**UNIVERSITI PUTRA MALAYSIA**

# ***WEB-GEOSPATIAL WATER MANAGEMENT DECISION SUPPORT SYSTEM FOR TANJUNG KARANG RICE IRRIGATION SCHEME, MALAYSIA***

***MAINA MOHAMMED MAMODU***

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By

MAINA MOHAMMED MAMODU

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

April 2014

# DEDICATION

With due respect, I dedicated this work to my beloved Parents Ba Muhammad and Iya Maryam; my wife – Amina; Children - Salman and Leena.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy.

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**Chair: Professor Mohd Amin Mohd Soom; PhD, P.Eng., FIEM**
**Faculty: Engineering**

Irrigation water management in agriculture is very important because more than 70% of fresh water resources goes to agriculture. Rice alone for instance, consumes 45% of the freshwater diverted to irrigation. Many studies have shown that water application to rice can be reduced without compromising yield; in fact, it was evident that growing rice at saturation level of moisture increase yield. Lack of correct information of the parameters for scheduling irrigation and precise measurements to determine the water balance model components are the causes of over irrigation. Hence there is a need to develop a tool that is not yet available locally to assist water managers in precision rice irrigation management. The first objective of this study was to collect field data and make in-situ field measurements on Paddy ET and crop Coefficients (Kc) for paddy using field lysimeters and field telemetry of sensors. The second objective was to develop empirical relationships between local groundwater table depths and the standing water depth in paddy fields and vadose zone saturation levels during the crop growing season. Field taken measurements on nutrients of the surface and groundwater sources were for irrigation water in the Tanjung Karang Irrigation Scheme; user-friendly and interactive Web-Geospatial decision Support System was then developed for irrigation water management in the Tanjung Karang Rice Irrigation Scheme (TKRIS) area. The system will enable farmers and irrigation managers to view, analyze and query some aspects of the farm to obtain results that are useful for decision making. The telemetry system consists of Microflex-C Sensors, remote terminal units, and data server. For the shallow groundwater measurements, three wells were established installed with a Diver sensor, to monitor water table fluctuations in the farm throughout two rice growing seasons. The nutrient contents of the irrigation water were determined by obtaining weekly water samples from the strategic points in the farm, i.e. Canals, drains, paddy field and shallow well. These samples were subjected to the standard water quality testing method to determine the quantity of the crop nutrient elements in the water such as N, P, K, $NH_3$, and some water quality parameters such as pH, Turbidity, and Alkalinity. The web application was developed based on ESRI products. ArcGIS server 10.1, ArcGIS viewer for flex and Microsoft SQL database were used. The results from the first objective showed that the average crop coefficient (Kc) and measured rice crop evapotranspiration (ETc) of variety MR219 for the study area for the first season from February, March and April which corresponds with the early, mid and late stage of rice plant growth were 1.1, 1.3, and 1.2; 4.1, 3.9 and 4.0 mm/day respectively, with average percolation rate of 2.1 mm/day. On the other hand, the values of Kc and rice evapotranspiration for the second season from July, August and September which corresponds with early, mid and late stage of rice plant growth were 0.9, 1.0 and 1.1; 3.9, 3.7 and 4.0 mm/day respectively with an average percolation rate of 1.7 mm/day. The irrigation water from the canal which was the most important source was found to contain significant amount of N, P, and K at the rate of 25.7 kg/ha, 8.6 kg/h and 118.4 kg/ha, respectively. These information are vital to the farmers and irrigation managers; therefore, making it available online will improve decision making for best practices by the farmers. A DSS known as SWAMP (Soil Water And Management for Paddies) was developed using spatial data as input in the form of layers and published through the ArcGIS server, where the ArcGIS Viewer for flex access the data and display for viewing and analysis. The developed system is very interactive and the interface is simplified such that a novice user can explore and retrieve information. The managers can at a glance detect where to restrict and relax supply and give attention with regards to yield quantity and quality. The application of ultrasonic sensors to monitor field water depletion proved to be useful in ET monitoring and measurements to schedule irrigation. About 21% of the total water applied to the field by irrigation could be saved when contribution of groundwater is considered in the model. The newly developed SWAMP tool saves time and resources and is flexible with high accuracy in its overall output for real time information for best practice in rice precision farming. By publishing the crop water requirement and nutrients content of irrigation water, farmers will apply water strictly based on these information. Therefore reduced input leads to high efficiency and productivity for sustainable agriculture.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
Sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**SISTEM SOKONGAN KEPUTUSAN PENGURUSAN AIR SESAWANG GEO-RUANG BAGI SKIM PENGAIRAN PADI TANJUNG KARANG, MALAYSIA**

