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DEVELOPMENT OF GIS-BASED SEBAL MODEL FOR ESTIMATION OF EVAPOTRANSPIRATION IN IRAQ

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By

HUSSEIN SABAH JABER

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

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DEDICATION

This dissertation is dedicated to my father, who taught me the meaning of life, patience, and who provided unconditional support with my studies all the way since I entered this life. It is also dedicated to my mother, who has always given me courage to pursue my dreams.

I dedicate this work and give special thanks to my main supervisor Prof. Dato .Dr. Shattri Mansor .This dissertation is dedicated to my wife and my brothers, who have supported me during this research.

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

DEVELOPMENT OF GIS-BASED SEBAL MODEL FOR ESTIMATION OF EVAPOTRANSPIRATION IN IRAQ.

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Chairman : Prof. Dato' Shattri Mansor, PhD
Faculty : Engineering

A change in weather parameters and climate will result in a significant change in evapotranspiration. Iraq suffers from problems such as reduction in water availability and unpredictable climate change that would affect irrigated agriculture and evapotranspiration. Therefore, estimation of evapotranspiration and standardized measurement are important because evapotranspiration (ET) is the means for exploiting irrigation and irrigation is considered as the backbone of the peasant society.

Most of the studies in Iraq depend on traditional methods to estimate evapotranspiration. These conventional methods are not practical for large areas because it is difficult and costly. Therefore, this research aims to use remote sensing (satellite imagery data) and GIS as modern technologies to estimate evapotranspiration.

In this research, the proposed model has been developed based on equations of SEBAL by using GIS to make a simplified model for estimation of evapotranspiration automatically that leads to a reduction in cost and time and saves effort. Subsequently, the proposed GIS-based SEBAL model was evaluated with field data by using regression coefficient. The area surrounding the Al-Hindiyah barrage has been selected as a study area because it is one of the most significant water resources in the middle part of Iraq. A series of Landsat OLI (Operational Land Imager) satellite images and climate data of the study area have been collected to determine actual evapotranspiration using the GIS-based model. In addition, actual evapotranspiration has been used to assess irrigation performance based on several indicators and to analyze water balance depending on the curve number method in GIS for the study area, respectively.

The results indicate that the proposed GIS-based SEBAL model for estimation of actual evapotranspiration has reasonable agreement with the field data based on the values of coefficient of variance(CoV) equal to (0.75%, 2.2%, 0.68% and% 2.27%) indicates that the predicted results of the SEBAL model have high accuracy and consistency. The mean value of the SEBAL model was close to 1.0 (0.99, 0.98, 0.99 and 1.01), which indicated a good correlation between the measured and estimated Et. Therefore, the SEBAL model efficiently estimated the Et.

In addition, the results of irrigation performance were poor depending on comparison values of irrigation performance indicator results with recommended values of these indicators. Moreover, the results showed a close agreement between rainfall and runoff based on the value of the CoV values between Q observed/ Q proposed less than Q observed/ Q calculated indicates that the proposed model results have high accuracy and consistency than existing model. Therefore, the proposed model efficiently estimated the runoff.

Furthermore, the change of water content (ΔS) for the total study area was observed to have positive values that indicated that there was a percolation of groundwater in the crop root zone that can be used when water was insufficient.

This study concludes that the development of the GIS-based SEBAL model for calculating actual evapotranspiration provides an efficient and cost-effective means for estimation of evapotranspiration and it was verified that SEBAL will perform better if it is supported with field data. In addition, there should be a consensus between the period when water is provided from the source and the period when it is needed to increase the irrigation performance. This study provides the possibility of simulating the runoff either on a daily, monthly, seasonal or an annual scale for each rainfall. It can be useful for estimating runoff at places where observed runoff records are not available.

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

PEMBANGUNAN MODEL SEBAL BERASASKAN-GIS UNTUK ANGGARAN PENYEJATPELUHAN DI IRAQ

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Perubahan parameter cuaca dan iklim akan menyebabkan perubahan penyejatpeluhan yang ketara. Iraq mengalami masalah seperti pengurangan ketersediaan air dan perubahan iklim yang tidak menentu yang akan menjejas pertanian pengairan dan penyejatpeluhan. Oleh itu, anggaran penyejatpeluhan dan pengukuran yang seragam adalah penting kerana penyejatpeluhan (ET) adalah cara untuk mengeksploitasi pengairan dan pengairan dianggap sebagai tulang belakang kepada masyarakat petani.

