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Estimating Occurrence Likelihood of Heat Waves Using Fuzzy Logic (Case Study: Southern Part of Central Alborz)

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Abstract: Heat waves are among the most important climatic evils that leave every year detrimental environmental consequences on the nature. Accordingly, the main objective of the present research is to identify occurrence likelihood of heat waves in Tehran and Doushan Tappeh regions. For this purpose, daily statistics of maximum temperature belonging to climatic station in the area of study were used during statistical interval from beginning of 2009 to the end of 210 (730 days). In the present research, turning point test was applied in order to verify randomness of data which shall be checked in the first step. The results indicated that fuzzy logic underestimates heat waves for temperatures below 30°C and overestimates the phenomena for temperatures over 30°C.

Key words: Occurrence likelihood, heat waves, fuzzy logic, Tehran and Doushan Tappeh, Iran

INTRODUCTION

Excessive increase in use of fossil fuels, change in land uses, increased world population and consequently, exceeding expansion of industrial activities for supplying welfare and requirements of the planet have caused noticeable and gradual alterations in the earth's climate following industrial revolution. The most notable change is a rise in average global temperature, increase of extreme climate phenomena such as floods, storms, hail, tropic hurricanes, heat waves, sea level rise, melting of polar ices, drought and so on. Therefore, global warming process is among the most significant climate changes in the present century which have been analyzed by researchers at regional and global scales (IPCC, 2007). Presence of global warming phenomenon is "certain". Earth's temperature has increased 1.3°F (0.72°C) during the last 100 years and sea level has risen 0.007 inch per year since 1961 onward. If average global temperature increases for another 2.7°F, approximately 20-30% of all fauna and flora will be threatened by extinction. If the increase is 6.3°F, between 40-70% of living species will be extinct. Heat waves are among the extreme atmospheric events causing severe losses in human life and destroy the environment. A heat wave is a warm period that can persist for a couple of days up to several weeks and it might be accompanied with intense humidity as well. Heat waves are considered as a type of extreme phenomena that occur with increasing temperature trend in arid regions during cold and warm periods. The respective heat waves are followed by a series of problems as below:

- Heat burn and the resulting death
- Rise in ambient temperature and thereby, problems in electricity consumption and electricity outage
- Reduction in snowfall and as a result, negative impact on underground waters (aquifers)
- Decline of garden crop yields as a result of temperature abnormalities in winter and premature arrival of spring (e.g. in early March in Iran)
- Rise in ambient temperature resulting in forest fires
- Retreat of mountain glaciers and decrease in river water fed by the respective glaciers which generally lead to disruption of water cycle
- Odd allergies and reemergence of diseases which were prevalent only in distant past
- Mental and social effects on people

Occurrence of heat waves, especially in cold season of year, is one of the most significant factors that can reduce durability of snow reserves in mountainous basins and adversely affect moisture rate of soil (Ostro *et al*., 2009). Ascending temperature trend is more intense in stations of Northwestern, Northern and to some extent,

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Western mountainous and snow-capped regions of Iran than the Southern regions. And their annual snow reserves will melt with greater acceleration in future and river sediments will increase. Hence, the accelerating dam construction trend in these regions shall be resumed more cautiously and necessity for priority of implementing water infiltration projects (watershed management) and water collection (dam construction) shall be taken into account more seriously.

In Iran, stations nearer to seal level and located at lower latitudes exhibit greater potential to experience heat fociduring the cold half of the year. Yet, this phenomenon has another aspect which is revealed by identifying spatial foci of their waves. When a heat wave persists longer during a cold season, it becomes more detrimental to snow reserves in elevated and mountainous areas. Detrimental impact of such waves resulting from incremental effects of heating factors like increase in positive balance of soil temperature in consecutive days is by far greater than the heat wave with a single and sudden peak. Winter melting of snow in mountain flanks unexposed to sunlight is more sensitive to overall increase in ambient temperature than to smaller increases both in terms of time and space. Role of humans in changing land uses in North and Northwest areas including excessive deforestation and expansion of urban spaces has given rise to the recent increase in prevalence of heat waves during cold seasons. The factor that might worsen the situation in the respective regions is intimidation of deterring capitals as a result of more frequent occurrence of fires in North forests during Autumn and occasionally late Winter and early Spring.

Despite many research works conducted on synoptic factors of heat wave generation and their environmental and human consequences (Rensch, 2009, 2006; Benjamin *et al*., 2006), few studies have been carried out on climatic behaviors such as abundance (frequency), intensity and durability of this phenomenon (Abaurrea *et al*., 2007). It must be admitted that heat waves gave become more frequent, more extensive and more prolonged as a result of climate changes. Therefore, it is vital to identify the features of heat waves, their durability and distribution (Esmaeel Nezhad *et al*., 2011).