Oleh

**MAINA MOHAMMED MAMODU**

**April 2014**

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Pengurusan air pengairan dalam pertanian adalah amat mustahak kerana lebih 70% sumber air tawar digunakan untuk pertanian. Misalnya, penanaman padi sahaja menggunakan 45% air tawar yang diagihkan untuk pengairan. Banyak kajian menunjukkan bahawa penggunaan air bagi penanaman padi dapat dikurangkan tanpa pengurangan hasil, sebenarnya ia merupakan satu bukti bahawa menanam padi pada lembapan tepu boleh meningkatkan hasil dan ianya bercanggah dengan pandangan para petani yang berpendapat bahawa penanaman padi memerlukan air yang banyak secara berterusan. Kekurangan maklumat yang tepat seperti parameter bagi penjadualan pengairan dan pengukuran yang tepat bagi menentukan komponen model imbangan air adalah penyebab kepada pengairan berlebihan. Maka, ianya merupakan satu keperluan bagi membangunkan sebuah peralatan yang masih belum terdapat dalam pasaran tempatan untuk membantu pengurus air dalam pengurusan air penanaman padi secara presis. Objektif utama kajian ini adalah untuk mengumpul data dan membuat pengukuran di lapangan berkenaan sejat-pemeluhan dan pekali tanaman (Kc) bagi pokok padi dengan menggunakan lysimeter dan penderia pemfailan telemetri. Objektif kedua pula adalah untuk membangunkan perkaitan empiris antara kedalaman aras air bumi dan kedalaman air takungan di petak sawah serta tahap zon tidak tepu semasa musim penanaman padi. Pengukuran nutrien yang terdapat pada sumber air bumi dan air permukaan telah dilalukan untuk air pengairan bagi skim pengairan Tanjung Karang. Satu Sistem Sokongan Keputusan WebGIS yang interaktif dan mesra pengguna seterusaya telah dibunguakan untuk pengurusan air pengairan di kawasan Skim Pengairan Tanjung Karang (TKRIS). Sistem ini akan membolehkan petani dan pengurus pengairan untuk melihat, menganalisis dan membangkitkan persoalan beberapa aspek tentang sawah padi bagi mendapatkan maklumat yang berguna untuk membuat keputusan. Kaedah-kaedah yang digunapakai bagi mencapai matlamat ini adalah dengan menggunakan sistem telemetri bagi pengukuran beberapa komponon bagi model imbangan air secara presis di dalam sawah. Sistem telemetri merangkumi penderia Microflex-C, unit terminal jarak jauh dan server data. Bagi pengukuran paras air bumi cetek, tiga telaga telah dibina di dalam kawasan sawah dan penderia Diver telah dipasang untuk memantau pasang surut paras air bumi sepanjang dua musim penanaman. Kandungan nutrien yang terdapat pada air pengairan telah ditentukan dengan mengambil sampel air dari lokasi strategik dalam kawasan sawah seperti tali air pengairan, parit, sawah padi dan telaga pada setiap minggu . Sampel-sampel ini tertakluk