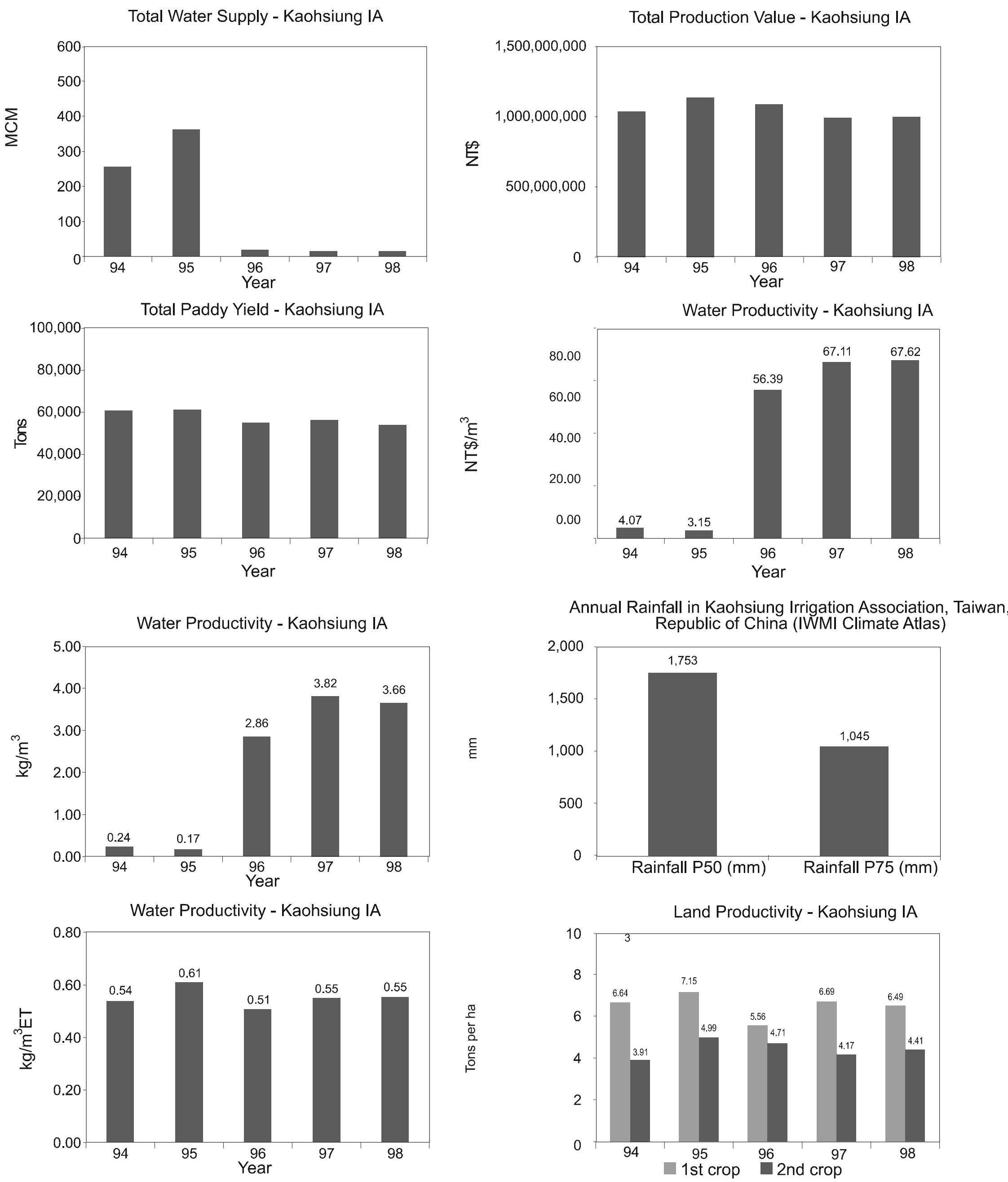
For the 5-year period (1994-1998) land productivity and water productivity were worked out and are presented in figures 14 and 15, respectively, for Taoyuan and Kaoshiung. The water productivity has been worked out with respect to both diverted and consumed water. As seen, the land productivity for Taoyuan for the two seasons remains more or less the same at about 4.25 t/ha with the first season yield always being slightly higher than the second (rainy) season. On the other hand, for Kaoshiung, the dry season land productivity is much higher at about 6.5 t/ha compared to the wet season productivity at about 4 t/ha. On the whole, land productivity at Kaoshiung is higher than at Taoyuan.

