# Water Productivity at Different Geographic Scales in Zhanghe Irrigation District, China

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## Abstract

*In the context of the increasing cereal demand due to population growth, improvement of water productivity in irrigation systems is of paramount importance. The collection of necessary information to assess the various uses of water in an irrigation system may require a lot of field investigations. The cost increases exponentially for large and especially complex systems like the Zhanghe Irrigation District in Hubei Province, China.*

*In this paper, estimations of rice yield and of seasonal evapotranspiration of rice areas were made using remote sensing and GIS (Geographic Information Systems) techniques. Ground data was limited, yet sufficient to calculate evapotranspiration by energy-balance, and rice yield by radiation-based remote sensing models. Information derived from remotely sensed data was combined with irrigation inflow measurements at four levels of geographic scale of gross irrigated area, namely a field, a medium sized irrigation unit, a Canal Command and the Zhanghe Irrigation District. A water accounting method was used to transform the data into water productivity information.*

*Using the above mentioned tools, it was proven possible to calculate the water-accounting indicators using remote sensing data in a study area where the availability of ground data was minimal, therefore providing important information to water managers within very limited costs. Also, the water-accounting indicators were studied at various geographic scales, and their scale dependency was indicated.*

## 1. Introduction

The increase in food demand is proportional to population growth. This calls for an increase in food production, and should be mainly addressed to irrigated areas, which are currently producing 40% of total global production (FAO, 2003). With irrigated agriculture being the biggest consumer of fresh water, many countries are currently facing a serious water shortage problem (Seckler et al., 1998). Increasing irrigation efficiencies seems to be a practical way to *"save"* water (Droogers and Kite, 2001). Water saving is becoming a top-priority issue in the management of water in irrigation systems, yet assessment methods of water productivity terms by traditional means might become a very expensive monitoring item, especially for large systems. A low-cost technique covering a wide area is the best solution for such situations.

Remote sensing is a source of reliable, consistently collected data over large areas, usually at high spatial resolution. Its use is emphasized in remote regions, or areas where ground data collection is limited. During the last years, remote sensing has been increasingly developed to assess land (Moran, 1994 and Thiruvengadachari et al., 1995) and, especially, water components of irrigation-system management (Menenti et al., 1995). Initially, evapotranspiration was calculated as the residual of the water balance equations, estimated from reference evapotranspiration, or from field estimations from weather stations (Penman, 1948, Hargreaves and Samani, 1982, Monteith, 1981). In the mid-90s it was addressed by many researchers, proposing methodologies which were solving the energy-balance of thermodynamic fluxes at the surface of the earth by using both remote sensing and ground data (for a Review see Bastiaanssen,

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1998, Menenti, 2000). A number of studies have indicated the contribution of remote sensing and GIS in the biomass assessment (Groten, 1993, Pereira et al., 1994 and Gower et al., 1999). Most of them are using spectral vegetation indices and simple empirical models to estimate the crop production, but with low correlation coefficients (Dalezios et al., 2001). Recent developments on the ecological production model, originally presented by Monteith (1972), permitted Bastiaanssen and Ali (2003) to extract yields of major crops by remote sensing. The reported accuracy of their model is good (80%) for rice, wheat and sugarcane, but much lower for cotton, probably due to the small mixed fields and to the low correlation of plant biomass with cotton fiber. The advantage of estimating ET and yield using remote sensing is to supplement spatially distributed information of critical interest for water managers. The only ground information requirement for processing of such remote sensing information is limited reference meteorological data. In this study, the evapotranspiration was estimated using the Surface Energy Balance Algorithm for Land (Bastiaanssen, 1998), while yield estimations were modeled by the methods found in Bastiaanssen and Ali (2003).

A number of studies have proposed the use of indicators or systems for the characterization of the performance of irrigation systems, as quoted in Molden and Sakthivadivel (1999). Performance can be evaluated for various reasons, such as to improve system operations, to assess the sustainability of a system, and to compare actual results to planned targets. Among them, the water-accounting indicators (Molden, 1997 and Molden and Sakthivadivel, 1999) are used in this study to quantify the water use, and provide useful information to water resources managers and decision makers regarding the existing situation, as well as the planning of actions for improvement. The depleted fraction (Table 1) reveals the scope for further use of water resources, and how sustainable a system is. The process fraction is part of the beneficial utilization of water and is connecting the amount of water used for all beneficial uses with the available water. This indicator is providing a precise image of the system's productivity, since it takes into account the water used for sensitive ecosystems, as well as for human activities. The productivity of water indicators are evaluating the resultant value from the water used. For agricultural areas, they can be expressed as yield per volume of water consumed from the crops.