Kebanyakan kajian di Iraq bergantung kepada kaedah tradisional untuk menganggarkan penyejatpeluhan. Kaedah konvensional tidak praktikal untuk kawasan yang besar kerana ia sukar dan mahal. Oleh itu, kajian ini bertujuan untuk menggunakan penderiaan jarak jauh (data imej satelit) dan GIS sebagai teknologi moden untukmenganggarkan penyejatpeluhan.

Dalam kajian ini, cadangan reka bentuk SEBAL telah dibangunkan dengan menggunakan GIS untuk membuat suatu model mudah untuk menganggarkan penyejatpeluhan yang membawa kepada pengurangan dalam kos dan masa dan menjimatkan usaha. Kemudiannya, model SEBAL berasaskan-GIS yang dicadangkan telah dinilai dengan data lapangan dengan menggunakan pekali regresi. Kawasan di sekitar empangan rendah Al-Hindiyah telah dipilih sebagai kawasan kajian kerana ia adalah salah satu sumber air yang paling penting di bahagian tengah Iraq. Satu siri imej satelit Landsat OLI (Operational Land Imager) dan data iklim kawasan kajian telah dikumpulkan untuk menentukan penyejatpeluhan sebenar menggunakan model berasaskan-GIS. Di samping itu, penyejatpeluhan sebenar telah digunakan untukmenilai prestasi pengairan berdasarkan beberapa petunjuk dan untuk menganalisis keseimbangan air bergantung pada kaedah keluk angka dalam GIS untuk kawasan kajian, masing-masing.

Keputusan menunjukkan bahawa model SEBAL berasaskan-GIS yang dicadangkan untuk anggaran penyejatpeluhan sebenar mempunyai persetujuan yang berpatutan dengan data lapangan berdasarkan (CoV) ialah antara (0.75%, 2.2%, 0.68% and% 2.27%). Tambahan lagi, hasil prestasi pengairan adalah tidak baik bergantung kepada nilai perbandingan petunjuk prestasi pengairan dengan nilai-nilai petunjuk yang disyorkan. Selain itu, keputusan menunjukkan persetujuan rapat antara hujan dan air larian berdasarkan nilai Cov=0.10 yang diperolehi. Tambahan pula, ΔS bagi keseluruhan kawasan kajian telah diperhatikan sebagai mempunyai nilai-nilai positif yang menunjukkan bahawa terdapat penelusan air bawah tanah di zon akar tanaman yang boleh digunakan apabila air tidak mencukupi.

Kajian ini menyimpulkan bahawa pembangunan model SEBAL berasaskan- GIS untuk mengira penyejatpeluhan sebenar menyediakan cara yang cekap dan kos-efektif untuk anggaran penyejatpeluhan dan ia telah mengesahkan bahawa SEBAL akan berprestasi lebih baik jika ia disokong dengan data lapangan. Di samping itu, perlu ada konsensus di antara tempoh apabila air disediakan dari sumber dan tempoh apabila ia diperlukan untuk meningkatkan prestasi pengairan. Kajian ini menyediakan kemungkinan simulasi air larian sama ada pada skala harian, bulanan, bermusim atau tahunan bagi setiap kali hujan. Ia mungkin menjadi berguna untuk menganggarkan air larian di tempat-tempat di mana rekod air larian yang diperhatikan tidak

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

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LIST OF ABBREVIATIONS

AVHRR	Advanced Very High Resolution Radiometer
ANNs	Artificial Neural Networks
ANFIS	Adaptive Neuro-Fuzzy Inference System
CN	Curve Number
CWD	Crop water deficit
DF	Depleted fraction
ET	Evapotranspiration
ETM+	Enhanced Thematic Mapper Plus
EBEC	Energy-budget eddy covariance
FAO	Food Agricultural Organization
FAR	Field application ratio
FFBP	Feed Forward Back Propagation
GIS	Geographic Information Systems
GEP	Gene Expression Programming
LAI	Leaf Area Index
LULC	Land Use Land Cover
LC	Land Cover
LISS-III	Linear Imaging and Self Scanning–III
MODIS	Moderate Resolution Imaging Spectroradiometer
MAE	mean absolute errors
MRE	mean relative errors
MBE	Mean Bias Errors
METRIC	Mapping Evapotranspiration with high Resolution and Internalized Calibration
MLR	Multi Linear Regression
NDVI	Normalized Difference Vegetation Index
NOAA	National Oceanic Atmospheric Administration.
NSE	Nash–Sutcliffe efficiency
NDWI	Normalized Difference Water Index
OLI	Operational Land Imager
PF	Penman –FAO
PM	Penman Monteith
RMSE	Root mean square error