Figure 14. Water and Land Productivity, Taoyuan Irrigation Association, Taiwan, 1994-1998.



Year	Total Water Supply (MCM)	Total Rainfall (mm)	Total Yield (tons)	Total Value of Production (NT$)	Water Productivity (NT$)	Water Productivity (kg/m3)	Water Productivity (kg/m3 ET)	Total Irrigated Area (ha)
94	418	2,771	131,317	2,434,724,000.00	5.83	0.31	0.44	31,400
95	494	2,375	157,666	3,047,070,000.00	6.17	0.32	0.51	32,875
96	317	2,579	138,658	2,719,780,000.00	8.57	0.44	0.50	29,532
97	501	2,626	163,584	3,058,644,000.00	6.11	0.33	0.50	34,607
98	501		159,511	3,057,747,000.00	6.11	0.32	0.49	34,430

Figure 15. Water and Land Productivity, Kaohsiung Irrigation Association, Taiwan, 1994-98.



Year	Total Water Supply (MCM)	Total Rainfall P50 (mm)	Total Yield (tons)	Total Value of Production (NT$)	Water Productivity (NT$/m3)	Water Productivity (kg/m3)	Water Productivity (kg/m3 ET)	Total Irrigated Area (ha)
94	256	1,753	60,933	1,039,527,000	4.07	0.24	0.54	11,068
95	361	1,753	61,044	1,137,564,000	3.15	0.17	0.61	9,794
96	19	1,753	55,022	1,086,423,000	56.39	2.86	0.51	10,626
97	15	1,753	56,438	992,360,000	67.11	3.82	0.55	10,036
98	15	1,753	54,127	999,964,000	67.62	3.66	0.55	9,571

The water productivity with respect to consumed water (per m^3 of ET) is about 0.5 for Taoyuan and about 0.55 for Kaoshiung, not much different from that of Taoyuan. On the other hand, the water productivity with respect to diverted water is very different for Taoyuan and Kaoshiung. For Taoyuan, it is more or less constant at 0.33 kg/m^3 except for 1996 which is a dry year. The water productivity for Kaoshiung vary widely from 0.17 to 3.82 kg/m^3. This is mainly because of the varying quantitues of diversion effected in these years (figure 15). These water productivity figures indicate that there is a large opportunity to hike up these values through better water management.