Fuzzy logic has been deployed in other fields as well. For example, it was used for estimating flow rate by Nabizadeh *et al*. (2012) or estimation of evapotranspiration (Moradi *et al*., 2012) and or in combination with ArcGIS for zonation of natural disasters. Thus, the objective of the present research is to assess occurrence likelihood of heat waves in Tehran and Doushan Tappeh regions by means of fuzzy logic technique because heat waves can turn more frequent, more intense and more durable than before as a result of recent climate changes (WHO, 2003). It is noteworthy that the present research is highly crucial for two main reasons: lack of studies on this subject and on other hand as the most significant climatic threat.

MATERIALS AND METHODS

This research was performed in Southern part of Central Alborz. To carry out the present project, fuzzy logic method in MATLAB software was used as follows:

Fuzzy logic: The fuzzy logic proposed by Asgar Zadeh (1965) provides a language with meanings and syntax, in which one is able to translate the qualitative knowledge about the problems that shall be resolved. Fuzzy logic is a greatly powerful problem-solving method with endless applications devised for information control and processing. Fuzzy logic offers a simple and remarkable way for acquiring certain results from uncertain and irregular data. It can be in fact asserted that fuzzy logic simulates human's decision-making using approximate solutions and data with high capability. Numerous factors are considered for increase of questions but the most important one is rapid growth of fuzzy logic application and software computation in design of intelligent systems. As one of the most significant constituents of software computations, fuzzy logic plays a key role in designing different systems. There are two concepts in fuzzy logic that play essential part for prediction model of heat waves. The first concept is linguistic variable; the variable whose values are words and sentences in natural language. The second concept is the "if-then" fuzzy rule in which the results are prepositions that comprise lingual variables. The necessary function generated by linguistic variables is their prominence and dependences. Linguistic variables and if-then fuzzy rule can be applied in software computations via analysis. In this relationship, fuzzy logic has a major ability in simulation of human brain for saving data and making decisions because decision-making is mainly considered in fuzzy logic techniques or its alternative techniques. The present research takes advantage of fuzzy logic for creating security strategy for managerial objectives. The theory of fuzzy sets is used to complete this framework for deployment of fuzzy behavior aimed at judgment by decision-makers.

Fuzzy sets of operations: The fuzzy sets used in the current study include:

- Fuzzy temperature

- Fuzzy time
- Fuzzy supplement

Fundamentals of fuzzy rules: This model is presented in its general form and adjusted such that it would be able to match the data from a simulation error recognition process. The respective model is capable of accurately classifying and matching 90% of temperature behaviors while applying similar rules in nearly 70% of the respective time. The problem-solving rules of this model were selected based on retrieval values, efficiency and simplicity. These rules were mainly applied in information searching based on the information of their abbreviations. A generation rule consists of two parts: condition and conclusion. If the conditions are met, the activity will take place:

- The first rule: if (temperature C is high) and (ratio C is good) and (validity C is also good); then, the decision is recorded
- The first rule: if (temperature C is low) and (ratio C is bad) and (validity C is also bad); then, the decision is rejected

Fuzzy inference system editor: Fuzzy Inference System (FIS) editor classifies a high level of data for the system. Like number of input and output variables and their names, different kinds of "OR" and "AND" operators as well as membership function methods are used for system variables.

Rule editor: This is enables the user to define and edit certain rules that describe system behavior.

Rule reviewer: This is an only readable tool that incorporates the whole fuzzy inference plot.

Surface reviewer: This is also an only readable tool that determines how an output data depends on one or two input data

Membership function: A Membership Function (MF) is a curve that shows how each point of input space is mapped to a membership value (or membership degree) ranging from 0-1. Input space is normally referred to as "the world of discourse". In this model, the authors have defined rule for each single parameter of temperature data of provinces. The only condition that a membership function must actually satisfy is to range between 0 and 5. The function itself can be any sort of arbitrary function. The form of this function might vary in terms of simplicity, flexibility and efficiency in order to attract the authors' satisfaction.

The fuzzy logic toolbox contains 11 types of premade membership functions. The authors used trapezoidal functions for the given dimensions in the present research. These functions are available in SIMULINK library.

Fuzzy logic toolbox: For construction of system using fuzzy logic toolbox in MATLAB software, only the graphic interface available in fuzzy logic toolbox was used.

Five major graphic tools were prepared for constructing, viewing and editing the system in this toolbox:

- Fuzzy Inference System (FIS) editor
- Membership function editor
- Rule editor
- Rule viewer
- Surface viewer

These graphic interfaces are interconnected dynamically such that change in system using each of the mentioned tools will impose appropriate changes on each of the open tools.