Table 1 : Definition of the water-accounting indicators (Molden, 1997).

| Water-Accounting Indicator | Equation used |
|---|---|
| Depleted Fraction per unit of gross inflow (%) | $DF_{gross} = \frac{ETs}{Q*} \times 100\ \%$ |
| Process Fraction (rice) per unit of gross inflow (%) | $PF_{Gross(rice)} = \frac{ETs_{Rice}}{Q*} \times 100\ \%$ |
| Productivity of Water for rice per unit of irrigation (kg/m$^3$) | $PW_{irr.(rice)} = \frac{Grain\,Weight_{Rice}}{Q*}$ |
| Productivity of Water for rice per unit of ET (kg/m$^3$) | $PW_{ETs(rice)} = \frac{Grain\,Weight_{Rice}}{ETs_{(Rice)}}$ |
| *Q, the gross inflow. | |

The influence of scale in various phenomena and measured variables is widely accepted (Goodchild and Quattrochi, 1997). Droogers and Kite (2001) found that values of performance indicators in the Gediz basin of western Turkey vary according to the size of the studied area. Wolock and Price (1994) found that the change of geographic scale influences the outcome of a hydrologic model. The term ***"Geographic Scale"*** is used to describe the extent (size) of the study area, and is different from the "Measurement Scale" that describes the amount of detail observed, which coincides with the spatial resolution of satellite imagery (Cao and Lam, 1997).

Table 2 : Water accounting indicators at different scales.

| Scale | $DF_{gross}$ | $PF_{gross(rice)}$ | $PW_{ETs(rice)}$ | $PW_{irr.(rice)}$ | Yield | G. Area | G. Area |
|---|---|---|---|---|---|---|---|
| | (%) | (%) | (kg/m$^3$) | (kg/m3) | (kg/ha) | (ha) | (%) |
| Zhanghe Irrigation District | 88 | 32 | 1.03 | 2.41 | 5,264 | 466,800 | 100 |
| Canal Command* | 106 | 42 | 1.03 | 2.66 | 5,379 | 196,388 | 42 |
| Tuanlin* | 10 | 6 | 0.99 | 0.61 | 6,122 | 309 | 0.0662 |
| Field** | 67 | 67 | 1.19 | 1.64 | 7,427 | 0.76 | 0.0002 |

* The command area is not only the agricultural command area, but comprises all land uses and catchments areas (Loeve et al., 2002).
** Ground data (Dong et al., 2001).

Table 3 : Difference between remote sensing and ground data in Tuanlin site.

| Scale | $DF_{gross}$ | $PF_{gross(rice)}$ | $PW_{ETs(rice)}$ | $PW_{irr.(rice)}$ | Yield |
|---|---|---|---|---|---|
| | (%) | (%) | (kg/m$^3$) | (kg/m3) | (kg/ha) |
| Remote sensing | 10 | 6 | 0.99 | 0.61 | 6,122 |
| Ground data* | 9 | 5 | 1.00 | 0.53 | 6,330 |
| Difference | +1 | +1 | -0.01 | +0.08 | -208 |
| | | | | | |
| Difference (%) | +10 | +16 | -1 | +15 | -3 |

*Source: Dong et al., 2001.

The aim of this paper is to explore the effect of calculating water-accounting indicators at various geographic scales. The specific objectives are to (i) determine the possibility of calculating different water-accounting indicators by remote sensing, especially in a study area where the availability of ground data is limited, and (ii) explain the differences that are highlighted at different geographic scales of observation.