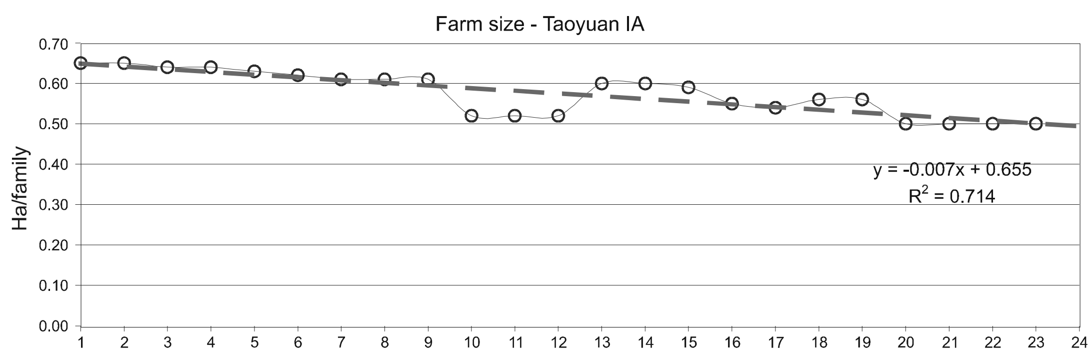
Regression Analysis

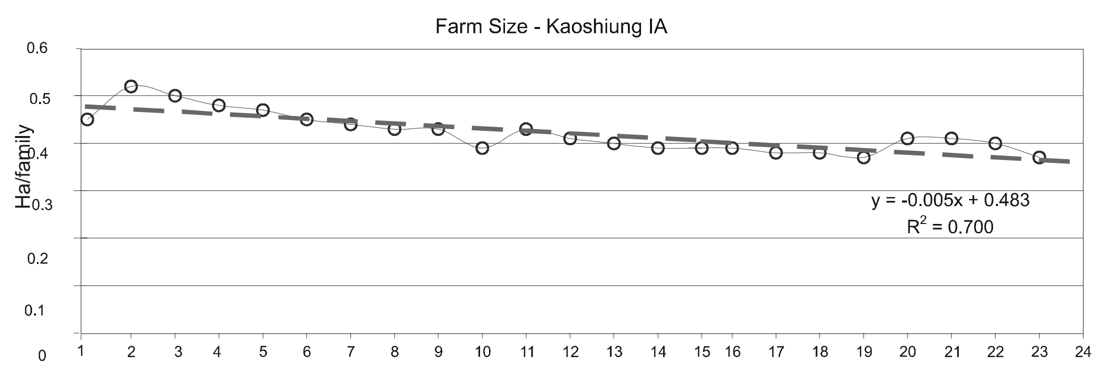
A multiple regression analysis was carried out with land productivity as dependent variable and diverted water, conveyance canal density, distribution canal density, drainage canal density, cost of cultivation. The regression analysis results are summarized in Annex A. The results indicate that while in Taoyuan both water use per hectare and drainage density (m/ha) have an impact on land productivity, in Kaoshiung none of these factors have an impact.

Farm Size Variation

Figure 16 shows the farm size variation in the two systems. In both systems, the farm sizes declined over the years. The rate of decline in Taoyuan is higher than that in Kaoshiung.

Figure 16. Farm size, Taoyuan and Kaohsiung Irrigation Associations, Taiwan, from 1972-1995.



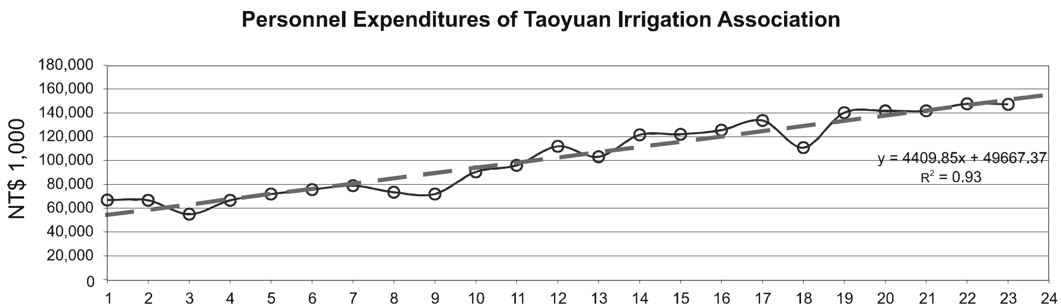


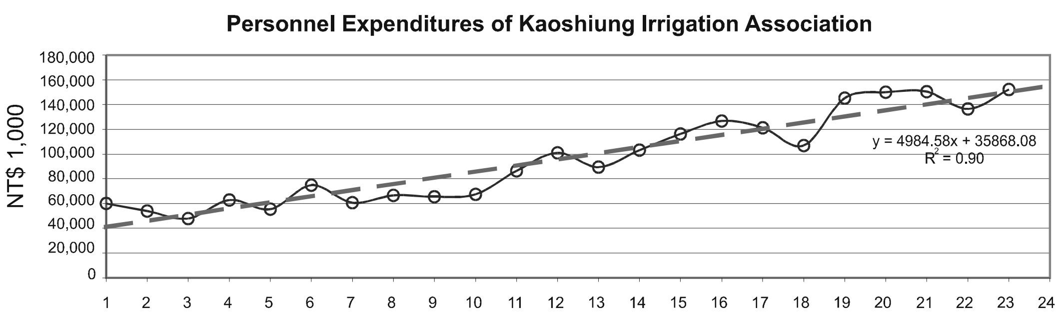
(The dashed line is the linear regression line.)

Annual Personnel Expenditure

The annual personnel expenditure for the two systems as a function of time is shown in figure 17. In both the systems, they are in the increase; however personnel expenditure appears to be very high in the overall expenditure of the two systems. In order to reduce personnel expenditure, the management is attempting to introduce automation to reduce the number of personnel.

Figure 17. Annual Personnel Expenditures, Taoyuan and Kaohsiung Irrigation Associations, Taiwan, from 1972-1995.





Water Quality Parameters

Urbanization and industrialization of the country have resulted in the pollution of river and irrigation water that has became a serious problem since the 1960s. The irrigation associations and COA have been monitoring the water quality at a variety of locations throughout the irrigation systems since 1975. pH, temperature, and electrical conductivity (EC) of irrigation water have been periodically checked, and when these values exceed the criteria for irrigation water quality standard, a number of other water quality parameters such as SAR, copper, chromium, lead, nickel, zinc, and other parameters are analyzed from water samples.