Definition of fuzzy variables: The estimation model of heat waves has 11 dimensions each of which have their own sub-dimensions. In the defined systems, first letter of each dimension word is assumed as the name of the variable. A fuzzy inference system was also designed for each sub-dimension; these systems are Mamdani-type. Output of each system is given to the main system which is of Sugeno type whose rules are updated, tested and trained by means of a back-propagation neural network. A sample of these variables is observed in Fig. 1. Output of mamdani system is fuzzy but output of sugeno system is crisp.

Generation of sugeno fuzzy system output: Takagi, Sugeno and Kang proposed and introduced Sugeno Fuzzy Model in 1985. In this model, members of output fuzzy set are either linearly correlated or are constant. A typical fuzzy term or rule can appear as below: "If the first input equals X and the second input equal Y; then, the output will be $z = f(x, y)$".

If $f(x, y)$ is a first-order polynomial, FIS is called a fuzzy model of the first order. If $f(x, y)$ is constant, FIS is called zero-orderSugeno fuzzy model.

Data pre-processing: Before any processing can be performed on the data, their randomness shall be verified first. In this stage, turning point test is used for this

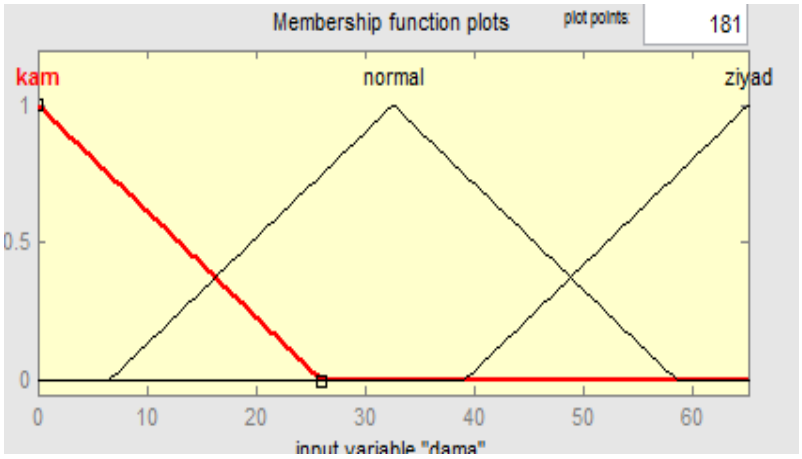

Fig. 1: A sample of fuzzy variables

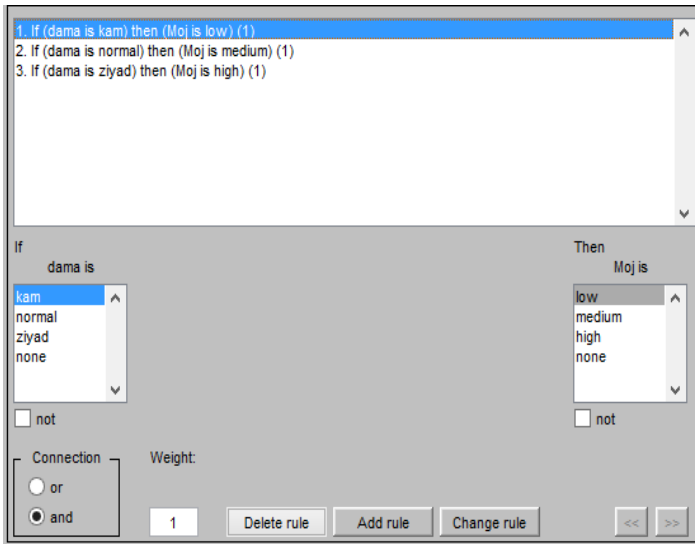

Fig. 2: The rules implemented in estimation of heat waves

Table 1: Turning point test results

Parameter	P	E(P)	Var (P)	Z
Maximal temperature	13	12	3/23	0/93

p is number of inflection points, E(p) number of expected turning point points, Var(p) is variance of P, Z is describer of p based on normal standard (Alizadeh, 2006)

purpose (Nabizadeh *et al*., 2012). The results of this test indicate that the data are absolutely random and Z values for the input parameter are in the permissible interval of (-1.96+1.96) (Table 1).

Determining model inputs: Based on the literature review (Esmaeelnezhad *et al*., 2013) in the present research, the input parameter for this work is maximal daily temperature data, which were analyzed for the years 2009 and 2010 in Doushan Tappeh and Tehran regions.

Prediction of heat waves by fuzzy logic

Fuzzification of input and output variables: Times series of input and output variables are arranged as a set in which each row has a series of input data in the first column and output data in the last column. In the next step, three intervals of "small", "moderate" and "large" are assumed for these data such that the data are distributed almost equally in three intervals.