kepada piawaian ujikaji kualiti air bagi penentuan kandungan elemen nutrien di dalam air seperti N, P, K, $NH_3$,dan beberapa parameter kualiti air seperti pH, kekeruhan dan kealkalian. Pengaplikasian sesawang telah dibangunkan berasaskan kepada produk ESRI. ArcGIS server 10.1, ArcGIS flex viewer dan sistem pangkalan data Microsoft SQL telah digunakan bagi membangunkan sesawang ini. Hasil kajian bagi objektif pertama menunjukkan bahawa purata pekali tanaman (Kc) dan sejat-pemeluhan pokok padi (ETc) yang diukur bagi varieti MR219 bagi kawasan kajian ini pada musim pertama iaitu dari bulan Februari, Mac dan April yang sejajar dengan peringkat tumbesaran pada awal, pertengahan dan akhir peringkat masing-masing adalah 1.1, 1.3 dan 1.2; 4.1, 3.9 dan 4.0 mm/hari dengan purata kadar penyusupan dalam adalah 2.1 mm/hari. Selain itu, nilai Kc dan sejat-pemeluhan tanaman padi bagi musim utama iaitu dari bulan Julai, Ogos dan September yang sejajar dengan peringkat tumbesaran pada awal, pertengahan dan di akhir peringkat masing-masing adalah 0.9 , 1.0 dan 1.1 mm/hari; 3.9, 3.7 dan 4.0 mm/hari dengan purata kadar penyusupan dalam air ialah 1.7 mm/hari. Air pengairan dari taliair yang merupakan bahagian paling penting didapati mengandungi kadar nitrat, fosforus dan potassium pada kadar yang ketara iaitu 25.7 kg/ha, 8.6 kg/ha dan 118.4 kg/ha. Maklumat ini adalah sangat penting bagi petani dan pengurus air pengairan, maka penyediaan maklumat secara atas talian akan dapat menambah baik didalam membuat sesuatu keputusan oleh para petani. Sistem ini dikenali sebagai SWAMP (Air Tanah dan Pengurusan untuk Padi) telah dibangunkan menggunakan data ruang sebagai bahan input dalam bentuk lapisan dan dicetak melalui ArcGIS server dan disimpan dalam pangkalan data yang mana ArcGIs flex viewer mencapai dan memaparkan data bagi tujuan melihat dan menganalisis. Sistem yang dibangunkan adalah amat interaktif dan paparan pemukanya adalah ringkas sekali membolelikan orangawan meneroka dan mendapatkan semula maklumat. Pengurus boleh mengesan dengan sekali pandang hawasan perlu bekalan disekat dan dibiarkan dan member; perhatian berhubung dengan kualiti dan kuantiti hasil padi. Penggunaan penderia ultrasonic untuk memantau penyusutan air sawah terbukti sangat berguna dalam pemantauan ET dan pengukuran untuk penjadualan pengairan. Sekitar 21% jumlah air yang digunakan dalam sawah padi menerusi pengairan dapat dijimatkan apabila sumbangan dari air bumi dipertimbangkan di dalam model berkenaan. Peralatan SWAMP yang baru dibangunkan dapat menjimatkan masa dan sumber serta ianya sangat fleksibel dengan keseluruhan outputnya berketepatan tinggi untuk maklumat masa nyata bagi amalan terbaik pertanian presis padi.

