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Probable Maximum Precipitation (PMP) Prediction Using Rule-Based Fuzzy Inference System: A Comparison with Classic Methods

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ABSTRACT

Precipitation is predicted for different days of the year using fuzzy logic, the Mamdani fuzzy system, and IF-THEN rules. The input variables include five parameters of relative humidity, cloud cover, wind direction, temperature, and surface pressure, each with three membership functions ranging from 0 to 1. The final answer will likely be the amount of rainfall. All input variables are fuzzy, and two types of membership functions are selected. As many as 51 rules are considered for each station. Finally, the best situation of precipitation is chosen, and PMP obtained is applied to Kahir catchment basin, Sistan and Baluchistan. The fuzzy PMP is then calculated and compared with the Hershfield classic method for calculating PMP. Results show that fuzzy PMP estimation is more accurate and reliable for the studied area than the Hershfield method. All implementations are performed with MATLAB.

1. Introduction

Precipitation prediction methods are often based on classical and statistical methods, which based on the method of feature selection and suitable ergodicity structure, favorable by the designer, and dependent on judgment and subjective elements involved in their implementation. Practically, modeling these types of systems with classical statistical methods involves many difficulties and complicated calculations, while fuzzy systems can usually provide valid answers. In the classical method, precipitation is estimated by a set of assumptions such as linear and normalization equations, and ergodicity is taken into account. However, the nature of fuzzy systems is based on simplification, which can be more convenient in modeling hydrologic systems [1]. Some researchers, such as Tsonis and Elsner (1992) have discussed the uncertainty of meteorological systems [2]. Sivakumar et al. (1999) studied on model uncertainties [3]. Sivakumar (2001) worked on model uncertainties and stated that disordered patterns were considered atmospheric phenomena that are another source of uncertainty [4]. Shao (2000) considered cloud cover, cloud type, wind speed, and relative humidity as fuzzy inputs for temperature prediction [5]. Hansen (2003) suggested the amount of cloud for predicting a fuzzy-based method [6]. Suwardi (2006) concluded that neural fuzzy systems can be used to predict more seasons [7]. Arnud et al. (2007) created a model based on independent variables [8]. Ellouze et al. (2009) reviewed precipitation occurrence in southern Tunisia based on data analysis on a monthly and yearly basis [9] . Melani (2010) used satellite images to study summer monsoon precipitation in Africa [10]. Charabi and Alhatrashi (2010) studied the relationship between winter precipitations in a broad area conducted with synoptic methods on a monthly basis [11].

Bookh Hagen (2010) conducted a study in the Himalayan region for precipitation incidents. Further works in this area are statistical models [12]. Statistical solutions are dependent on statistical techniques in most cases, but disturbed systems such as the atmosphere are not compatible with these statistical methods. Research has shown that statistical methods and predictions contain errors due to atmospheric uncertainties and there is not sufficient knowledge of formulation for Ergodicity modeling [12]. Another problem is often simplifying the equations. The fuzzy logic seems suitable for modeling complex systems in this field. So far, fuzzy techniques have been applied for predicting precipitation [13], climate division [14], and temperature-humidity indexes based on fuzzy rules [1].

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2. Materials and Methods

2.1. THE REGION UNDER CONSIDERATION

The Kahir desert (Long. 60°45' E., Lat. 25°25' N.) is located in the southern part of Sistan and Baluchistan province, 80 km west of Chabahar in North of Pozam Gulf. Kahir village is the largest oasis in the region with a population of 900 located near the Kahir River. It is linked to Konarak with a 60-km asphalt road. Rainfall is low in the region, but short-term rainstorms are frequent and severe. The average rainfall is annually reported to be mm. The only and most important river that flows into Kahir is the Nik Shahr River, known as the Kahir River, in the southern section. The area of the catchment basin is almost 4700 km^2. Fig. 1 displays the location of this catchment [15].

