GIS-based irrigation water management for precision farming of rice

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Abstract: Precision farming aims to manage production inputs over many small management zones rather than on large zones. It is difficult to manage inputs at extremely fine scales, especially in the case of the rice irrigation system. However, site-specific irrigation management can potentially improve the overall water management in comparison to irrigated areas of hundreds of hectares. A critical element of the irrigation scheduling and management is the accurate estimation of irrigation supplies and its proper allocation for the irrigation offtake structures based on the actual planted areas. All irrigation scheduling procedures consist of monitoring indicators that determine the need for irrigation. The final decision depends on the irrigation criterion, strategy and goal. Irrigation scheduling is the decision of when and how much water to apply to a field. The amount of water applied is determined by using a criterion to determine irrigation need and a strategy to prescribe how much water to apply in any situation. The right amount of daily irrigation supply and monitoring at the right time within the discrete irrigation unit is essential to improve the irrigation water management of a scheme. This paper presents the GIS capability to achieve the goal in the view of irrigation strategy and goal with special reference to precision farming of rice. The GIS-based water management model was developed for the scheduling daily irrigation water deliveries and regular monitoring of irrigation delivery performance. The "Scheduling" program computes the right amount of irrigation deliveries based on crop water requirements. The "Monitoring" program gives information on the uniformity of water distribution and the shortfall or excess. The displayed results allow the manager to view maps, tables and graphs in a comprehensible form to ease decision making that where the irrigation amount will be delivered as the season progresses. GIS was used as a useful tool to assist the irrigation water management program in the context of precision farming.

Keywords: irrigation, monitoring, precision, farming, rice, GIS

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批注 [微软用户1]: The first three word belong to EI words.

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1 Introduction

Irrigation management of the scheme has usually been used with the optimum crop production and efficient use of water resources. Precision farming aims to achieve maximum yield with optimum utilization of resources and its proper management. In the rice irrigation system, allocation of the right amount of water to the field is very difficult. Because many factors such as canal system, hydraulic units, rice field condition, field off-takes, inflow, and farmers' attitude affect timely irrigation and its proper distribution in the scheme. Besides, the rice irrigation schemes have large volume of spatially distributed data covering climatological, hydrological, agricultural and administrative information concerning water management. Therefore, it is essential that information from all interacting factors must be incorporated.

Good water management means the applying the precise amount of water at the right time and the right place and its proper performance evaluation. Many computer-aided tools have already been developed with the aim to improve water management of irrigation projects. However, overall irrigation efficiency of

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paddy schemes is less than 50% and lowers in the wet season than in the dry season[1]. The irrigation management should be based on measured field values[2]. A detailed monitoring of irrigation supply by individual irrigation compartment and block should be carried out to evaluate compliance with water allocations[3]. Effective utilization of available water resources for irrigation supplies and impartial water allocation with suitable water management practice are the key factors for increasing rice production[4]. Therefore, a coordinated approach at different levels of the irrigation system is required for improving water management of the rice system.

A GIS is a system of hardware and software used for storage, retrieval, mapping and analysis of spatially referenced data[5]. It creates a link between spatial data and their related descriptive information. This emergence technology has the integrating capability of all spatial and temporal data and information sources to complement practical managerial decisions. The capability of GIS makes it appropriate for decision-making[6]. It is currently being used as an information and decision-making tool through simple or complex operation for the management of spatial information. The numerical-statistical information and its graphical representation in the real world system are needed for the timely irrigation deliveries and monitoring in improving water management of the scheme. GIS user-interface for rice irrigation can provide the appropriate information systems and improve the decision making process through simple or complex operation for the management of spatial information in rice irrigation. This paper presents the strength of GIS user-interface technique to improve the decision-making in the daily operation and management activities of irrigation water allocation for precision farming of rice.