# ACKNOWLEDGEMENT

Glory be to Almighty Allah Who decreed and make all things possible.
First, I would like to express my sincere gratitude to my supervisor, Prof. Ir. Dr. Mohd Amin Mohd Soom, for his unreserved support, guidance, advice, and encouragement throughout the period of my study, I appreciate every bit of your support.

I am very grateful and sincere appreciation to all the members of my supervisory committee. Dr. Aimrun Wayayok, Dr. Samsuzana Abd Aziz and Dr. Md Rowshon Kamal for their advice, and active contribution by accompanying me to the research site during equipment installations, calibrations and data collection. Which shows how dedicated you are in assisting me to succeed in this work.

The very single person I must acknowledge apart from my supervisors is Haj. Mohd Yazid who has been with me since the beginning of this work, offering several supports such as the set of telemetry equipment for data collection and guidance on how to conduct some readings. He further established for me good relationship with the local farm owners, whom we eventually became friends such as Mr. Zulkifili of Sawah Sempadan area of Tanjung karang.

Furthermore, I would like to thank Mr. Mohd Azwan who helped me with a set of automatic weather station which was installed for one year at my site. Also not forgetting Mr. Ezrin Mohd Husin and Mr Mohd Azlan Othman of smart farming laboratory for assisting me with laboratory equipment and devices used during my studies. Same goes to my friend in the laboratory Mr. Faisal Mohammad for helping me with many computer technical aspects and whom I learnt a lot about local information.

In addition, I would want to thank my friends and colleagues such as Alhaji Abba A. Hammajam, Dr. Mohd Shuaib Abubakar and Mr. Mehdi and his wife Dr. Asa Gholozadeh who helped me in one way or the other, and for memorable time of sharing ideas and academic discussions.

Finally, to my wife and children for being patient with me for not being with them at the time they needed me most. Also acknowledged is my sister Habiba Mohammed for calling me frequently to encourage, showed moral support and empathy.

Thank you all and God bless you.

I certify that a Thesis Examination Committee has met on 25 April 2014 to conduct the final examination of Maina Mohammed Mamodu on his thesis entitled "Web-Geospatial Water Management Decision Support System for Tanjung Karang Rice Irrigation Scheme, Malaysia" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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Date: 19th May, 2014

# DECLARATION

## Declaration by Graduate Student

I hereby confirm that:

- This thesis is my original work;
- Quotations, illustrations and citations have been duly referenced;
- This thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- Intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (research) Rules 2012;
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Name and Matric No.: Maina Mohammed Mamodu GS 29717

**Declaration by Members of Supervisory committee**

This is to confirm that:

- The research conducted and the writing of this thesis was under our supervision;
- Supervision responsibilities as slated in Rule 41 in Rules 2003 (Revision 2012-2013) were adhered to.

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| API | Application Programming Interface |
| ArcGIS Server | The technology used in ArcGIS for server |
| ArcGIS for Server | Tool for publishing and displaying data for web applications |
| ArcGIS Viewer | Application Builder for web application based on JavaScript for Flex API |
| DID | Department of Irrigation and Drainage |
| DOA | Department of Agriculture |
| DR | Drainage Requirement |
| DSS | Decision Support System |
| ET | Evapotranspiration |
| ETc | The crop evapotranspiration is the evapotranspiration from a disease-free, well-fertilized and under optimal soil-water and agronomic conditions growing crop (ETc = ETo * Kc). |
| ETo | Reference crop evapotranspiration (or reference evapotranspiration) is defined as the evapotranspiration rate from a reference surface which is hypothetically a well-watered grass crop with specific characteristics. |
| Kc | The crop coefficient (Kc) is an experimentally determined coefficient relating ETc to ETo (ETc = ETo * Kc). |
| FAO | Food and Agriculture Organization |
| GUI | Graphical User Interface |
| JICA | Japan International Cooperation Agency |
| MOA | Ministry of Agriculture |
| Paddies | Flooded rice fields |
| PWI | Ponding Water Index |
| RF | Rainfall |
| RO | Surface Runoff |
| RWS | Relative Water Supply |
| VBA | Visual Basic for Application |
| SWAMP | Soil Water Assessment and Management for Paddies |
| SOAP | Simple Object Access Protocol |
| TAKRIS | Tanjung Karang Rice Irrigation Scheme |
| TASS | Tali Air Sawah Sempadan |

# LIST OF NOTATIONS

| | |
|---|---|
| $e_a$ | Mean actual vapour pressure of the air |
| $e_s$ | Mean saturation vapour pressure of the air |
| $e^o(T_{min})$ | Saturation vapour pressure at daily minimum temperature |
| $e^o(T_{max})$ | Saturation vapour pressure at daily maximum temperature |
| $R_a$ | Extra-terrestrial radiation |
| $R_i$ | Daily rainfall amount in day i |
| $R_n$ | Net radiation at crop surface |
| $R_{nl}$ | Net long-wave radiation |
| $R_{ns}$ | Net short-wave radiation |
| $R_s$ | Incoming short wave radiation |
| $RH_{max}$ | Maximum Relative Humidity |
| $RH_{min}$ | Minimum Relative Humidity |
| $RH_{mean}$ | Mean Relative Humidity |
| $\Delta$ | Slope vapor pressure curve |
| $\gamma$ | Psychometric constant |
| $\alpha$ | Surface reflectivity or albedo |
| $\delta$ | Solar declination |
| $\sigma$ | Stefan-Boltzman constant |
| $\omega_s$ | Sunset hour angle |
| $\eta$ | Manning's coefficient |
| $\varphi$ | Latitude |
| $\lambda$ | Latent heat of vaporization of water |