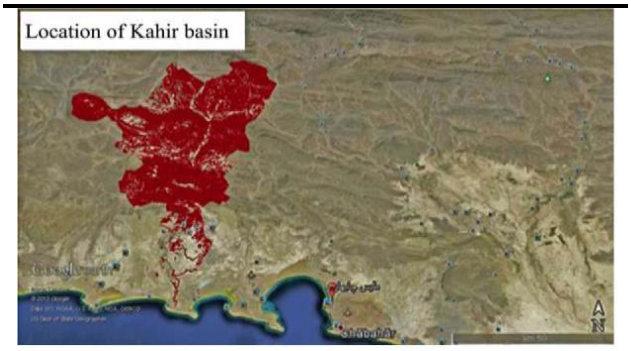


Figure 1. The location of the Kahir catchment basin

2.2. FUZZY LOGIC

A membership function shows the degree of belief that an object belongs to a particular set of objects. The membership degree is continuously chosen between 0 and 1, and the usual set of properties can be extended to fuzzy sets. There are various ways to obtain a fuzzy concept, such as the use of common sense and knowledge of expert systems, as well as statistical methods. Statistical methods are divided into two categories of direct estimation and abundance. In the abundance method for the selection of a membership function, specialists are chosen in certain fields to ask if an object is the member of a desire set. However, in the direct estimate method, experts are asked in the certain scale to give their opinions. For instance, by setting a questionnaire with certain words to form «x member of A», they are asked to rate their beliefs as in the certain scale of zero to one hundred announce. By taking the average of membership degree into account, elements are calculated from the set. The above methods are considered manual methods and set membership function. In recent years, genetic algorithms and neural networks are used as intelligent methods to obtain membership functions. Membership functions can have taken depending on the nature the problem and comments people many forms which went on, to most common these forms including of triangular membership function, Gaussian, trapezoidal, etc. for more information refer to [17].

2.3. MAMDANI INFERENCE SYSTEM

In Mamdani inference system, combination turning (AND) to combine membership functions prior conventional techniques include minimum and multiplication algebraic and order to disjunction Seasonal (OR) for combination membership functions typical methods maximum and Probabilistic. This system is mostly used to turn from min operator. For implication rules to mean impact and signification prior rule on Tali, it becomes min (minimum) or prod (multiplication algebra) can be used. For aggregation results, rules the individual in this system max (maximum), sum (sum or Summation) or Prober (multiplication algebra) are used. The desired relations can be made through such characteristics. Mamdani-type inferences are required for membership function of the output of the fuzzy set. Aggregation process for each output variable requires defuzzification to obtain a unique output. Defuzzification methods include centroid of level, bisector and smallest of maximum, the largest maximum, and the mean maximum amount output set (middle of maximum or MOM).

It is possible to construct relationships with such characteristics. The system is described to illustrate this example. In this example, the current weather conditions are determined according to two fuzzy variables including temperature and humidity. According to the steps to solve the fuzzy expression, the initial fuzzy system is determined as the Mamdani fuzzy inference system. Then, membership functions and fuzzy sets for both input and output variables and in the different modes are performed. Afterward, fuzzy sets prior to the help of conjunction or that season with turning (AND) and from type (min) are combined. Here, it is if need any of the weight distribution the weight between zero and one (the sum of them per rule is one) takes. After weighting the rules, their powers can be changed in the implications and inferences. Power rule first and third one and two other law 0/5. For implications and provision on functions or fuzzy sets, outputs from the method of least (min) are used. Then, for the aggregation of the maximum and at last, by using centroid method Non-fuzzy, the unique results are obtained. Rules are as follows [18]:

1 – In case of high temperature and high humidity, when the weather is hot, then rule weight = 1

2 - If the average temperature and humidity are high, then the weather is normal and rule weight =0.5

3 - If the temperature and humidity are low during cold weather, then weight = 1

4 - In the case of average temperatures and low humidity, the weather is typical and rule weight = 0.5

3. CASE study

Here, we try to predict precipitation for different days of the year using fuzzy logic and obtain information to be carried out separately for each day. The Mamdani fuzzy system and IF-THEN rules are administered. As many as 5 parameters including relative humidity, amount of cloud, wind direction, temperature, and surface pressure are considered input variables. The final answer will likely be the amount of rainfall. Each variable includes three membership functions ranging from 0 and 1. All input variables are fuzzy. Two types of membership functions are selected: triangular and trapezoidal membership functions. The trapezoidal membership function is defined as follows:

$$f(x,a,b,c,d) = \max(\min(\frac{x-a}{b-a}),1,(\frac{c-x}{d-c}),\circ) \quad (1)$$