### *1.1. Study Area*

Limited spatial data availability is a reality for the large and complex Zhanghe Irrigation District (ZID). Situated in Hubei Province, Central China, ZID is located north of the Yangtze River (Changjiang). The net irrigated area reported is approximately 160,000 hectares, and is providing a large proportion of Hubei Provinceís rice production. Barker et al., (2001), report that the recent decline in water availability for agricultural purposes has not affected much the production of rice. This is due to a combination of different factors like the introduction of crop variety, water-related infrastructural buildings, rehabilitation of medium and small reservoirs, the introduction of water saving irrigation techniques to the farmers and the use of chemical fertilizers. Even though the system is running under the main operation of the Zhanghe reservoir, there is evidence that thousands of small-sized reservoirs, small basins and pump stations in ZID are partly incorporated into the irrigation system and that, sometimes, they operate independently (Loeve et al., 2001). Also, a characteristic feature of the area is the reuse of drainage water by downstream farmers. This complexity of water related infrastructure leads to great difficulties in quantifying the volumes of water used, leading to uncertainties in assessing the water productivity of the system as a whole. Tuanlin irrigation unit, which is situated in central ZID, has been monitored extensively (Dong et al., 2001) and the information collected is used to process the remote sensing estimations.

## 2. Materials and methods

### *2.1. Materials*

The materials used were: (i) low spatial resolution multitemporal satellite imagery, which included five images of the AVHRR (Advanced Very High Resolution Radiometer) sensor on board the NOAA (National Oceanic and Atmosphere Administration) satellite, which were covering temporally the growing period of rice (May to September, 2000) at a spatial resolution of 1.1 km. (ii) a single date high resolution (30x30m) Landsat 7 ETM+ (Enhanced Thematic Mapper) image, acquired on 10 July 2000, (iii) ground observations of inflow and outflow water from the study area, weather station measurements, as well as rice yield measurements and reports (Dong et al., 2001), and (iv) paper maps displaying main irrigation features of ZID, which were provided by governmental agencies. Multi-temporal AVHRR satellite images were selected based on their cloud cover, as clouds is a major limitation of the remote sensing methods used. Selection of cloud free images was a difficult task because clouds appear frequently during rice growing season in ZID.

### *2.2. Methods*

### *2.2.1 Estimation o f Agricultural Water use*

The actual evapotranspiration (ETa) in the study area was calculated by applying the Surface Energy Balance Algorithm for Land (SEBAL) on the satellite images. SEBAL is a thermodynamically based model, using the partitioning of sensible heat flux and latent heat of vaporization flux as described in Bastiaanssen (1995). The heat fluxes partitioning ratio (or evaporative fraction : Λ) is an output of SEBAL, and was calculated as

$$\Lambda = \frac{\lambda E}{R_{net} - G_0} = \frac{R_{net} - G_0 - H}{R_{net} - G_0} \quad (-)$$

Equation 1

Where, $R_{net}$ is the instantaneous net radiation *($W.m^{-2}$)*, $G_0$ is the instantaneous soil heat flux *($W.m^{-2}$)*, H is the instantaneous sensible heat flux *($W.m^{-2}$)* and $\lambda E$ is the instantaneous latent heat of $\lambda E$ vaporization *($W.m^{-2}$)*. The underlying assumption is that the partitioning ratio is constant over the day, or said differently : the instantaneous partition of $\lambda E$ and $H$ is equal to the average diurnal partitioning ratio. Brutsaert et al., 1992, considered the difference between Λ at the moment of satellite overpass and Λ derived from the daylight hours integrated energy balance as non significant. A recent study questions such assumptions, finding diurnal variations to be large (Farah, 2001). Farah concluded, *"a good relationship between $\Lambda_{midday}$ values (12.00 to 13.00 hrs) and the average day Λ was obtained with $r^2$ of 0.74 at two experimental sites"*.