## CHAPTER ONE

## INTRODUCTION

### 1.1 Background

The population is fast growing, and it was estimated that by the year 2050 world population will rise to nine billion people (Molden, 2007). Therefore, the pressure on the limited fresh water resources is becoming severe. Fresh water resources are becoming scarce. Water and food security are intimately linked because access to water resources is key to crop production and invariably ensures food security. These can be observed from the soaring recent rise in global food prices and more than ever before cases of hunger around the world is on the increase. About 20% of the agricultural land is being irrigated and much of the needed crop production will come from irrigated land (Chapagain & Yamaji, 2009).

The previous years have been marked by growing water scarcity worldwide. The situation is aggravated by the current climate change and global warming. The need to manage and judicious water application in irrigated agriculture is necessary especially where huge amount of fresh water is diverted to irrigation most of which are wasted. The water saved could be used for other activities (domestic and industrial) and/or expand irrigated farming to produce more crops. Growing rice takes about 50% of irrigation water (Molden, 2007). However, some scholars argued that rice is very sensitive to water stress. Attempts to reduce water in rice production may result in yield reduction and may threaten food security not only in Asia but globally.

Reducing water input for rice will change the soil from submerged to aerate. These shifts may have great and to some extent unknown consequences on the sustainability of the lowland rice ecosystem. The growing water shortage means there is an urgent need to device methods of growing rice with less water without compromising yield. In Malaysia for example, more than 65% of its fresh water withdrawal goes to rice irrigation but with only 45% efficiency due to loss from spillage, seepage, deep percolation and evaporation (Akinbile et al., 2011). Water saving techniques in paddy rice irrigation should be explored with intense research in order to develop potentials of saving water and protect soil environmental conditions and widely improving yields and yield components in rice production (Yang et al., 2012).

In those days and even today the reason for inundating rice field is to control or suppress weed. Furthermore, during dry season flood irrigated farming is prevalent but under huge water loss, hence it results in low efficiency (Michael, 2004). The current system of agricultural practice is costly, difficult, and eventually turns out to be boring. Farmers are looking out for smarter ways of farming where there will be precision and more profit by increasing crop, land, and water productivity with less labor. This can be achieved through precision farming which is evolving with application of modern sensors, computer technologies and cross disciplinary approach to solve problems in agriculture is showing promising outcomes (Power, 2003).

Precision water management of lowland irrigated rice is becoming crucial in global water resource management. Many irrigation schemes are exploring different, cheaper and more efficient ways of curbing huge water losses from flood irrigation system of rice. The application of modern technology such as GIS, GNSS, Sensors and Remote Sensing to agriculture has brought unprecedented revolution in agricultural water management.

It is clear from previous studies that rice can be grown with minimal depth of ponding even up to saturation level without sacrificing yields. Many alternatives device and methods are improvised in order to curb the situation of huge water loss. Furthermore, the world is moving toward exploiting space technology in the area of agriculture. To deliver the right amount of water at the right time to the right location requires a real time approach; this is a phenomenon that could be achieved by integrating real time information and spatio-temporal data from the field and models (Rowshon et al., 2009).

Agricultural productivity system is an outcome from complex interactions of seed, soil, water and agro-chemicals. Therefore, judicious utilization and management of all inputs is essential for the sustainability of this complex system. The focus on enhancing productivity with total neglect or disregard to proper management of inputs and without considering the impact on environment has resulted into environmental degradation. Another similarity is the fact that labor availability to agriculture is on constant decline, and therefore, a quick and sustainable alternative has to be provided.