Determining rules of models: In this section of research, 3 rules are considered in MATLAB software environment as illustrated in Fig. 2. Analysis of output the designed fuzzy system is shown in Fig. 3.

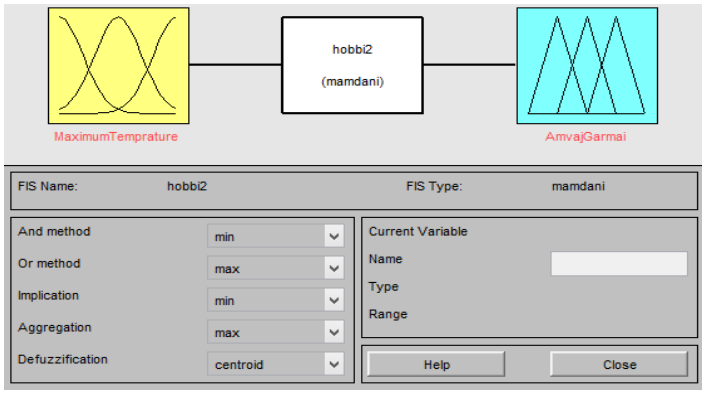

Fig. 3: The fuzzy system designed for model

Fig. 4: Estimated of heat values for years 2009 and 2010 in Tehran and Doushan Tappeh (Vertical axis: heat wave value-horizontal axis: year)

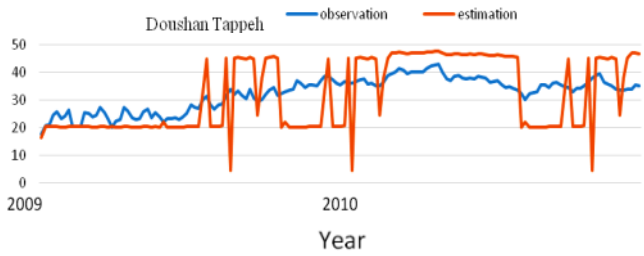

Fig. 5: Estimated of heat values for years 2009 and 2010 in Tehran and Doushan Tappeh (Vertical axis: heat wave value-horizontal axis: year)

RESULTS AND DISCUSSION

Identification and detection ofheat waves and extreme temperatures is different from other evaluations of environmental hazards. Climate diversity and variability cause different extreme temperatures from one place to another and from one time to another and complicate our insight and comprehension of heat waves.

Figure 4 and 5 illustrate estimated values of heat values for years 2009 and 2010 in Tehran and Doushan Tappeh. The estimated values were also compared with observed data. MATLAB software and efficiency of fuzzy logic in estimation of heat waves implied that the simulation underestimates temperatures below 30°C and overestimates the temperatures over 30°C. Overall; temperature varies in different months of the year. It is colder in the first 6 months, i.e., Spring and Summer and heat waves are more likely to occur than the latter six months (Autumn and Winter).

Model performance: According to Fig. 6, the results of fuzzy logic have the proper accuracy and precision for predicting heat waves.

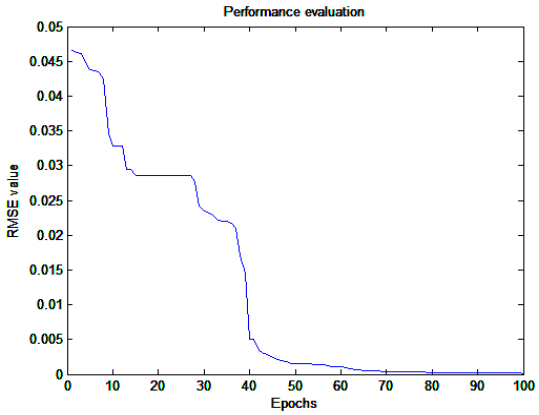

Fig. 6: The results of fuzzy logic the proper accuracy and precision for predicting heat waves

CONCLUSION

Heat waves occur repeatedly in Iran's climate and are among the most critical climatic hazards all around the world. In the present research, fuzzy logic system was used to predict heat waves. Initially, turning pointtest was applied to verify randomness of data. To assess overall conditions of the heat wave governing a zone, maximal daily temperature data of Tehran and Doushan Tappeh were used. Performance of fuzzy logic in estimation of heat waves demonstrated that the software simulation underestimates temperatures below 30°C and overestimates temperatures over 30°C. In general, temperature varies in different months of the year. Based on the estimations, occurrence likelihood of heat waves is low in cold seasons, especially Winter and the highest during the Summer months. Therefore, it is deeply crucial to pay attention to heat waves and identify them in the entire year because some measures can be devised to mitigate threats and harms of these hazardous waves via identifying and predicting them.

RECOMMENDATION

It is recommended at the end to use other methods for estimation of the heat waves in order to identify an accurate method for this purpose.

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