DEVELOPMENT OF A FUZZY INFERENCE SYSTEM TO PREDICT RUNOFF USING ONLY RAINFALL DATA FOR ROW CROP WATERSHED IN THE CLAYPAN REGION

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Estimation of surface runoff from a watershed is a pre-requisite to determine pollutant loss, develop regulatory measures such as Total Maximum Daily Loads (TMDL), and to forecast the water supply during spring and early summer (Mahabir et al., 2003). Regression models used for forecasting runoff for water supply often do not perform well especially in forecasting low and average runoff events, and when data are limited (Mahabir et al., 2003). These researchers emphasize that regression equations are site specific and must be developed for each site. Sen (2009) states that mathematical modeling which forms the basis for many hydrological modeling systems is based on a set of restrictive assumptions and often overlooks the fuzziness or variability in the problem. Sen (2009) also states that hydrologic events are often too complex to be described precisely using mathematical formulae. In hydrology, the two most valuable sources of information are: hydrologist's expert views and measured data. In classical hydrologic modeling, there is no role for valuable experience of the expert. In most instances of hydrologic studies, numerical data may be limited, but the hydrologist's observations provide a set of linguistic information that can lead to logical and rational thinking and formulation of a preliminary set of rules (Sen, 2009).

Fuzzy logic offers a way to incorporate expert opinion into the internal structure of modeling through fuzzy sets (Zadeh, 1965). Another advantage is that fuzzy systems are independent of the volumes of historical data. In fuzzy inference systems (FIS), the performance of the inference engine depends on the fuzzy membership functions and fuzzy rules. To make a good inference, a well constructed problem with specific membership functions and set of rules governing the solution are essential. Rainfall-runoff relationships are somewhat uncertain in nature and optimization of a fuzzy inference system is essential to develop best combinations of input and output. The genetic algorithm (GA) which mimics the process of natural evolution is one of the most popular types of Evolutional Algorithms (EA) consisting of a generic population based meta-heuristic optimization algorithm (Frazer, 1957). The goal of this study was to investigate the potential of an FIS to predict runoff from measured rainfall data for three long-term monitored watersheds at Greenley Memorial Research Center, Knox County, Missouri (Udawatta et al., 2002). Objectives were to develop fuzzy membership functions for input rainfall and output runoff, develop a set of rules optimized by GA, train the FIS model using measured runoff data from the Center watershed and validate using the measured runoff data from the East and West watersheds.

Fuzzy toolbox of MATLAB 7.10.0 was used for FIS development. Five Membership Functions (MF) for both rainfall (Figure 1a) and runoff (Figure 1b) and five FRs (fuzzy rules; Table 1) were developed using measured rainfall-runoff data for1991 to 1997 for the center watershed. The FIS's type was Mamdani, AND method was min, OR method was max, Implication was min, Aggregation was max, and defuzzification method was centroid. The GA initial population consisted of five chromosomes in which five genes are used to represent five input and output membership functions. Each chromosome with an alternative set of rules was evaluated for its fitness by the FIS and the error sum of squares was determined using the measured and FIS output for runoff. The chromosomes of each generation were sorted according to the probability calculated based on the fitness values before the selection process. For the selection of first pair of parents for crossover, elitism was used hence the top two from the list are always selected for the next generation. The rest of the parent pairs were selected using roulette wheel selection. Random one point crossover was carried out with the probability of 0.8. Mutation was carried out by replacing a random gene with a random number representing the rules with a probability of 0.1. One hundred iterations were carried out and the highest fitness chromosome was selected as the best rule base for the FIS. After convergence when no more changes occur that rule set was used by the FIS to predict the runoff from rainfall. FIS with GA optimized MFs and FRs was used for validation using data from the East and West watersheds.

The FIS system predicted daily runoff with an r^2 value of 0.74 during calibration of the Center watershed (Figure 2a). Coefficients of determination of 0.72 (Figure 2b) and 0.83 (Figure 2c) values were obtained during validation for West and East watersheds, respectively. The developed FIS system automatically adjusts the problem specific conditions of rainfall-runoff relationships by the GA. These results shows that the GA optimized FIS has the potential to predict rainfall-runoff relationships. The potential of FIS for better prediction of runoff than classical regression models has been demonstrated for other geographic regions (Şen, 2009; Mahabir et al., 2003; Barreto-Neto and Filho, 2007; and Yu and Yang, 2000). The current study utilized only the GA for optimization of the rule base. Optimization of membership functions using GA would further improve the FIS predictability of this system. Additionally, fuzzy models have been transferable to other watersheds (Mahabir et al., 2003).