DSS is defined as “a class of computerized information system that supports decision-making activities. DSS are interactive computer-based systems intended to help decision makers to use communications technologies, data, documents, knowledge and/or models to complete decision process tasks” (Power, 2003). Often the types of decisions that DSS are designed to address take advantage of the ability of computers to manipulate large amounts of data, but also rely on a decision maker’s judgment. Depending on the time frame and the scope for system manipulation, decisions can be classified as operational, tactical, and strategic.

In another version of the definition, DSS is a set of tools and procedures that works interactively to manage a particular system; it is capable of enhancing the quality of the decision-making processes in the system. Decision support systems are sub-set of computer-based information systems. It is a collection of varieties of information systems such as office automation systems, transaction processing systems, management information systems and management support systems. Management support systems consist of DSS, expert systems and executive information systems.

Much more literatures are evolving on Decision Support System. Many of the early researches were on automated report generation using main frame computers (Power, 2003). It is worth to reiterate that DSS is a decision support and not making decision, this was due to the fact that it addresses the advantage of computer to manipulate large amount of data but yet rely on human decision and judgment, meaning that it cannot take decision on its own.

Heilman et al. (2005) present several arguments concerning the early application and development of DSS including the most recent ones which were often design based on spatial database in Geographic Information System (GIS) format. Multi-objectives decision making tool also incorporated in GIS application (Malczewski, 1999), which opens a new window for transforming decision support approach in agriculture.

The concept of the recently developed Rice Irrigation Management Information System (RIMIS) was to favorably manage irrigation system (Rowshon and Amin, 2010). RIMIS was built based on ArcGIS VBA and used as desktop computers which limits its accessibility, the dynamism of technology warrant the need for modification with total overhauling the system to accommodate more delivery performance such as system efficiency, and of course to increase accessibility to the user by making it web-based system. Most of the data used in RIMIS were based on estimates; the development platform was VBA which is no longer supported by ESRI's ArcMap 10.1.

In this study digital ultrasonic sensor – Microflex-C was used  for level measurements and ArcGIS Server 10.1, Microsoft SQL database with ArcSDE and JavaScript API were used in developing the map application system called SWAMP (Soil Water Assessment and Management for Paddies). These materials were chosen to ensure that the system withstand the dynamism of technology while continued to achieve its purpose into the future.

## 1.2 Research questions

The research sought to explore answers to questions such as, how to model water allocation to ensure adequate supply to meet crop water requirement? How to incorporate web based information into GIS modeling theme and to determine what quantity of water that is just enough to sustain plant growth without compromising yield? What techniques are used to measure irrigation field losses such as seepage, deep percolation and field drainage? What is the measured amount of deep percolation (DP)? What is the nature of the shallow groundwater table fluctuation in the vadose zone following flood irrigation?

Effective rainfall is one of the parameters in the water balance model that is difficult to obtain its precise value. How does the interaction between rainfall and irrigation water allocation change over time? Does Irrigation water contain any crop nutrients of fertilizer components? These and many related questions are to be answered by field experiment, analysis, and cross discipline analysis to provide customized solutions. Ultimately the answers will lead to the development of web based decision support system tool for Tanjung Karang Rice Irrigation Scheme.

## 1.3 Statement of the problem

Addressing future problem of water scarcity is of no doubt begins today, the challenge of feeding nine billion people by year 2050 (Seckler et al., 1999), which means increased present food production by 50% under declining fresh water resources is a serious challenge. There is an urgent need to come up with a viable idea centered on water saving and road map to curb the effect of future disaster from water shortage.

Rice is a staple food crop that is consumed in every part of the world and therefore, rice production will continue to rise at even higher rate in order to meet the food requirement of the world growing population. The systematic approach to show equivalent or higher yield from water saving rice irrigation system is to explore resources used and to estimate the overall water saving. Some scientists have contrary view and finally conclude that rice thrive well under inundation than otherwise (De Datta, 1981).