2 Study area

The Tanjong Karang Rice Irrigation Scheme shown in Figure 1 is located on a flat coastal plain in the Northwest of the Selangor state in Malaysia. The total net command area of the scheme is about 13,848 ha. The

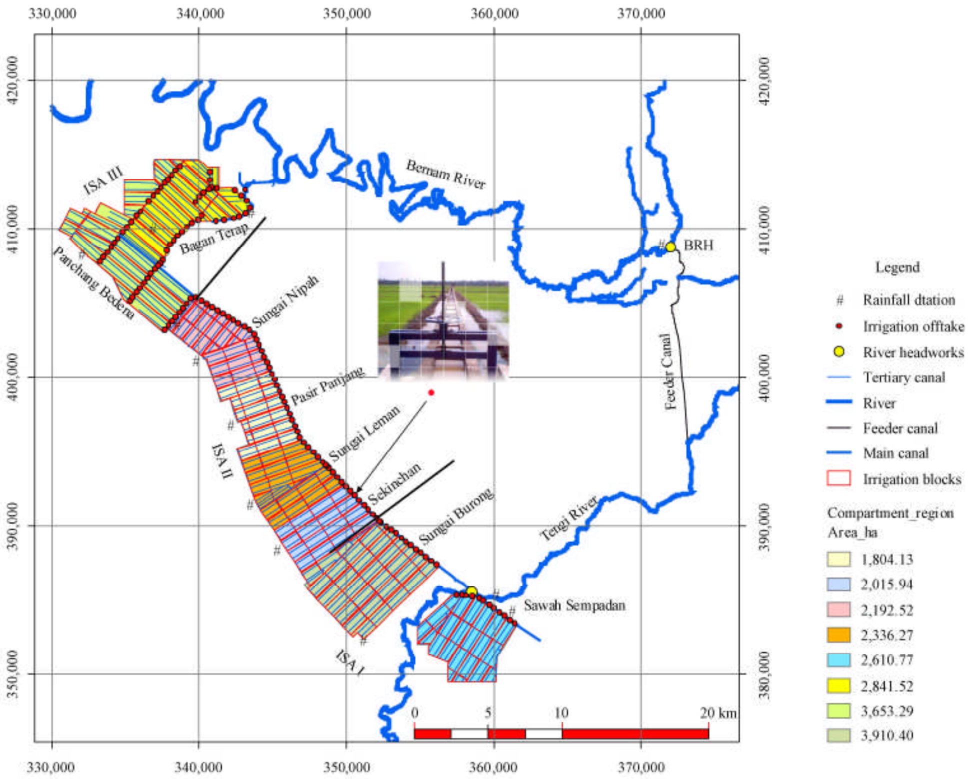

Figure 1 Tanjung Karang rice irrigation scheme

scheme has extended in a Northwest direction over a length of 40 km along the coast with a width of 5 km on average. Rice is grown two times in a year, mainly from August to January (main/wet season) and February to July (off/dry season).

The Bernam River is the only source for the irrigation supplies which is diverted by Bernam River Headwork (BRH) into the feeder canal. Then water is conveyed into Tengi River and thence to the intake point of the main canal at Tengi River Headwork (TRH). The distance from BRH to TRH is about 36 km. The feeder canal from the BRH passes towards the Southeast through the Tanjong Karang swamp and flow into Sg. Tengi, and thence to the Sg. Tengi Headworks. Irrigation water is delivered directly from the main canal to tertiary canals, which are spaced 400 m apart along the main canal. A standard irrigation block has a net command area of about 150-200 ha. Irrigation blocks receive water in their paddy plots direct from two tertiary canals. The annual rice yield is 9.5 ton/ha.

3 Methodology

3.1 Water balance model in a rice basin

A quantitative estimation of the major components of field water balance is essential for improving water delivery performance. Analysis of water balance can give management decisions on how the scheme ought to be operated to ensure better distribution of irrigation water to the service areas. The components of the water balance model for a rice field for a given period are shown in Figure 2.

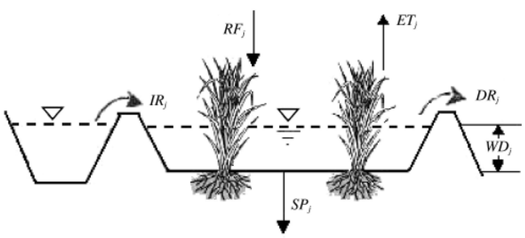

Figure 2 Water balance components of a model in a rice basin

The generalized water balance equation for rice field can be expressed as follows:

$$WD_j = WD_{(j-1)} + IR_j + ER_j - ET_j - SP_j - DR_j \quad (1)$$

Where: WD_j is standing water depth in the field on the j^{th} day, cm; $WD_{(j-1)}$ is standing water depth in the field on the $(j-1)^{th}$ day, cm; IR_j is amount of irrigation water supplied on the j^{th} day, cm; ER_j is rainfall received on the j^{th} day, cm; ET_j is crop evapotranspiration on j^{th} day, cm; SP_j is water lost through deep percolation and seepage on the j^{th} day, cm; DR_j is drainage requirement on the j^{th} day, cm; j is irrigation period, day.