RS	Remote sensing
RIS	Relative Irrigation supply
RET	Relative evapotranspiration
RHmean	Relative Humidity average
RWS	Relative water supply
SEBAL	Surface Energy Balance Algorithm for Land
SEBS	Soil Energy Balance System
SEBI	Surface energy balance index
S-SEBI	Simplified surface energy balance index
SVAT	Soil vegetation atmosphere transfer
TSEB	Two-source energy balance
SDISTA	Semi-distributed time area
SWAT	Soil and Water Analysis Tool
SDISTA	Semi-distributed time area
SWAT	Soil and Water Analysis Tool
WDVI	Weighted Difference Vegetation Index
WUE	Water Use Efficiency
ETp	the evapotranspiration's potential in mm
Pe	the value of (effective) precipitation in mm
Vc	volume of supplied water used for irrigation
Pg	gross precipitation in mm
ETc	Crop Evapotranspiration
Kc	Crop Coefficient
Rn	Net Radiation
R	correlation coefficient
R^2	Coefficient of Determination
Rs ↓ and Rs ↑	Incoming and reflected shortwave radiations
RL ↓ and RL ↑	Incoming and outgoing long wave radiations
Gsc	The solar constant equal to 1,367 W m^{-2}
θ	Solar inclination angle in radians
de-s	the relative distance between Earth and Sun in astronomical units
τ_{sw}	One-way atmospheric transitivity
Ɛs	Surface emissivity
Ts	Surface temperature

ρ	Air density (kg/m3)
Cp	air specific heat (1004 J/kg/K)
dT (K)	the temperature difference (T1– T2) between two heights (z1and z2)
rah	The aerodynamic resistance to heat transport (s/m).
k	constant value (von Karman)
ux	wind's speed measured in m/s at a particular height
z_{om}	The momentum roughness length (m).
u*	the friction velocity
λET	an instantaneous value for the time of the satellite overpass (W/m2)
ETinst	the instantaneous ET (mm/hr)
λ	The amount of heat absorbed for a kilogram of water that evaporates (J/kg)
ETrF	reference ET Fraction
ETr-24	the cumulative 24-hour ETr for the day of the image
F	Actual Retention (mm)
S	Retention (mm).
Q	Runoff Depth (mm).
P	Total Rainfall (mm)
I	Initial Abstraction (mm).
ΔS	The change in the amount of water stored in the surface layer (root zone (mm month $^{-1}$).
Ts	Surface Temperature
ea	Actual vapor pressure (kPa).
es	Saturation vapor pressure (kPa).
G	Soil heat flux (MJ m-2 d-1).
H	Soil heat flux (MJ m-2 d-1).
Rn	Net radiation at the crop surface (MJ m-2 d-1)
Rs	Solar radiation (MJ m-2 d-1)
Tmean	Average air temperature (ºC)
U2	Wind speed measured at 2 m height (m s-1)
Z	Altitude of the location (m).
ETa	Actual Evapotranspiration.
ep	overall consumed ratio

CHAPTER 1

INTRODUCTION

1.1 Background

Evapotranspiration (ET) is one of the major components in the hydrological cycle (Telis & Koutsogiannis, 2007). Hence, estimation of this parameter and standardized measurement related to ET possesses high degree of importance. ET varies by location, climate, crop type, soil type, and moisture availability. Evapotranspiration increases with increasing radiation, decreasing humidity, increasing temperature, and increasing wind speed. The increase in evapotranspiration should be of necessary concern to permit studies to estimate the increases and integrate in water management strategies. It is vital to put forth the effort to know the impact of climate change on evapotranspiration and use the information for developing adaptations in water resources management (Allen et al. 2005).