ETa was calculated based on $\Lambda$, multiplied by the diurnal net radiation at earth surface ($Rn_{day}$), calculated spatially from the surface broadband albedo data (ρ0, Calculated from the Satellite Images) and according to Tuanlin meteorological information to derive the single-way transmissivity of the atmosphere ($\tau_{sw}$).

$$ET_a = \Lambda \times Rn_{day} = \Lambda \times \left[ \left( (1-\rho_0) \times K_{day}^{\downarrow} \right) - 110 \times \tau_{sw} \right] \quad (-)$$

Equation 2

One image of the satellite AVHRR was used per month, and temporally integrated as explained in Chemin and Alexandridis (2004) in order to obtain an estimation of the seasonal ET (ETs) for the whole system. Using this method, the crop coefficient Kc was calculated spatially for each month using ETa derived from satellite images with the SEBAL model. Daily calculated ETo with the Penman-Monteith equation was used as the time component to simulate daily ETa images, which were integrated using GIS techniques to formulate the seasonal evapotranspiration (ETs). The spatial resolution of ETs from AVHRR was originally of 1.1x1.1km, and was subsequently improved to 30x30m, using a simple linear distribution model (Chemin and Alexandridis, 2004). This model redistributed the original value of ETs found in a pixel of 1.1x1.1 km to a higher spatial resolution, using as guide the high spatial detail of the Landsat 7 ETM+ image. The aim of the model was to keep the initial values of ETs unchanged, which was accomplished successfully.

### *2.2.2 Estimation of Rice Yield*

After Bastiaanssen et al., 2001, Bastiaanssen and Ali, (2003) and Laguette et al., (1995, 1997), the Absorbed Photosynthetically Active Radiation (APAR), biomass growth and rice yield were calculated. APAR (Equation 3) is the multiplication of the absorption factor (f), which is a Normalized Difference Vegetation Index (NDVI)-related function (Bastiaanssen and Ali, 2003) with the Photosynthetically Active Radiation (PAR), which depends on the solar incoming radiation chlorophyll electromagnetic spectrum window.

$$APAR = [-0.161+1.257 \times NDVI] \times [0.48 \times K_{24}\downarrow] \quad (W/m^2)$$

Equation 3

Where, $K_{24}$ is the incoming diurnal solar radiation *(W/m²)* and *NDVI* is the Normalized Difference Vegetation Index (-).

As the light-use efficiency is dependent on the stomata aperture of the leaves, a plant water stress index was used. The evaporative fraction data were used to describe this effect, being spatially distributed, as calculated in SEBAL (Equation 4).

$$Biomass^{NOAA}_{daily} = APAR \times [\varepsilon' \times \Lambda] \times 0.0864 \times 10 \quad (kg/ha/day)$$

Equation 4

where, $\varepsilon'$ is the maximum biomass conversion factor for rice (taken as 2.5), $\Lambda$ is the evaporative fraction (SEBAL output) representative of the crop water stress, 0.0864 is the factor for converting from MJ/day to W/m², and 10 is the factor for converting from g/m² to kg/ha.

The biomass growth map was produced at NOAA AVHRR pixel size (1.1x1.1 km) by integrating the data over the period covering the rice-growth season, accepting each satellite image to be representative of a proportional part of the period. Each representative image of biomass growth for a respective number of days was then added to create the accumulated biomass growth during the rice-growing season in ZID.

To improve the spatial distribution of the biomass growth map, the Landsat satellite image (30 x 30 m Spatial Resolution) was used to direct the variation of information within a NOAA AVHRR pixel. The acquisition date of the Landsat image was at the full growth of rice (July 10th, 2000). This date not only fitted well the best variability of rice pixels with other land classes but also the pixel-to-pixel variations of rice crop internally. A spatial model was created to proportionally redistribute the seasonal biomass growth from 1.1x1.1km to 30x30m using the Landsat derived biomass-growth map as a weight. The non-rice areas were masked out using a land cover map derived from the Landsat image, and finally, a Harvest Index value of 0.5 was used for biomass to rice yield conversion, after Bouman (2001). The resolution improvement method was similar to the one used for ETs, (Chemin and Alexandridis, 2004), and was adapted to biomass in Equation 5.

$$RiceYield^{30x30}_{Season} = \left(Biomass^{NOAA}_{Season}\right) \frac{\left(Biomass^{landsat}_{July\ 10}\right)}{\left(\overline{Biomass}^{1.1\ km}_{July\ 10}\right)} \times HI \quad (kg/ha)$$

Equation 5

Where, $RiceYield^{30x30}_{Season}$ is the rice yield at Landsat pixel size for the rice-growing season *(kg/ha)*, $Biomass^{NOAA}_{Season}$ is the biomass growth for the rice-growing season for all AVHRR pixels *(kg/ha)*, $Biomass^{landsat}_{July\ 10}$ is the biomass growth of July 10th, 2000 from Landsat *(kg/ha)* and $\overline{Biomass}^{1.1\ km}_{July\ 10}$ is the averaged Landsat biomass growth for each corresponding AVHRR pixel of 1.1 km *(kg/ha)*. *HI* stands for the Harvesting Index, the mass ratio of harvested grains to the whole plant biomass.