The water balance approach was used for determining the irrigation schedules and the depth of water to be applied. Parameters were available and obtained from routine measurements in the irrigation system. The maximum water depth of 100 mm and minimum water depth of 50 mm at which irrigation is to be given are considered. The daily crop evapotranspiration (*ET*) was determined as the product of Reference Crop Evapotranspiration (ET_0) using the FAO-Penman Monteith method[1] and appropriate crop coefficient values. Values for seepage and percolation (*SP*) were adopted as 2 mm/d[4]. Rainfall occurred on the previous day will add to the water balance equation to the extent that the field is capable of retaining the rainfall based on the initial depth of water for the next day. At the beginning of each irrigation period, the water depth in the paddy field was updated using actual climatic and field data. The components of the water balance equation were computed on a daily basis to find the depth of water at the end of the irrigation period. The depth of water in the field at the end of a subsequent day is estimated using the same water balance equation discussed above. Finally, the depth of irrigation or drainage for the subsequent day was estimated.

3.1.1 Effective Rainfall (*ER*)

Effective rainfall is that portion of rainfall over the command area that potentially could contribute to the water requirements of growing rice in the field. The effective rainfall for the irrigated condition was determined by the drainage model of International Rice Research Institute[7] as follows:

$$ER_j = \left(1 - \frac{DR_j}{RF_j + IR_j}\right) * RF_j \quad (2)$$

Where: RF_j is rainfall during j^{th} day, mm; DR_j is drainage requirement from the paddy field during j^{th} day, mm.

When the field water depth exceeds the maximum standing water depth the excess water will be considered as drainage.

3.1.2 Crop Evapotranspiration (*ET*) and Seepage-Percolation (*SP*)

Determination of irrigation demands relies on estimates of actual evapotranspiration. The crop evapotranspiration is the product of the reference evapotranspiration and crop coefficients which is ($ET_j = ET_0 \times K_c$). The crop coefficient (K_c) values were experimentally determined in[8]. FAO Penman-Monteith method[1] was used to compute daily Reference Crop Evapotranspiration (ET_0).

3.1.3 Crop water demand and recommended irrigation supply

Water demand estimation is the primary considerations for planning and design of the irrigation scheduling of a scheme. For the rice irrigation systems in Malaysia, typical design presaturation and supplementary modules are 2.31 L/s/ha (20 mm/day) and 1.16 L/s/ha (10 mm/day), respectively. The total water requirement for rice production is about 1,000–1,500 mm depending on the variability among rice granaries[4]. The water requirement for pre-saturation is theoretically 150–200 mm but can be increases as for longer duration. A huge amount of water is supplied to inundate fields for presaturation before planting of the crop. The required irrigation water during the normal irrigation period shall be allocated on the basis of the equation (3):

$$GIR_j = \frac{(ET_0)_j \times K_c + SP_j - ER_j}{IE} \tag{3}$$

Where: GIR_j is gross irrigation water requirement, mm/d; $(ET_0)_j$ is reference crop evapotranspiration, mm/d; SP_j is seepage-percolation loss, mm/d; ER_j is effective rainfall, mm/d; K_c iscrop coefficient; *IE* is irrigation efficiency of 60% at tertiary level[5].

If part of the water requirement is met by utilization of rainfall during crop growing period, then the net irrigation requirement on a particular day is determined as[4]:

$$IR_j = WD_j - WD_{(j-1)} + ET_j + SP_j - ER_j \tag{4}$$

3.2 Cumulative Relative Water Supply (*CRWS*)

It is defined as the cumulated value of the ratio of supply to the demand computed over short intervals of time starting from a particular time of the season. It can be expressed as follows:

$$CRWS_j = \sum_{j=1}^{n} \left(\frac{IR_j + ER_j}{ET_j + SP_j} \right) \tag{5}$$

The Relative Water Supply (*RWS*) helps to identify acute access or shortage while the *CRWS* gives the integrated value. It keeps track of water delivery of a sub-system. The *CRWS* can lead itself to identify where the irrigation supply is inadequate or inequitable or both in an irrigation system. It can help to identify the necessary remedial measures to rectify the situation.