The triangular membership function is defined as follows:

$$f(x,a,b,c) = \max(\min(\frac{x-a}{b-a},\frac{c-x}{c-b}),\circ) \quad (2)$$

MATLAB software is used for this purpose. Five inputs and one output were defined. According to the characteristics of the studied area, relative humidity is ranged from 0 to 100%, and three membership functions include poor, medium, and excellent. The degree of cloud ranges between 0 and 8. It was considered for three membership functions of poor, medium, and excellent modeled by the trapezoidal membership function. Pressure in the study area ranges between 995 hpa and 1030 hpa. During the statistical period in the table, there are three membership functions including low, medium, and high temperatures ranging between 5 and 50°C in the region. Climatology and synoptic stations in the region are presented in Table 1.

As many as 51 laws are written for each station, for example:

1- IF humidity is excellent AND IF total cloud is excellent AND IF wind direction is excellent AND IF pressure is low AND IF temperature is excellent, then rain measure is high.

2-IF humidity is poor AND IF Total cloud is poor AND IF wind direction is poor AND IF pressure is high AND IF temperature is poor, then rain measure is low.

The output membership functions are types of triangular and four conditions including poor, low, medium, and high in [0-1]. The membership functions are selected with successive tests among different membership functions. After defuzzification, responses are obtained. The centroid method was selected for defuzzification. This is as follows:

$$Z = \frac{\sum_j^4 z_j u_c(z_j)}{\sum_j^4 u_c(z_j)} \quad (3)$$

This is z centroid u_c membership function amount z_j.

Table 1. Geographical location area stations and statistical period [6]

statistical period	Height from sea level	longitude	Latitude	Type of station	Name of station
57-91-51-61	50	60-80	25-37	Climatology	Kahir
55-62-52-86-60-63	70	60-53	25-45	Climatology	Pirsohrab
63-91	8	60-30	25-30	synoptic	Konarak
60-91	12	59-20-24	25-42-52	Climatology	Zar abad
83-91	395	60-10-46	26-90-51	Climatology	Jalaiee kalak

The validity of the model was checked by the probabilistic method. The prediction probabilities, i.e., the probability of the occurrence of a phenomenon, range from 0 to 100 (0 to 100%). Practically, predicting the occurrence probability

of a phenomenon is meaningless and is checked for a set of parameters. Here, we checked this phenomenon in which the fuzzy system is malfunctioning to what extent in predicting. For investigating the probability of occurrence of rainfall, the probability of occurrence p_i for phenomena that predicted correct occurrence, probability $(O_i = 1)$ and for those that have not joined occurred probability $(O_i = \circ)$, verified by two parameters Bier Score which have been carried out mean square error of predict probability [19].

$$Bss = \frac{1}{N}\sum_{i=1}^{n} (p_i - O_i)^2 \quad (4)$$

$$Fss = 1 - Bss \quad (5)$$

That their difference with Score Fss in this any $Fss = 1 - Bss$ what will be better answer is occurred probability closer to zero. Finally, for reviews, statistical stations mentioned from 2006 to 2012 conducted by Excel, the parameter Fss here used for each station is as follows. Whatever parameter Fss is closer to one, better answer is achieved (Table 2).

Based on the results taken from Somia et al. (2011) fuzzy modeling results, they show that to what extent the model has been successful in predicting occurrence of rainfalls [18]. They introduced a similar model for the monthly occurrence of rainfall for two meteorological stations used in Egypt and rainfall fuzzy modeling for this area was evaluated as highly desirable but it is noteworthy to mention that choosing the type of membership function is very important in verification model. Also, although this expressed simplicity is much more Fuzzy methods toward Numerical Weather Prediction (N.W.P) answers are consistent with reality. Also, it has been mentioned that better answers are achieved with increasing data and statistical years. Also, taking fog and thunrdersome into account in the area, more careful responses will be achieved.