Remote sensing-based surface energy flux modeling is good for mapping spatially distributed ET for large area application, where conventional measurement are not practical. Various models are available and these models have some limitations and are mostly applied to agricultural areas mainly for quantifying crop evapotranspiration for irrigation management. Remote sensing offers data valuable to estimate surface energy fluxes in the thermal infrared portion of the spectrum (Bastiaanssen et al., 2001; Bos et al., 2005).

The mean for exploiting irrigation is evapotranspiration (ET).Irrigation is considered as the backbone of the peasant society. This society constitutes the largest percentage of the world population. It is estimated that around 70 percent of global water usage is demanded for irrigation, which in turn contributes to approximately 30 to 40 percent of the world's food production (Bastiaanssen et al., 2000).Hence, the assessment of irrigation performance and analysis of water balance require the usage of effective tools. These tools enable the decision makers to study large area and at the same time analyses large number of variables related to irrigation performance and water balance. Remote sensing and GIS techniques are considered as efficient techniques that can be used for achieving such works. (Molden et al., 1998).

1.2 Problem Statement

Currently, in some countries such as Iraq, that faces challenges such as reduction in water availability and unpredictable climate change where a change in weather parameters and climate will result in a significant change in evapotranspiration. The worst-case state for water supply is decreasing rainfall, increasing temperatures, and increasing evapotranspiration that Iraq suffer from it. Therefore, estimation of evapotransipration and standardized measurement are challenging.

Most of the studies in Iraq depend on traditional methods to estimate evapotranspiration **.** Measurement of evapotranspiration based on traditional methods and climate data is difficult and costly particularly on large area .Therefore, the current study aims to use remote sensing (satellite imagery data) and GIS as modern technologies to calculate evapotranspiration. Based on the best knowledge of the author of this thesis, there is no studies have been carried out to estimate of evapotranspiration parameters via remote sensing and GIS techniques in Iraq. Remote sensing techniques can be used to gather data over an entire areas, while traditional field data collecting depended on sample areas. Combination remote sensing data with field data can be an extremely active tool to study the performance of large irrigated areas and to develop spatiotemporal data**.** Therefore, using GIS and remote sensing techniques for estimating of evapotranspiration have many advantages, these include reduction in cost, time, efforts and providing an integrated assessment approach for irrigation. Studies focused on estimating of evapotranspiration are very significant because these studies help in irrigation management practices. In current study, Geographic Information Systems (GIS) -based Surface Energy Balance Algorithm for Land (SEBAL) model has been developed and used to estimate of evapotranspiration as the first time in Iraq.

The SEBAL model has been developed by using GIS to make a simple model for estimation of evapotranspiration that leads to minimize the cost and time. In addition, estimation of evapotranspiration from the SEBAL model is the most crucial part in this research for irrigation performance and water balance analysis. SEBAL can be applied and implemented for solving evapotranspiration and irrigation problems.

1.3 Objectives

The overall objective of this study is to develop a GIS-based SEBAL model for estimation of evapotranspiration in Iraq. Specifically, the objectives of this research are summarized as follows:

1- To develop a geospatial Surface Energy Balance Algorithm for Land (SEBAL) based on Geographic Information Systems (GIS) for evapotranspiration modelling.
2- To evaluate the hybrid GIS- SEBAL model for estimation of evapotranspiration.
3- To assess irrigation performance analysis of the study area (Al-Hindiyah Barrage, Babil city, Iraq) based on SEBAL model and several indicators.
4- To build rainfall-runoff model for analyzing of the water balance for the study area.

1.4 Thesis Outline

Chapter one presents an introduction to the research conducted which contains research background, problem statement, research objectives and the overall organization of this thesis.

Chapter two highlights the general literature review of the research. In this chapter, information about the research objectives is described.

Chapter three focuses on the research methodology as well as the materials used in the study.

Chapter four discusses the results obtained from the research objectives that are divided into four sections. The first section presents the production of evapotransipration parameters maps in GIS. The second section contains the discussion and evaluation of the SEBAL results using field data. The third section presents the assessment of irrigation performance for the study area. The final section contains the modeling of rainfall-runoff and analyzing of water balance for the study area.

Chapter five presents the conclusions obtained from this research. Discussion on future works is also presented.

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