3.3 Ponding Water Index (*PWI*)

The index can measure the state of irrigation delivery performance for the successive periods of the irrigation season. Ponding Water Index (*PWI*) indicates shortage or excess of water with respect to the desired water depth in the field during a crop growing period[9]. Well-watered condition for $PWI = 0$ and critical condition for $PWI = -1.0$. An over or under irrigation will be shown when the values of *PWI* will be greater than or less than zero.

$$PWI = \frac{WD_j - Dd_j}{Dd_j} \tag{6}$$

Where: WDj is standing water depth on j-th day; Dd_j is maximum desired water depth on j-th day.

3.4 GIS user-interface development

The methodological workflow of designing GIS user-interface for rice irrigation water management shown in Figure 3 illustrates the components and operation strategies. The MapBasic Programming Language was used for developing the user-interface and MapInfo for visualizing outputs.

3.5 Menu structure of GIS user-interface

On activation, the main menu for “Rice Irrigation” appears directly within the Menu Bar of MapInfo window.

The two modules namely “Scheduling” and “Monitoring” as shown in Figure 4 are available for selection of any of the two modules. A dialog window appears by clicking on this menu item, which activates drop-down menus. The user needs to input the appropriate values and options for viewing the results.

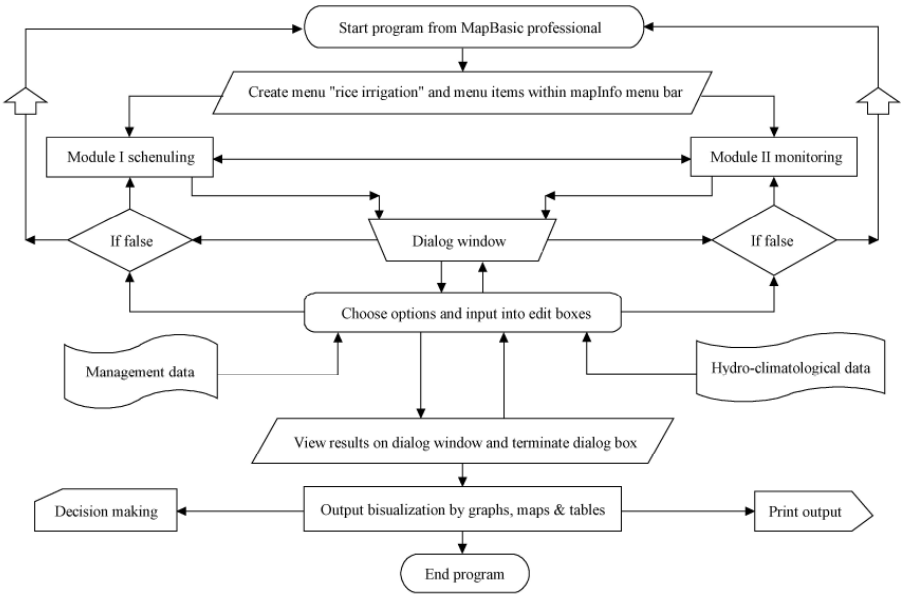

Figure 3 Schematic diagram of the working flow

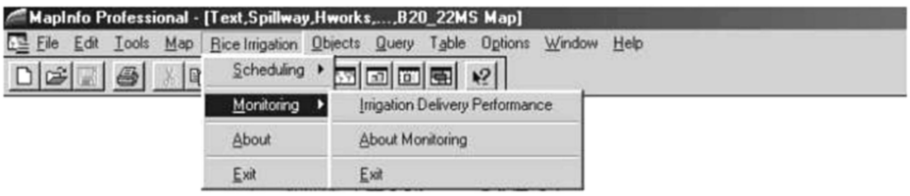

Figure 4 Menu items of a user-interface technique

3.5.1 Scheduling irrigation delivery

A dialog window shown in Figure 5 appears on selecting the menu "Scheduling". Evaporation and expected rainfall are to be entered into the CheckBoxes. Inputting data into the relevant boxes and clicking "OK" button will compute and display the targeted irrigation supplies for the Constant Head Orifices (CHO's) for the selected compartment.