Table 1 shows the irrigation area, number of industries, and amount of effluent from the industries in the Taoyuan and Kaoshiung irrigation systems in 1999. It is noted that although there are fewer number of industries in the Taoyuan area than in the Kaoshiung area, the total amount of effluent is much more in the Taoyuan area. This is because half of the industries in the Kaoshiung area are livestock (300), while the main industries in the Taoyuan area are heavy industries and the textile industry. In fact, the irrigated area affected by poor water quality in Taoyuan is much higher than that in Kaoshiung (table 2). Tables 1 and 2 reveal that the pollution problem in Kaoshiung appears to be not as serious as in Taoyuan.

Table 1. Irrigation and Industries in Taoyan and Kaoshiung irrigation areas in 1999.

	Irrigation area (ha)	Branch number	Delivery capacity (CMS)	Number of industries	Industrial effluent (ton/day)
Taoyuan	25,983	64	61.9	184	176,218
Kaoshiung	13,659	501	95.0	541	47,040

Source: COA, 2000

Table 2. Irrigation Area Affected by Industrial Effluent in Taoyuan and Kaoshiung irrigation areas in 1999.

	Season	Irrigation area	Irrigation supply (10^6 m^3)	Amount of water of failed quality standard (10^6 m^3)	Percent failed	Affected area (ha)
Taoyan	1st season	20,130	24,996	2,007	8.0	3,576
	2nd season	20,080	22,468	2,001	8.9	3,465
	other	-	-	-	-	-
	Total	40,210	47,464	4,008	8.4	7,041
Kaoshiung	1st season	4,091	27,122	260	1.0	1,413
	2nd season	4,083	27,286	87	0.3	1,811
	Other	298	-	117	-	-
	Total	8,472	54,408	464	0.9	3,224

Source: COA, 2000

A plot of pH and EC along with their standards as a function of period of measurement (July1992-July1999) is shown in figure 18 for Taoyuan. For Kaoshiung, they are shown as monthly averages in figure 19.

For Taoyuan, one can see that the parameters are on the increase with time of measurement and are well above standards. Pollution appears to be a serious problem in the irrigation service area. On the other hand, pH is within limit whereas EC is slightly higher than standards in Kaoshiung. Figure 20 shows the other parameters measured during 1998 and 1999 in the Box and Whisper plot in Taoyuan. The figure shows that water quality parameters vary in a wide range, and many samples exceeded the standards for irrigation use.

Systematic monitoring of water quality that has been carried out in Taiwan certainly help to understand the degree of pollution entering irrigation water. However, due to the lack of manpower in the environmental authorities for putting regulatory rules in place and enforcing it, it would take a long time to improve the water quality as COA is willing and wishes.

Figure 18. pH and Electrical Conductivity Variation in Taoyuan Irrigation Association.

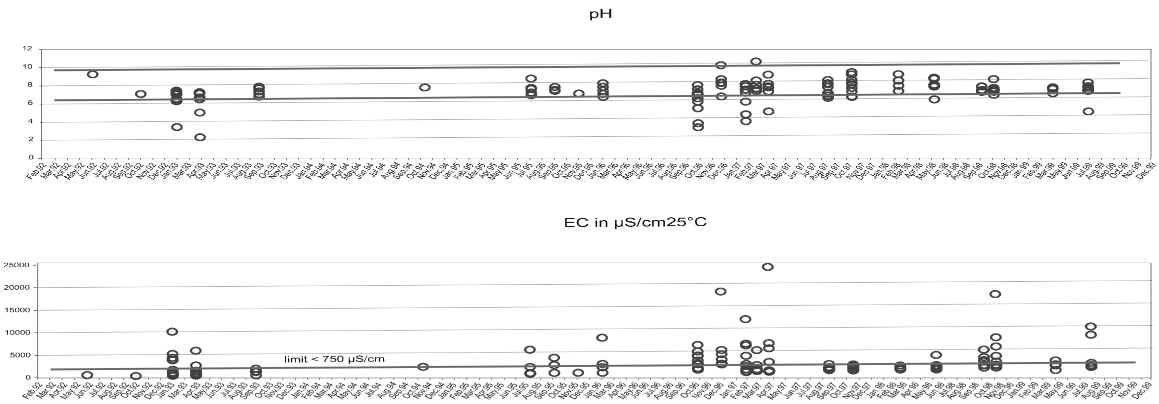


Figure 19. pH and Electrical Conductivity Variation in Kaohsiung Irrigation Association.