Table 2. Fuzzy rainfall model validation

Dec	Nov	Oct	Sep	Aug	July	June	May	April	Mar	Feb	Jan	month Name of station
FSS	FSS	FSS	FSS	FSS	FSS	FSS	FSS	FSS	FSS	FSS	FSS	Kahir
0/85	0/961	0/966	0/9714	0/95	0/9819	0/9735	0/965	0/96	0/97	0/84	0/91	
0/84	0/935	0/943	0/98	0/95	0/954	0/969	0/975	0/984	0/887	0/988	0/98	Pirsohrab
0/8668	0/96	0/9745	0/97	0/9610	0/8697	0/9652	0/98	0/9642	0/6462	0/7275	0/9609	Konarak
0/7023	0/91	0/9510	0/9201	0/8682	0/9362	0/8822	0/913	0/8232	0/8257	0/8681	0/8577	Abad Zar
0/7195	0/989	0/9109	0/7954	0/8083	0/8461	0/965	0/979	0/8530	0/9085	0/9199	0/9135	Kalak Jalaei

After validating the fuzzy precipitation process, now according to the validation process, the fuzzy method is used to calculate PMP and compare it with classic methods. Table 3 lists the Hershfield method illustrated step wisely. In Table 3, $\overline{X}_n$ is the mean maximum daily precipitation, δ_n is the standard deviation of the maximum daily precipitation, $\overline{x}_{n-m}$ is the mean maximum daily precipitation after removing the high amount, δ_{n-m} is the standard deviation of the maximum daily precipitation after removing the high amount, $C\overline{X}_{\max}$ is the mean correction coefficient of the maximum amount of observations, $C\delta_{\max}$ is the standard deviation correction coefficient of the maximum amount of observations, $C\overline{X}_{data}$ is the mean correction coefficient for statistical during the period, $C\delta_{data}$ is the standard deviation correction coefficient for statistical during the period, and Km is the Hershfield coefficient.

The amount calculated with the fuzzy method, PMP is in accordance with before taking the items with the higher membership function of relative humidity and being Level 1 (excellent) and low-pressure and temperature in excellent condition and the output of number precipitation extracted from this value is 67%. Here, decisions are made based on this percentage of maximum precipitation located in the region PMP more to consider. The most favorable conditions of rainfall in the region during the long period have been gained and it is expected if takes precipitation in this region with regard to the climatic conditions of the

region because extracting is situated greatest precipitation in area. Date is calculated:

The Hershfield PMP estimating method based on Chow equations is a common type of calculating. This equation was modified as follows in the standard Hershfield method.

$$X_{PMP} = \overline{X} + K_m \delta_n \quad (6)$$

in which X_{PMP} is probable maximum precipitation and K_m is a coefficient. Differences of the Hershfield method modified is more in K_m calculation. In the Hershfield method, modified accordance instructions Meteorological Organization (WMO, 1986) obtains at first K_m from $\overline{X}$.

Table 3. Calculation of PMP for Kahir station according to Hershfield method

Pirsohrab	Kahir	Station
38/5	30/4	$\overline{X}_n$
19/68	17/63	δ_n
37/1	29	$\overline{X}_{n-m}$
18/1	15/9	δ_{n-m}
96/4	95/9	$f(x) = \frac{\lambda^B (y-\varepsilon)^{B-1} e^{-\lambda(y-\varepsilon)}}{x\mu(B)}$ $\lambda = \frac{S_y}{\sqrt{B}}$, $B = [\frac{2}{C_s(y)}]^2$, $\varepsilon = y - S_y\sqrt{B}$, $y = \log x$
0/92	0/90	$\frac{\overline{\delta}_{n-m}}{\delta_n}$
0/99	0/99	$C\overline{X}_{\max}$
1/01	1/01	$C\delta_{\max}$
1/03	1/01	$C\overline{X}_{data}$
19/9	1/03	$C\delta_{data}$
18	30/3	Adjusted $\overline{X}_n$
19/9	17/8	Adjusted δ_n
18	18/01	km
396/2	351	PMP