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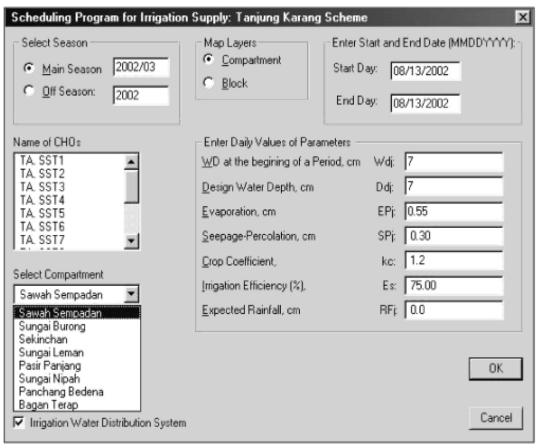

Figure 5 Dialog window for scheduling irrigation supply

Inputting data into the relevant boxes and clicking "OK" button will compute and display the targeted irrigation supplies for the Constant Head Orifices (CHO's) for the selected compartment.

3.5.3 Monitoring daily irrigation water distribution

On selecting this module, a dialog window is activated as shown in Figure 6. Data are entered into the EditBox and options pertaining to the output display selected before clicking "OK". Output for a particular compartment will be computed and displayed in the form of maps, tables and graphs.

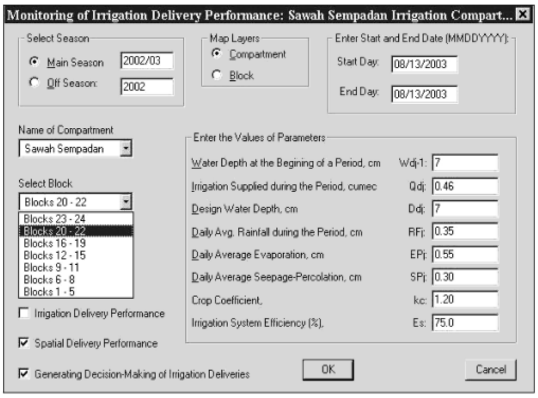

Figure 6 Dialog window for monitoring irrigation system

4 Results and discussion

The system is entirely designed for rice irrigation. The system was applied to an irrigation system in Malaysia, where distribution of water to farmers and water delivery service are inherently poor.

4.1 Recommended irrigation supply

The interactive dialog window computes irrigation deliveries for command areas under each CHO of a selected block/compartment. The recommended daily irrigation supply can be viewed instantly for each hydraulic unit (CHO) of the selected compartment. The thematic bar chart and map together with browse through window for targeted discharges is displayed upon clicking the CheckBox "Irrigation Water Distribution System" in the dialog window shown in Figure 4. The thematic bar chart visualizes irrigation deliveries for each CHO in the Sawah Sempadan compartment together with targeted blocks, canals, CHO and tracks of water distribution from Bernam River Headworks through the feeder canal to the paddy fields as shown in Figure 7. The significance of the thematic map is to visualize how much and where irrigation is to be supplied through the irrigation networks to the field.