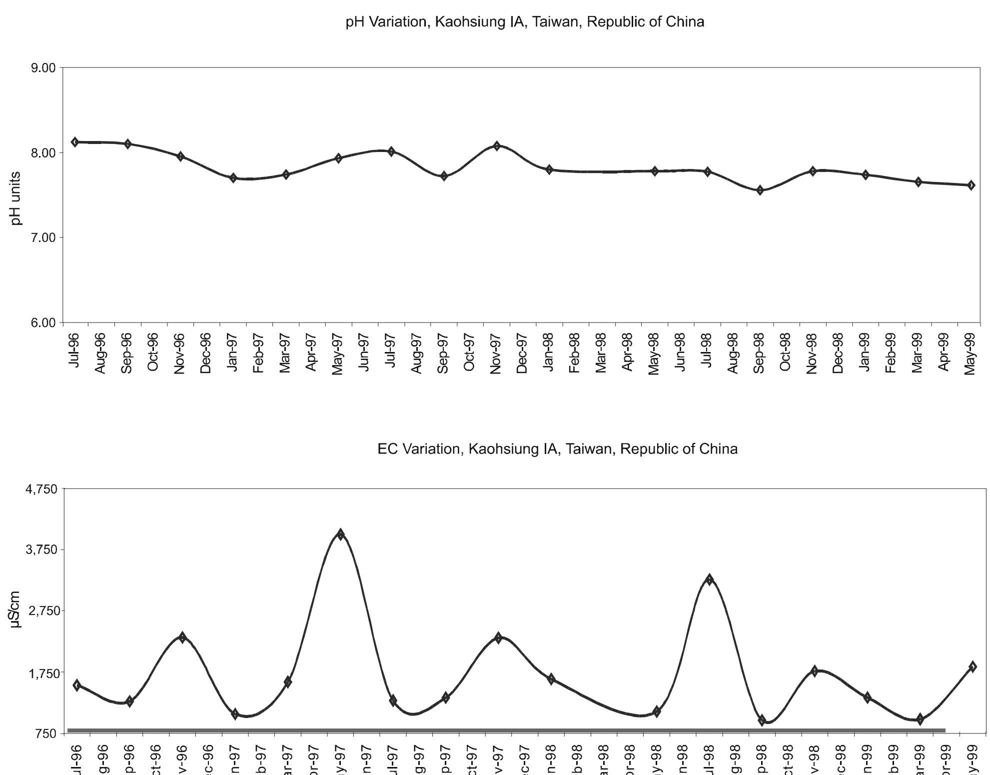
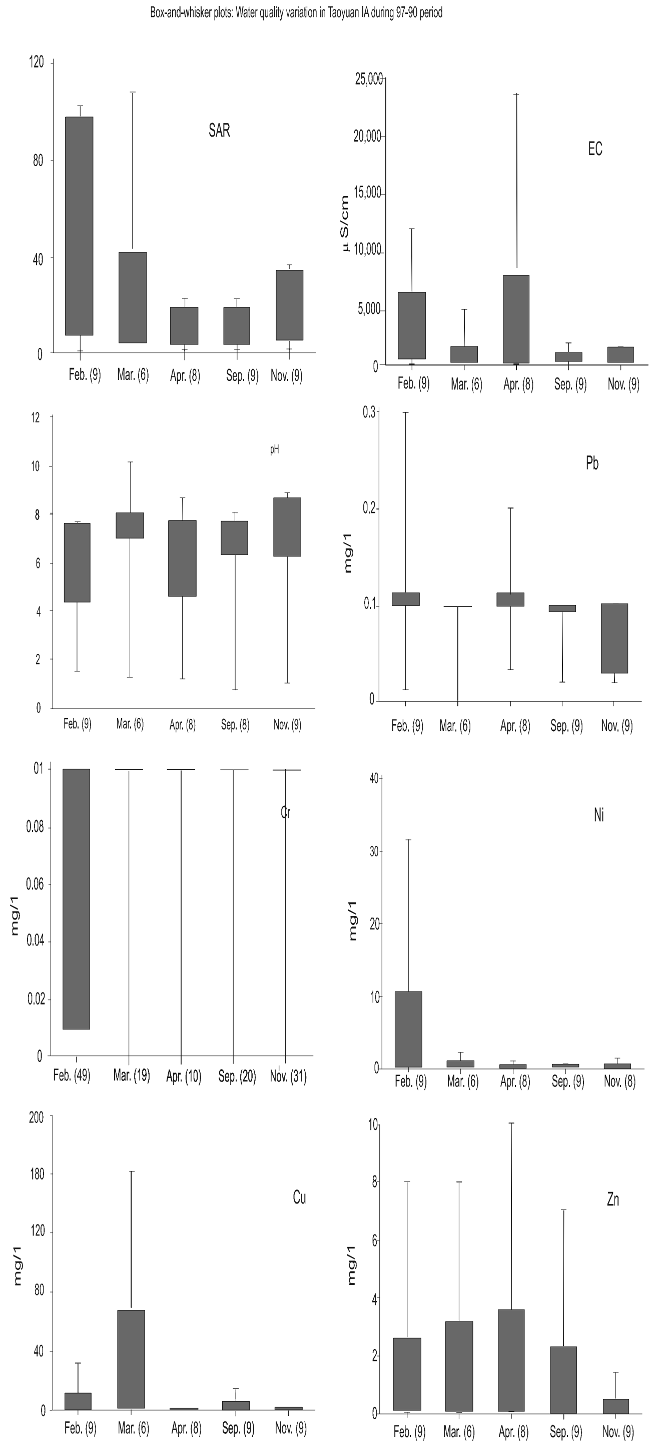