Rice was formerly considered as aquatic plant, but now scientific research have shown that water application can be reduced without sacrificing yield, indeed small increase in yield can be obtained with less water under drained soils (Ramasamyet al., 1997; Guerra et al., 2007). Those who have contrary view in the true position of rice growth create the necessity to carry out more comprehensive studies by using precision farming system in order to refine the true position of these arguments.

Our challenge is to develop socially acceptable, economically viable, and environmentally sustainable rice-based systems that allow rice production to be maintained or increased in the face of declining water availability (Bouman & Tuong, 2001).

The need to adopt precision farming is uncompromising for the fact that food demand is on the increase and water resources is becoming scarce, rainfall is erratic and therefore water for irrigation becomes competitive. Judicious utilization of scarce water resources becomes imperative to meet the growing demands from industrial, domestic and above all irrigation supply. Most rice irrigation schemes in Malaysia are practicing double cropping cultivation, and five cropping cultivation in two years is under way. Hence crop establishment is successive based on the water availability as a result of the erratic nature of rainfall. The water shortage becomes clear to the farmers with this year's season drought which resulted to acute water shortage to farmers downstream which consequently resulted into yield lost.

It became necessary that the scheme needs daily estimation of the available water for irrigation and its unbiased allocation among tertiary canals. The water distribution system are placed on regular weekly interval which was not based on the crop water requirement. It is difficult to adjust to meet the crop demand, hence the practice of continuous flow throughout the crop growing season is adopted. Huge amount of water is being wasted under this system as water flows unrestricted into the drain leading to scarcity downstream.

It is also essential that the Irrigation scheme to be equipped with balancing techniques as to know when to restrict water under deficit irrigation and when to relax the restriction to adequately meet the field demands. In contrast, full irrigation has been the traditional pattern of irrigation even in the worst drought season. It became imperative for the scheme to stress on how and when to restrict supply and how to allocate available water supply as the growing season advances.

Proper scheduling is not just supplying water regularly but to introduce the right quantity of water at the right time in the right place. This will certainly be difficult only when proper studies were done to exactly know the field demand in terms of crop water requirement and losses. Water demand and allocation is sometimes complex and therefore difficult to meet the demand of water users concurrently. Therefore, the need for development of an on-line system that can explicitly handle water allocation and absolute irrigation management is necessary.

## 1.4 Objectives

The broad objective of the study was to develop a web-based geospatial information system for on-farm water management for the Tanjung Karang rice irrigation scheme.
The specific objectives were;

1. To determine rice evapotranspiration (ETc) and rice crop coefficients (Kc) using field lysimeters and telemetry system.

2. To develop empirical relationships between local groundwater table depths and the standing water depth in paddy fields and vadose zone saturation levels during the crop growing season.

3. To determine the availability of nutrients in the surface and groundwater sources for irrigation water in the Tanjung Karang Rice Irrigation Scheme.

4. To develop a user-friendly and interactive WebGIS Decision Support System for irrigation water management in the Tanjung Karang Rice Irrigation Scheme.

## 1.5 Significance of the Study

The study on the water saving strategies in paddy rice farming is of tremendous importance, considering the huge amount of water that is wasted, which could have been used for other productive activities such as domestic and industrial uses. It could also be used to expand the irrigated farming area to produce more crops.

The application of precision farming approach in this area will enhance the validity of research output while appreciating the impact of information and communication technology on improving field agricultural water management. The management of agricultural production is undergoing a change, both in philosophy and technology. In this respect, Ultrasonic Microflex-C Sensors were used to collect field data throughout the data collection period at an interval of 15 minutes to ensure consistency.

A geospatial system defined as a computer based information system will help in storing, retrieving, processing, analyzing and presenting the information for making work smarter rather than work hard to achieve successful outcomes.

GIS technology facilitates the combination of both computer based techniques and spatial information to help in planning and developing irrigation water management efficiently. Presently, resources are scarce, modeling and management across time and space in irrigation and water resource management is cost effective than its field techniques counterpart.