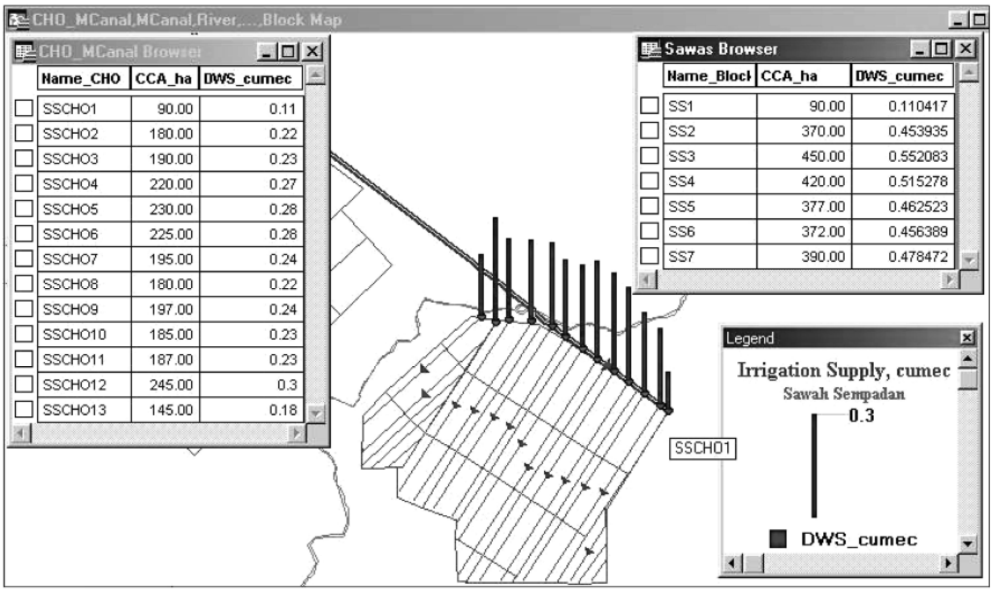

Figure 7 Thematic bar chart showing recommended irrigation supply

4.2 Monitoring irrigation delivery performances

A daily monitoring is essential to characterize the irrigation delivery performance and to improve the water management as the season progresses. The color-coded maps and graphs are displayed instantly when users select the CheckBox(s) "Irrigation Delivery Performances", "Spatial Delivery Performance" and "Generating Decision-Making of Irrigation Deliveries" from the dialog window shown in Figure 6. It views computed results together with detailed information for a given day. The thematic bar chart displayed in Figure 8 represents the spatial variation of *RWS* and different parameters such as Irrigation Requirements (IR_j), Rainfall (RF_j), Effective Rainfall (ER_j), Drainage Requirement (DR_j) and Total Water Depth ($TWD_j = IR_j + ER_j$) for the different blocks. It gives an idea of how much water delivered with respect to the Maximum Desired Water Depth (D_d) in the field. The Browse Window, shown in the Figure 9 build the database on daily irrigation water deliveries.

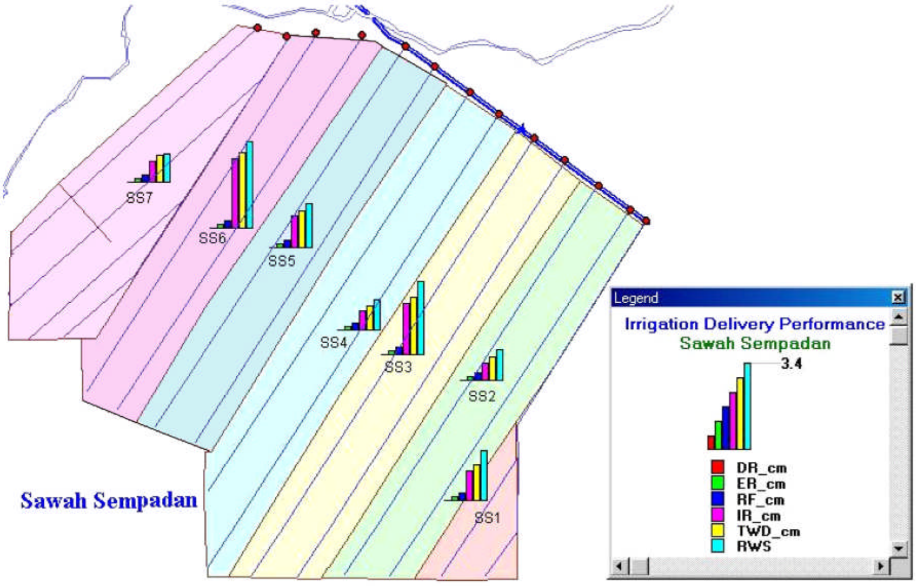

Figure 8 Daily spatial variation of RWS, IR, RF, ER, DR and TWD

MapInfo Professional - [BlockS Browser]

File Edit Tools Browse Rice Irrigation Objects Query Table Options Window Help

Name_Block	CCA_ha	ET_cm	IR_cm	RF_cm	ER_cm	SP_cm	RWS	DR_cm	TWD_cm
SS1	90.00	0.41	1.20	0.35	0.21	0.30	1.99	0.00	1.41
SS2	370.00	0.47	0.72	0.35	0.21	0.30	1.21	0.00	0.93
SS3	450.00	0.49	2.05	0.35	0.21	0.30	2.86	0.00	2.26
SS4	420.00	0.50	0.79	0.35	0.21	0.30	1.25	0.00	1.00
SS5	377.00	0.54	1.27	0.35	0.21	0.30	1.76	0.00	1.48
SS6	372.00	0.57	2.75	0.35	0.21	0.30	3.40	0.00	2.96
SS7	390.00	0.65	0.86	0.35	0.21	0.30	1.13	0.00	1.07