Then, the maximum effect observed in the data is set, and also statistics during the period on mean and standard deviation is obtained for them. Finally, the correction coefficient of probable maximum precipitation is calculated. Calculating Coefficient K_m has broad sense world. In 1996, Hershfield of frequency general equation and by having high daily statistical before 90 percent in 2600 station was in America, are calculated K_m amounts. But, the Hershfield type II method is shown in Table 5:

$$K_m = \frac{X_1 - \overline{X}_{n-1}}{\delta_{n-1}} \quad (7)$$

where:

x_1: The highest maximum amount of annual precipitation observed

$\overline{X}_{n-1}$: mean annual maximum except for the maximum amount observed; namely x_1.

δ_{n-1}: Standard deviation of the annual maximum except for the maximum amount (x_1) .

The PMP with the Hershfield type II method was calculated for Chabahar area stations. The results of this study are related to two basins of Pirsohrab and Kahir in Table 5.

Table 4. Calculation fuzzy amounts

PMP Fuzzy amount	Date of occurrence	Maximum recorded precipitation	Station
217/1	85-86	130 mm	Kahir
143/62	77-78	86 mm	Pirsohrab

Table 5. Calculated parameters with Hershfield type II method

$K_m 2$	$K_m 1$	δ_{n-1}	$\overline{X}_{n-1}$	X_1	δ_n	Statistical period	$\overline{X}$	Name of station
2/8	2/45	17/7	27/3	77	19/6	31	29/8	Kahir
2/49	2/2	20/6	34/7	86	22/5	28	36/5	Pirsohrab

Using Table 4, PMP values are calculated with the Hershfield type II method as follows:

Table 6. PMP amounts with Hershfield type II method

Pirsohrab	Kahir	Method
92/525	83/78	Hershfield type II

In Table 7, the results of two Hershfield methods type I and II and also fuzzy method are presented for comparison.

Table 7. The comparison of three calculation methods of PMP

Pirsohrab	Kahir	Method
396/2	351	Hershfield type I
92/525	83/78	Hershfield type II
143/62	217/1	Fuzzy method

According to the maximum precipitation recorded in the Kahir station in 2006-2007, which was 130 mm, it is known that the Hershfield method type II correctly estimates PMP for the Kahir region.

In general, the fuzzy method presented in this section has very similar synoptic methods because in physical methods, probable maximum precipitation is based on Storms Properties Occurred to some extent rests in the area and is given through following relationships:

$$PMP = R \times r_m \times r_w \quad (8)$$

$$r_m = \frac{w_m}{w_s} \quad (9)$$

$$r_m = \frac{s_m}{s_s} \quad (10)$$

in which R represents observations of the maximum amount of precipitation, r_m is the maximum coefficient of moisture, r_w is the maximum coefficient of wind, w_m is the maximum precipitation available water of surface 100 mm Based on dew point with continuation of 12 hours and Return period of 50 years during statistical period the same time with storm, w_s is the maximum wind speed with continuation of 12 hours and return period of 50 years during the statistical period the same time with storm, s_m is the maximum wind speed with continuation of 12 hours and return period of 50 years during statistical period the same time with storm and s_s is the maximum wind speed with continuation of 12 hours and return period of 50 years during statistical period the same time with storm.

Therefore, considering which this fuzzy method rests on characteristics and condition of the area and increase Coefficient enters to the maximum observations

precipitation more than statistical methods is dependent on the physical characteristics of the area.

4. Conclusion

Here, the fuzzy inference system is used to model a complex phenomenon like precipitation prediction with the help of fuzzy methods, and PMP is calculated for the Kahir catchment basin and compared with aforementioned classical model (Hershfield type I, II). It can be seen that in general, the fuzzy method presented in this section has very similar synoptic methods because, in physical methods, probable maximum precipitation is based on storm properties Occurred to some extent rests in the area and is given through relationships that are considered in fuzzy methods. The fuzzy logic is a reliable method for modeling complex systems. Hershfield type II estimation is not accurate and Hershfield type I seems to be over-estimating. However, fuzzy estimation has validation and seems to be logical because it can pass BSS and FSS factors and it means that estimations are suitable and reliable for use in the PMP calculation process.

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