### *2.2.3 Validation and Further Improvements of Remotely Sensed Information*

Since the rice fields in ZID are small and the resulting improved resolution (Equivalent of Landsat 30x30 m) is not capturing field canals, field roads and rice-field bunds, a correction factor was applied to remotely sensed information. An area for field canals (5%), bunds (5%) and bare soil (4%) was estimated from the ground data on the rice fields of Tuanlin site. These areas were multiplied to their average respective land use ET in the Canal Command, and then added together as correction factor. In a similar way, rice yield values were corrected using a factor of 14% corresponding to the non-rice area which is included in the classified as rice pixels.

Validation of the remote sensing estimations (Rice yield, ET) was only possible for rice fields ocated in the Tuanlin area, because of lack of other ground surveys. Remotely sensed area classified as rice had a difference of 22ha (28%) when compared to the reported data from the Tuanlin site, which is acceptable considering the rice-field dimensions. This could be explained by the fact that farmers have the tendency to report smaller cultivated area in order to avoid taxes. The difference between the mean value of ETa estimated with the SEBAL model and ETc estimated with the Penman-Monteith equation was -0.84 mm. This can be attributed to lack of optimum conditions for the cultivation of rice, which is an assumption in the calculation of ETc, and to the fact that SEBAL calculated the conjunctive evaporation from a number of land cover types on a pixel basis. Nevertheless, comparison of the estimations of the two methods using paired t-test has proven that the difference was not significant at the 0.05 level (P=0.057). Similarly, the difference between rice estimated from remote sensing methods and the value gathered from ground survey was 208 kg/ha (3%).

### *2.2.4 Processing of Hydrological Data*

A series of ground measurements were conducted in the study area by Dong et al., 2001, Reference evapotranspiration (ET0) was calculated using the modified Penman-Monteith equation (Allen et al., 1998). The required meteorological data were collected thrice a day in the Tuanlin site station (N30° 52.370′, E112° 10.793′, altitude 100 m). Rainfall data were collected from 23 locations distributed in the irrigation District. Using Thiessen polygons, the volume of rainfall was estimated for the study area. Surface water inflow and outflow crossing the borders of the studied field and the Tuanlin irrigation unit was measured twice per day using a variety of measurement structures, like weirs, pipes and a current meter. Operating times of pump stations, as well as secondary data on water releases were used at the main canal command and the sub-basin levels. Rice yield measurements were conducted at the studied fields by a crop cut of 6m2 and at the Tuanlin irrigation unit by a socio-economic survey. The data collection process is detailed in Dong et al., 2001.

Lack of sufficient information on the extent of the canal commands has led to the implementation of surface hydrology analysis. A digital terrain model (DTM) was used together with a flow-direction map of the area to identify the natural stream network across the gently undulating landscape of ZID. Cross-checking with the existing main drainage system map from local sources resulted in an updated irrigation and drainage map of the main features of the system. This map was corrected using the geometry of the Landsat panchromatic layer (Resolution 15 m). The small size of the fields and the mixed features on the ground rendered interpretation a difficult task and, therefore, only the four main irrigation canals and the main drainage system were delineated successfully. Using this information, the gross main canal command areas were identified (Figure 1).