The computer application would be able to deliver efficiently, easy to use, and produce results that make sense to those who will use the outcome to make decision. However, model development is an unending endeavor. Precision agriculture change farm manager's philosophy, because focus of attention changes from average field conditions to the variation of those conditions and ultimately their interrelation and outcomes. The research methods that have contributed to today's production efficiency might not be the most appropriate for the future, this shows the dynamism of technology.

Agricultural research has focused mainly on identifying robust technologies and strategies such recommendations, or farming practices that can be generalized and applied across a diverse set of environments. Web GIS development and the expansion of the internet provide two key capabilities that can greatly help in the following:

1. Allows visual interaction with data and maps since the maps and charts can be viewed online.
2. Geospatial data can be widely accessible. It is worth to note that Web GIS is not without fault, the primary problem is speed because of the heavy graphics and connection speed over the internet which can be overcome with new breed of high specification computer systems. On the other hand the good news is that it is easy to use, it does not require an expert in GIS to use the system, and ArcGIS server does that easily.

### 1.6 Scope and Limitation of the Study

This study is to the development of a robust technology that could be applied for rice irrigation system. It involves developing field irrigation model that can be favorably applied for solving water related problems, and to understand the major constraints to equitable water distribution and offer solutions through a geospatial information system; a system that can ensure monitoring of the entire scheme using sensors and GIS technology. Field water demand as well as field standing water depth can easily be determined.

Creating and integrating data through Sensors, ArcGIS software and published online using ArcGIS Server and ArcGIS viewer for flex built on JavaScript API developer is of the interest. All these techniques ultimately lead to the formulation of a tool for decision making regarding water allocation using ArcGIS server 10.1 for a web based application. The limitation of this study is that it focused purely on rice irrigation system, to be precise on-farm water management, and the decision support system could be useful mainly for farm managers, irrigation engineers, farmers alike and to some extent policy makers. The system can be customized to be used on oil palm farm as well as other irrigation schemes in Malaysia. Data were obtained through sensors installed in the farm but future data acquisition will incorporate the use of remote sensing when real time satellite data are available. During the study, the research area was lacking instrumentation for real-time information from the field. Other farm activities can also be incorporated in the built system which will be listed under recommendations as part of future work.

## 1.7 Thesis Organization

The first chapter gives the general background of the study by defining some terms and discusses some issues concerning irrigation water management with particular emphasis on-farm water management. The statement of research problem is outlined together with the importance of the study. The scope and limitations of the study are enumerated, likewise the research questions are raised as a guide to what will be addressed in this study. In addition to the importance of the study, four objectives are stated.

The second chapter highlights some of the theoretical background of some equations, models and some historical background of rice irrigation in Malaysia. Literatures on the aforementioned issues were reviewed to unfold the need for further work in some aspects which give rise to discover the current problem. Literatures were reviewed on Web GIS, its development and applications in irrigation water management. The purpose is to summarize and synthesized the most useful approach used in developing web applications for irrigation water management. It encompasses variety of reports and publications for wider understanding of the topic. The review provides the concept, methodologies and various uses of the applications.

Critical analysis on the choice of structural framework and Graphical User Interface are discussed. Among problems encountered during system development such as; data management, Security, user needs, etc. are also highlighted. The use of Web GIS DSS is gaining more attention from Irrigation Engineers, system Developers and Cartographers. Web GIS and especially the real time capability can be of importance in solving many problems regarding irrigation water management. The future of development and application of web GIS applications are also discussed.

Third chapter presents the material used in this study as well as the procedures of setting up the equipment for data collection. It highlights all the equations used, also in the system development section, it provides the items and step by step procedures of using the web application builder to build the system. It follows the system life cycle development procedures.

The fourth chapter displays the results obtained from this study. It discusses the expected as well as the unexpected outcomes of the experiments. The results are presented sequentially corresponding to the objectives of the study. Results are presented graphically and in tables to display what was obtained during the studies.

The fifth chapter which was the last chapter of this thesis contains the summary and the main conclusion of this study. It also presents the recommendation for future research.

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