Figure 20.   Irrigation Water Quality Variation in Taoyuan irrigation system.



Annex A1. Regresseion Analysis Output, Taoyuan Irrigation Association, Taiwan

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.969
R Square	0.938
Adjusted R Square	0.885
Standard Error	0.264
Observations	14

ANOVA

	df	SS	MS	F	Significance F
Regression	6	7.389	1.231	17.652	0.001
Residual	7	0.488	0.070		
Total	13	7.877			

	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	3.2564	0.0000	65535.00		3.2564	3.2564
Water use per ha (m3)	0.0004	0.0000	8.41	0.0001	0.0003	0.0005
Canal density - conveyance (m/ha)	-0.0342	0.0250	-1.37	0.2139	-0.0933	0.0249
Canal density - distribution (m/ha)	-0.0306	0.0302	-1.01	0.3460	-0.1021	0.0410
Canal density - drainage (m/ha)	-0.0054	0.0000	65535.00		-0.0054	-0.0054
Operational cost (NT$/m3)	0.2470	0.0956	2.58	0.0363	0.0209	0.4732
Expenditure of Unit Irr. Area (NT$/ha)	0.0000	0.0000	-0.17	0.8701	0.0000	0.0000

RESIDUAL OUTPUT   *PROBABILITY OUTPUT*

Observation	Predicted yield per ha	Residuals	Standard residuals	Percentile	Yield per ha
1	3.407	0.133	0.688	3.571	3.36
2	3.667	-0.307	-1.583	10.714	3.50
3	3.881	0.114	0.587	17.857	3.52
4	3.464	0.040	0.204	25.000	3.54
5	3.744	0.001	0.004	32.143	3.75
6	3.814	0.175	0.904	39.286	3.79
7	3.766	0.061	0.313	46.429	3.83
8	3.872	-0.042	-0.217	53.571	3.83
9	3.997	-0.478	-2.468	60.714	3.94
10	3.976	-0.040	-0.204	67.857	3.99
11	3.838	0.306	1.579	75.000	4.00
12	3.791	0.001	0.003	82.143	4.14
13	6.475	0.042	0.216	89.286	4.50
14	4.509	-0.005	-0.027	96.429	6.52

Annex A2. Regresseion Analysis Output, Kaohsiung Irrigation Association, Taiwan

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.840
R Square	0.706
Adjusted R Square	0.453
Standard Error	0.306
Observations	14

ANOVA

	df	SS	MS	F	Significance F
Regression	6	1.573	0.262	2.797	0.102
Residual	7	0.656	0.094		
Total	13	2.229			