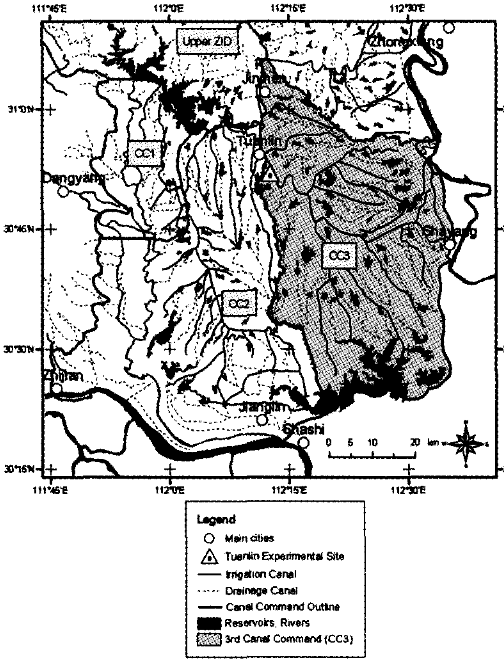

Figure 1 : General features of ZID.

### *2.2.5 Calculation of Water-Accounting Indicators at Various Levels of Scale*

Four study areas were extracted using GIS from the remote sensing data of ETs and rice yields in order to analyze the geographical effects of water productivity indicators. Each one of the smaller unit belongs to the irrigated area of the larger unit. Those four geographic scales of irrigation systems are namely, a field of 0.8 ha in Tuanlin irrigation unit, the whole of Tuanlin irrigation unit (309 ha), the third main canal command (196,388 ha), and the whole of ZID (466,800 ha). All of the study areas used is gross areas including cities, natural vegetation, and other land cover types, except the field area that is a net irrigated area. Additional canal commands 1 and 2 having 28,519 and 160,206 hectares have also been included in the results, but not in the scale analysis because of lack of smaller areas monitored within their command areas. Maps of each irrigation units studied were gathered in GIS either by GPS (Global Positioning System) for the field and the Tuanlin site, or from maps given by governmental agencies in ZID (Canal Commands and the whole of ZID).

In order to evaluate the performance of the system at various scales, the water-accounting procedure was adopted (Table 1). The ratios of water used by water inflow are concentrating on two types of water uses, the depleted fraction and the process fraction of rice. The depleted fraction per unit of gross inflow (DFgross) is the fraction of seasonal gross inflow that is depleted in the season by process and non-process uses (i.e. Rice Evapotranspiration and Non-Rice Evapotranspiration Respectively). The Process Fraction of rice per unit of gross inflow (PFgross (rice)) is the amount of rice seasonal evapotranspiration over the seasonal gross inflow.

When dealing with the amount of water used to grow rice, the productivities of water for rice are assessing the amount of crop production according to the amount of ET. Two types of water used were assessed, irrigation water and evapotranspiration water. The productivity of water for rice per unit of irrigation (PWirr.(rice)) is the rice production in kilograms divided by the seasonal irrigation inflow in cubic meters. The productivity of water for rice per unit of ETs (PWETs (rice)) is the ratio of the rice production in kilograms divided by the rice seasonal evapotranspiration in cubic meters. The water-accounting indicators were considered at the four geographic scales, which were chosen to capture the scale effects of the hydrologic processes of the basin (From Field Level to District Level).

## 3. Results

Results are summarized in Table 2, along with a gross area ratio in the last column, giving an idea of the variation of the area at each change of scale level. Overall in ZID, 32% of rainfall and diverted irrigation water is exclusively used for the actual rice water consumption of which 88% is depleted, giving 12% to outflow. The main trend observed is that the water-accounting indicators (Figure 2 and 3) showed a peak at the field scale and at the main canal command scale, while there was a noticeable reduction at the irrigation unit geographic scale, and a smaller one at ZID scale. The reason for the high values in the field scale level is that farmers are extremely cautious with the water they have to pay for, and are therefore very efficient. The indicators dropped at the irrigation unit scale, due to drainage out of the area, and increased dramatically at the canal command scale due to water reuse. Apparently, a certain size of geographic scale is necessary to depict the impact from the reuse of water in this system. At the ZID scale, there was a slight drop, which illustrates the different growing and farming practices among the canal commands of ZID.

