UNIVERSITI PUTRA MALAYSIA

REFERENCE EVAPOTRANSPIRATION ESTIMATION USING ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM

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By

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Chairman : Professor Lee Teang Shui, PhD

Faculty : Engineering

Evapotranspiration is an integral part of the hydrologic cycle and an important component in water resource development and management, especially in the arid and semi-arid conditions such as those found in Iran, where water resources are limited. The standard FAO-56 Penman Monteith (PM) equation requires several meteorological parameters for estimating reference evapotranspiration (ET_O) that are not usually available in most stations. In addition, traditional methods that require limited climatic parameters for ET_O estimation are not applicable to all climatic conditions. As an alternative to traditional techniques, soft computing techniques can be used for modelling this nonlinear phenomenon. This research investigates the potential of the Adaptive Neuro-Fuzzy Inference System (ANFIS) technique for daily reference evapotranspiration modeling under arid, semi arid and humid conditions of Iran. The Gamma Test (GT) technique is employed to find the best input combination and number of sufficient data points for the model calibration. The

training and testing data sets are chosen based on the *K*-fold method of cross validation. The estimates of ANFIS models are compared with FAO-56 reduced-set PM ET_O approaches and conventional empirical ET_O equations (Hargreaves, priestly Tailor, Makkink, Blaney-Criddle and Turc) that are calibrated with the Genetic Algorithm technique. The FAO-56 full-set PM method is adopted as the reference ET_O equation, and it is applied to calibrate other ET_O equations and ANFIS models. The accuracy of all models are measured based on MAE, MSE and STD values. The comparison results indicate that when similar meteorological inputs are considered, the ANFIS models performed better than all the methods pursued under arid, semi arid and humid conditions of Iran. In addition, the general ANFIS model (whose inputs are temperature, solar radiation, relative humidity, wind speed and aridity coefficient) performed well under arid, semi arid and humid conditions of Iran. It is concluded that after temperature, the wind speed data is the most important parameter that should be considered in the combination of inputs for ET_O estimation under arid and semi-arid conditions, however the effect of wind speed in the combination of inputs for ET_O estimation under humid conditions is found to be not significant. It has been found that the minimum required meteorological parameters that gives the low error rate under arid and semi-arid conditions are temperature and wind speed data, and under humid conditions are temperature data and estimated relative humidity data from temperature data (by FAO-56 reduced set approach). Therefore, using the ANFIS technique is strongly suggested as an alternative to the traditional methods that suffer from several stringent meteorological requirements or invalidity under various climatic conditions.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

ANGGARAN SEJAT PEMELUHAN MENGGUNAKAN ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM

Oleh

FATEMEH KARIMALDINI

Mei 2011

Pengerusi: Profesor Lee Teang Shui, PhD

Fakulti: Kejuruteraan

Penyejatpeluhan merupakan pelengkap kitar hidrologi dan suatu komponen penting dalam pembangunan dan pengurusan sumber air, terutamanya di kawasan keadaan gersang dan separa gersang seperti yang terdapat di Iran, dimana sumber air terhad. Persamaan piawaian FAO-56 Penman Monteith (PM) memerlukan beberapa parameter meteorologi yang tidak biasa tersedia ada di stesen meteorologi, demi untuk menganggar sejat pemeluhan rujukan (ET_o). Tambahan pula, kaedah tradisional yang memerlukan parameter iklim terhad untuk anggaran ET_o tidak sesuai digunapakai dalam semua iklim. Sebagai alternatif, teknik kiraan-lembut boleh digunapakai untuk pemodelan fenonmena tak lelurus. Kajian ini berkenaan potensi teknik Sistem Taabir Kelam Saraf Suai (ANFIS) untuk pemodelan sejat pemeluhan rujukan harian dengan data cuaca terhad dalam keadaan gersang, separa gersang dan lembab yang terdapat di Iran. Teknik Ujian Gamma (GT) dipakai demi mencari kombinasi masukan terbaik dan jumlah data mencukupi untuk penentukuran. Set data

latihan dan ujian dipilih berdasarkan kaedah pengesahan silang Lipat-K demi merangkumi semua data yang boleh dipakai. Anggaran model ANFIS dibandingkan dengan ET_o hasil daripada pendekatan FAO-56 PM berset-kurang dan beberapa persamaan empirik ET_o (Hargreaves, Priestly Taylor, Makkink, Blaney-Criddle dan Turc) yang ditentukur dengan teknik Algoritma Genetik. Kaedah set-penuh FAO-56 PM dianggap sebagai persamaan ET_o rujukan, dan ianya diguna untuk menentukurkan persamaan lain dan model ANFIS. Perbandingan keputusan menunjukkan bahawa bila masukan meteorologi yang sama ditimbangkan, maka model ANFIS lebih baik prestasi daripada semua kaedah untuk keadaan gersang, separa gersang dan lembab di Iran. Tambahan pula, model ANFIS umum (yang mana masukan adalah suhu, sinaran suria, kelajuan angin dan angkali kegersangan) didapati boleh digunapakai di Iran. Kesimpulan bahawa berikutan suhu, data kelajuan angin merupakan parameter terpenting berkesan terhadap sejat pemeluhan dalam keadaan gersang, dan dengan masukan kedua dua parameter tersebut kedalam model ANFIS maka terhasil anggaran ET_o tepat. Akan tetapi kesan kelajuan angin dalam penganggaran ET_o dalam keadaan lembab didapati tidak bererti. Oleh demikian, teknik ANFIS syor diguna sebagai alternatif kepada kaedah tradisional yang mana keperluan ketat data meteorologi atau kerana tak-absahan dalam beberapa keadaan iklim.

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I certify that a Thesis Examination Committee has met on 12 May 2011 to conduct the final examination of Fatemeh Karimaldini on her thesis entitled "**EVAPOTRANSPIRATION USING ADAPTIVE NEURO FUZZY INFERENCE SYSTEM**" 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 master degree.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for other degree at University Putra Malaysia or at any other institution.

FATEMEH KARIMALDINI

Date: 12 May 2011

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