	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0.5936	2.8952	0.2050	0.8434	-6.2524	7.4395
Water use per ha (m3)	0.0000	0.0000	1.6614	0.1406	0.0000	0.0001
Canal density - conveyance (m/ha)	0.0717	0.0614	1.1678	0.2811	-0.0734	0.2168
Canal density - distribution (m/ha)	0.0101	0.0081	1.2440	0.2535	-0.0091	0.0293
Canal density - drainage (m/ha)	-0.0185	0.0136	-1.3524	0.2183	-0.0507	0.0138
Operational cost (NT$/m3)	-0.1180	0.2882	-0.4096	0.6943	-0.7995	0.5634
Expenditure of Unit Irr. Area (NT$/ha)	0.0000	0.0000	1.0812	0.3154	0.0000	0.0000

RESIDUAL OUTPUT *PROBABILITY OUTPUT*

Observation	Predicted yield per ha	Residuals	Standard residuals	Percentile ha	Yield per
1	4.710	-0.007	-0.031	3.571	4.07
2	4.589	0.132	0.589	10.714	4.23
3	4.526	0.220	0.978	17.857	4.39
4	4.699	-0.310	-1.381	25.000	4.55
5	4.446	0.240	1.066	32.143	4.57
6	4.779	-0.058	-0.259	39.286	4.69
7	4.869	-0.300	-1.336	46.429	4.70
8	4.559	-0.334	-1.489	53.571	4.72
9	4.659	-0.107	-0.475	60.714	4.72
10	4.135	-0.061	-0.272	67.857	4.75
11	4.618	0.443	1.974	75.000	4.96
12	4.993	-0.038	-0.168	82.143	5.06
13	5.434	0.121	0.536	89.286	5.46
14	5.397	0.060	0.268	96.429	5.56

Taoyuan Irrigation Association

Year	Serial No	Yield per ha	Water use per ha (m3)	Canal density-conveyance (m/ha)	Canal density-distribution (m/ha)	Canal density-drainage (m/ha)	Operational cost (NT$/m3)	Expenditure of Unit Irr. Area (NT$/ha)
1981	1	3.54	9534	18.7	75.52	67.83	0.422	7484
1982	2	3.36	10138	18.7	75.52	67.83	0.62	11804
1983	3	3.995	10909	18.93	76.44	67.83	0.532	10825
1984	4	3.504	9728	19.36	77.68	67.83	0.747	13644
1985	5	3.745	9315	8.04	78.12	67.83	0.959	14832
1986	6	3.989	10817	19.81	79.49	67.83	0.901	18333
1987	7	3.827	10635	20.1	80.62	67.83	1.155	22803
1988	8	3.83	11220	20.56	82.49	67.83	1.041	21412
1989	9	3.519	11576	20.76	83.29	67.83	1.171	24235
1990	10	3.936	11625	20.96	84.1	67.83	1.139	22953
1991	11	4.144	11118	21.09	84.59	67.83	1.393	28859
1992	12	3.792	11167	21.15	84.83	67.83	1.382	163425
1993	13	6.517	18639	21.15	84.85	67.83	1.372	25866
1994	14	4.504	10707	19.8	79.43	67.83	3.942	68635

Kaohsiung Irrigation Association

Year	Serial No	Yield per ha	Water use per ha (m3)	Canal density-conveyance (m/ha)	Canal density-distribution (m/ha)	Canal density-drainage (m/ha)	Operational cost (NT$/m3)	Expenditure of Unit Irr. Area (NT$/ha)
1981	1	4.703	22594	46.79	43.7	29.32	0.611	13929
1982	2	4.721	18924	48.04	47.83	32.95	1.095	21629
1983	3	4.746	19815	46.42	46.21	31.83	0.921	18771
1984	4	4.389	21123	47.47	50.25	31.89	0.897	19953
1985	5	4.686	20761	44.35	52.48	33.97	0.889	20069
1986	6	4.721	21287	48.79	52.63	34.07	1.02	24061
1987	7	4.569	24102	48.23	50.41	31.93	1.007	23655
1988	8	4.225	24632	43.73	69.82	42.22	1.198	26987
1989	9	4.552	29109	46.6	39.94	42.22	1.016	25005
1990	10	4.074	27045	49.46	10.05	52.04	3.507	80661
1991	11	5.061	25699	46.17	61.77	48.31	1.341	48766
1992	12	4.955	25828	46.84	62.66	49.01	2.207	230433
1993	13	5.555	32995	50.42	67.35	36	1.638	37044
1994	14	5.457	32479	50.42	2.2	1.26	1.638	37044

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