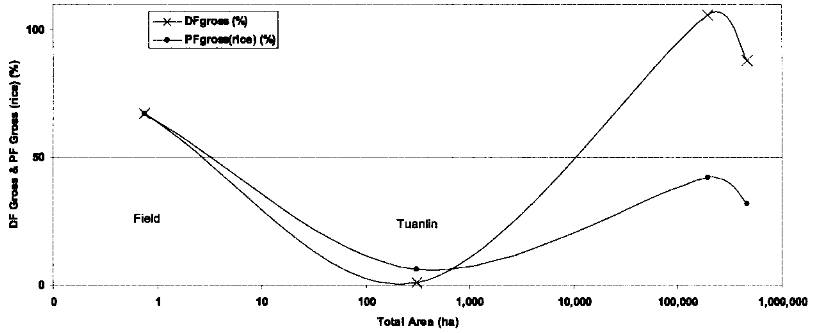

Figure 2 : Scale variations of depleted and process fraction of gross inflow (Field, Tuanlin, Third Canal Command, ZID).

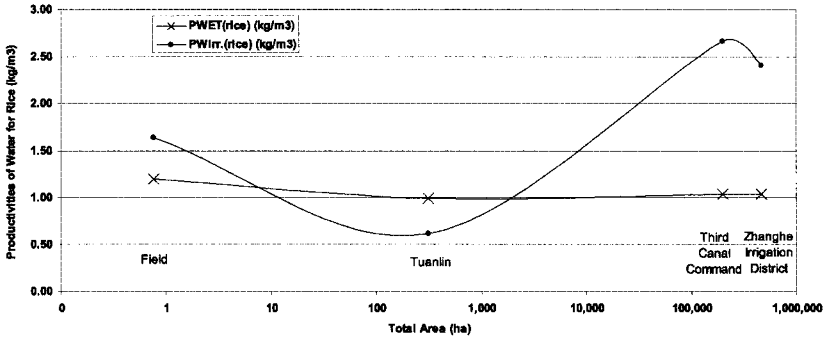

Figure 3 : Scale variations of productivity of water for et and irrigation for rice (Field, Tuanlin)

The water productivity per unit of evapotranspiration (PWETs(rice)) though, was almost constant in every geographic scale, indicating that the patterns of water evapotranspiration and rice production had similarities in the various scales. This is probably due to the similarities in the pattern of water evaporated and rice yield, both estimated with remote sensing techniques. There may be location specific differences in this value, but there is no reason to expect that this indicator is scale- dependent in ZID. Most probably, rice plants are consuming a certain amount of the supplied water to produce a certain amount of grain, which is dependant on the rice variety and independent of the studied geographic scale.

Comparison of water-accounting indicators estimated from remote sensing methods and from ground observations was only possible for Tuanlin site scale level. Results from this comparison (Table 3) were very encouraging, considering the low availability of other ground truth information for better validation of remote sensing methods. The differences may be directly related to the method of estimation. It is likely that water use and yield estimations by remote sensing are not properly mirroring the actual crop conditions, Harvest Indices of crop varieties and specific crop yield curve responses to water stress in the Tuanlin study site. However, no additional cross-checking of the remote sensing yield estimation with ground data from other areas in the irrigation district could be performed in order to provide a proper statistical confirmation for all ZID rice pixels.

## 4. Discussion and conclusions

This study assessed the possibility to supplement important hydrological data to water management organizations. The methodology uses minimal field data, while giving an effort to take the most advantage from satellite remote sensing imagery. The results were validated against limited field measurements and have shown minimum deviation.

Four water-accounting indicators were calculated using primarily remote sensing and GIS techniques. The particularity of this research was to analyze the water-accounting indicators at four geographic scales, while keeping the measurement scale (Pixel Size) constant at a 30x30m pixel size. The results indicate that three indicators were scale dependant, which highlights the importance of scale selection before any conclusions are drawn by decision makers.

Factors influencing the water-accounting indicators at each level of geographic scale are : the extreme water use efficiency at the field level, the outflow of water at the irrigation unit level, the water reuse at the canal command area and ZID levels. Water reuse from downstream users, which is the main hydrologic process that dominates in the study area. This reuse is so efficient, that only small volumes of water are flowing out of the system, which is a warning for upcoming environmental problems.

Future research can be focused on the analysis of the results within the same level of geographic scale, and provide information which could support the operation of the irrigation system. Moreover, spatial analysis of the relation between water consumption and rice production could give more insight to the scale independency of a water-accounting indicator.

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