Figure 9 Daily spatial variation of RWS, IR, RF, ER, DR and TWD

4.2.1 Cumulative Relative Water Supply (*CRWS*)

CRWS is the cumulative value of the ratio of supply to demand computed over daily time periods. This performance monitoring feature can keep track of the on-going water delivery program by identifying whether the supply is adequate, reliable and equitable and, if not, to apply necessary adjustments and management interventions to rectify the situation. This is shown in Figure 10. In adopting the CRWS curves, it is possible to select an operational range of upper and lower bound *RWS* values. It has to be maintained either at *RWS* = 1.0 or at a slightly higher. If there is an increasing slope of the *CRWS* curve with *CRWS* being closer to the upper bound it means that irrigation supply can be slightly curtailed in the next period. On the other hand, if the slope is downwards and is reaching the lower bound, supply has to be increased to maintain it within the desired boundaries.

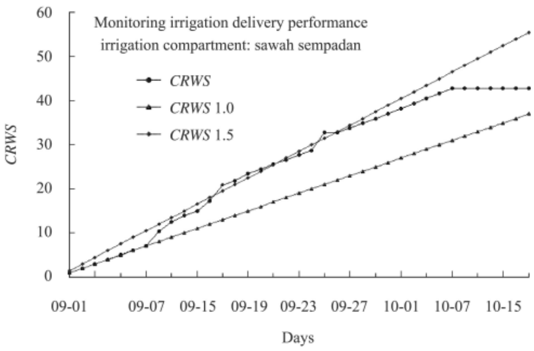

Figure 10 CRWS representing irrigation delivery performance

4.2.2 Ponding Water Index (*PWI*)

A weekly analysis of *PWI* shown in Figure 11 was plotted for the main and off seasons of 2002/03. The graph indicates that irrigation delivery performance obtained for the main season was poorer than for the off-season. Irrigation deliveries showed oversupply due to more rainfall in main season. It is evidence that utilization of rainfall is essential for efficient water management. Besides, it is observed in the graph that the undersupply was identified for the 4th, 7th, 13th and 15th weeks due to the shortage of water resources. The extreme values on 17th to 20th weeks were obtained due to continuing irrigation deliveries at the end of the off-season when drainage was required. The days on the x-axis at zero values show the well-watered condition. Irrigation manager can easily decide what needs to be done for the next period to maintain the desired ponding water depth in their service areas. Irrigation deliveries will be considered as over supply or under supply if *PWI* is more or less than zero, respectively. It is to be clear that much of water drained out from the scheme. Irrigation manager can simply identify and quantify the performance of irrigation deliveries for a given week and what decision has to be made for the next period.

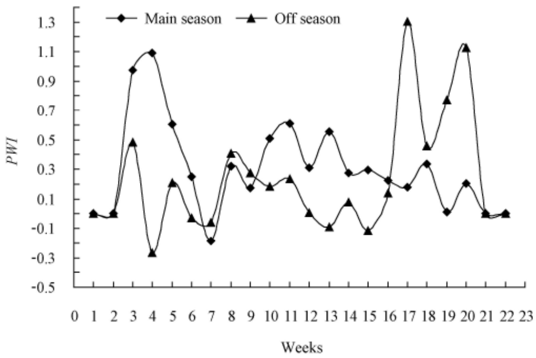

Figure 11 Weekly *PWI* representing irrigation delivery performance.

5 Conclusions

The development of up-to-date and competitive agriculture depends on the necessity of achieving sustainable management of available water resources for irrigation supplies. The information from all interacting sources is essential to assess crop water status and to efficiently irrigate rice crop as well as for improving water management. GIS user-interface technique linked with water management model can greatly assist to improve water management based on feedback of field information. The study gives comprehensible results along with new data sets and can assist irrigation managers to improve the decision-making process in the operation and management of the irrigation system. The system can improve the management of water allocation systems, monitoring water distribution system in existing schemes. This study has indicated that improvements in irrigation system management based on feedback of field information can satisfy the role of the precision farming.

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