Developed fuzzy models offer a simple tool for TMDL estimations of runoff using only runoff-rainfall relationships for a representative area of the watershed rather than requiring a large amount of detail about the watershed as is typically required for physically based models. This enables development of regulatory measures to control non-point source pollution from watersheds to water bodies where long-term data are unavailable. Using a set of training data, the developed fuzzy model could be used to estimate not only runoff but sediments, nutrients and other non-point source pollution for other regions.

Table 1. Set of fuzzy rules used for study.

IF Rainfall is low THEN Runoff is low
IF Rainfall is medium low THEN Runoff is medium low
IF Rainfall is medium THEN Runoff is medium
IF Rainfall is medium high THEN Runoff is medium high
IF Rainfall is high THEN Runoff is high

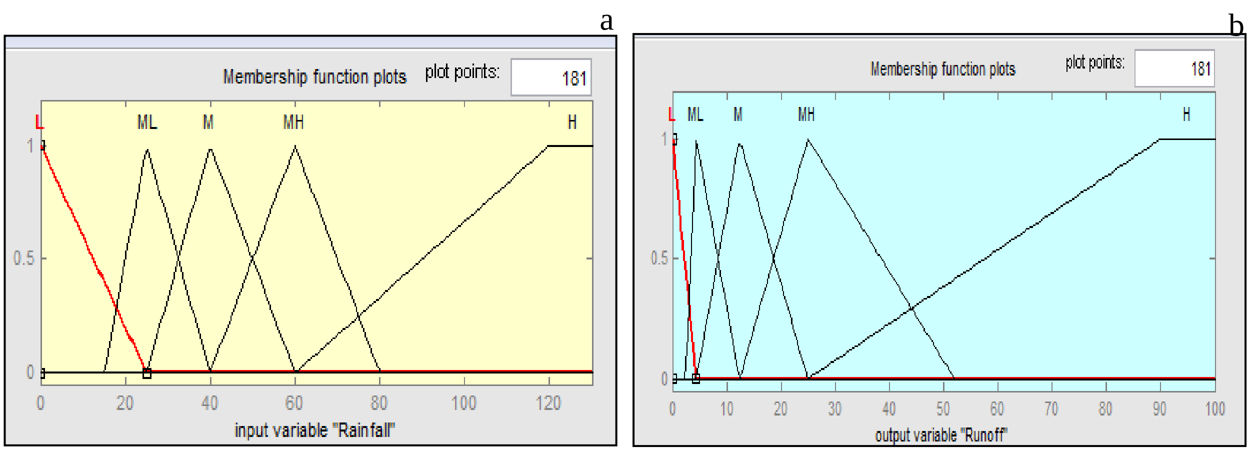

Figure 1. MATLAB representation of membership functions for input variable "Rainfall" (a) and output variable "Runoff" (b). The y-axis represents the degree of membership ranging from 0 and 1. Data label representation of membership functions: L- low, ML-medium low, M-medium, MH-medium high, and H-High.

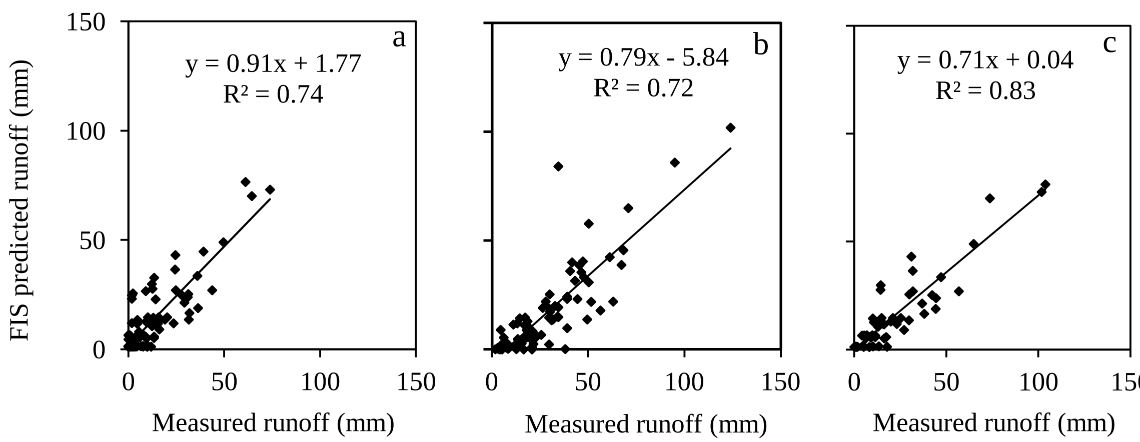

Figure 2. Measured and FIS predicted rainfall-runoff relationships for the Center, West, and East watersheds (a, b, and c) at Greenley Memorial Research Center, Knox County, Missouri.

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