DESERT

DESERT
Online at http://jdesert.ut.ac.ir

DESERT 15 (2010) 127-132

Comparison of physical and statistical methods for estimating probable maximum precipitation in southwestern basins of Iran

E. Fattahi[a*], A. M. Noorian[a], K. Noohi[a]

[a] *Faculty member, Atmospheric Science and Meteorological Research Center (ASMERC), Iran*

Received: 2 October 2009; Received in revised form: 11 August 2010; Accepted: 3 January 2011

Abstract

The probable maximum precipitation (PMP) is the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographical location at a certain time of the year. In this study a physically based method was compared with a statistical procedure to calculate PMP in the southwest arid regions of Iran. In order to estimate PMP using a physically or meteorologically oriented method, such climatological elements as precipitation, dew point temperature, and wind speed were studied in seven synoptic stations in the region. Synoptic maps of appropriate time scales were also studied. Then widespread and severe storms with various durations were selected and Depth-Area-Duration (DAD) curves for all the selected storms extracted. Using the physical method, PMP estimations were obtained at different locations and then the results applied to areas of 1000, 5000 and 10,000 km^2. PMP estimations were also obtained through statistical analysis of the series of annual maximum 24 hour precipitations. The result showed that the values obtained through statistical procedures are more than two times those of meteorological method, for all the stations. Comparison of estimates indicated that least difference between two methods belongs to Abadan and the most difference to Bushehr, the magnitude of PMP in physical method is 39.2 and 22.8 percent of statistical method, respectively. Thus using statistical method for an estimation of PMP in the region leads to unacceptable consequences for a construction of water structures.

Keywords: Probable Maximum Precipitation; (PMP); Hershfield's method; Depth-Area-Duration (DAD)

1. Introduction

According to WMO (1986), Probable Maximum Precipitation (PMP) is theoretically defined as the greatest depth of precipitation for a given duration which is physically possible over a given size storm area at a particular geographical location and at a particular time of year. Hydrologists use a PMP magnitude together with its spatial and temporal distributions for the catchments of a dam to calculate the Probable Maximum Flood (PMF). In the case where the risk of a dam overtopping is deemed unacceptable, an estimate of the PMP depth is used to determine the PMF for that location. Using the PMP for a generation of the PMF has become as a standard method for dam design in many parts of the world. Since 1950 a number of methods have been developed for estimating PMP in USA and Australia. The National Weather Service (NWS) has published and updated numerous Hydro Meteorological Reports (HMRs) for estimating the PMP in different regions of the United States. The NWS approach for estimating the PMP generally has three major components, namely: moisture maximization, transposition to the location of interest, and envelopment of the maximized transposed depth-duration and depth-area amounts. Generalized tropical method, for some regions of Australia that are affected by tropical storms, has been developed during 1970s Kennedy, (1982). The generalized short

* Corresponding author. Tel.: +98 21 44580651,
Fax: +98 21 44580651.
E-mail address: ebfat2002@yahoo.com

duration method, for small-area PMP estimation, was developed in the early 1980, Bureau of meteorology, (1985). The storm model approach uses such physical parameters as surface dew point, height of storm cell, and inflow and outflow, to represent the precipitation process Collier and Hardaker (1996).

Douglas and Barros (2003) evaluated a multifractal approach for estimating high-hazard engineering design criteria. They assessed the utility of applying multifractal analysis techniques to systematically calculate physically meaningful estimates of maximum precipitation from observations in the eastern United States.

Hershfield (1961) found that Log Normal is not suitable for return periods of more than 50 years. In another research Hershfield (1965) showed that (K) value is changed by variation in mean daily maximum precipitation. A localized study on statistical estimation of PMP was carried out in Selangor state in Malaysia by Desa (2001).

The tentative estimates of probable maximum precipitation for small areas up to 1000 km^2 may be obtained through the statistical method developed by Hershfield (WMO, 1994).

In Iran, Ghahraman and Sepaskhah (1994) improved the suggested model developed by Betlahmy (1984) and offered a new method for estimating extreme rainfall values for the southern parts of Iran. They showed that values calculated on the basis of Hershfield (1965) and Betlahmy (1984), have significant difference from values by synoptical estimated method, but the results of Betlahmy (1984) procedure by applying a moisture coefficient, tend to approximately the same result as synoptical model. Salehipak (1999) estimated PMP on the basis of synoptically method for Mamlo basin dam in Iran. The result showed that appropriate selection of the greatest storm and precise calculation of moisture inflow coefficient can tend to estimate precise PMP values for the basin. Paimozd, (2002) estimated PMP by using synoptical and statistical calculated methods at eastern basins of Hormozgan province and then the results were put to comparison. The study indicated that PMP estimated from Hershfield (1961) method resulted in estimating larger values in comparison to the synoptical method, but the values calculated from Hershfield (1965) were closer to synoptical method.

The purpose of this paper is to identify a procedure that can be used to estimate PMP for southwest basins of Iran with an area of more than $1000Km^2$.

2. Materials and methods

Statistical procedures for estimating PMP may be employed wherever sufficient precipitation data are available, and are particularly useful where other such meteorological data as dew point and wind records are not available. Another procedure is based on the meteorological approach. The meteorological approach consists essentially of moisture maximization and transposition of observed storms. Wind maximization is sometimes employed.

There are two procedures for estimation of PMP by meteorological or synoptic approach, namely orographic and convergence models. Synoptic convergence model were used in this study.

Climatological elements that are applied in estimation of PMP values in physical method are:

-Dew point temperature (mean monthly, mean ten day and maximum 12-hour)
-Wind speed and direction (mean monthly, mean ten days and maximum 12-hour)
-Pressure (mean air QFE[1] pressure)
-Precipitation (maximum 24-hour)
-Synoptic maps of sea surface and upper levels in stormy days.
-In addition to the above data, in order to synoptically analyze the selected storm, hourly of wind speed and wind direction data, air QFE pressure, dew point temperature, cloudiness, and dry and wet temperature of each stormy day are needed.

The records of seven synoptic stations located in the south west of Iran were taken into account in this study. Figure (1) shows the geographical position of the stations used in the study. The record period used was for the years 1965-2004.

Maximization dew point factor

The worldwide accepted procedure for estimation of PMP is the so-called Moisture Maximization Method. The method maximizes observed storms assuming that the atmospheric moisture would hypothetically rise up to a high value that is regarded as the upper limit of moisture which is estimated from historical records of dew point. However Papalexiou and Koutsoyiannis (2006) have argued that fundamental aspects of the method may be flawed or inconsistent.

1. QFE is the pressure at the station level

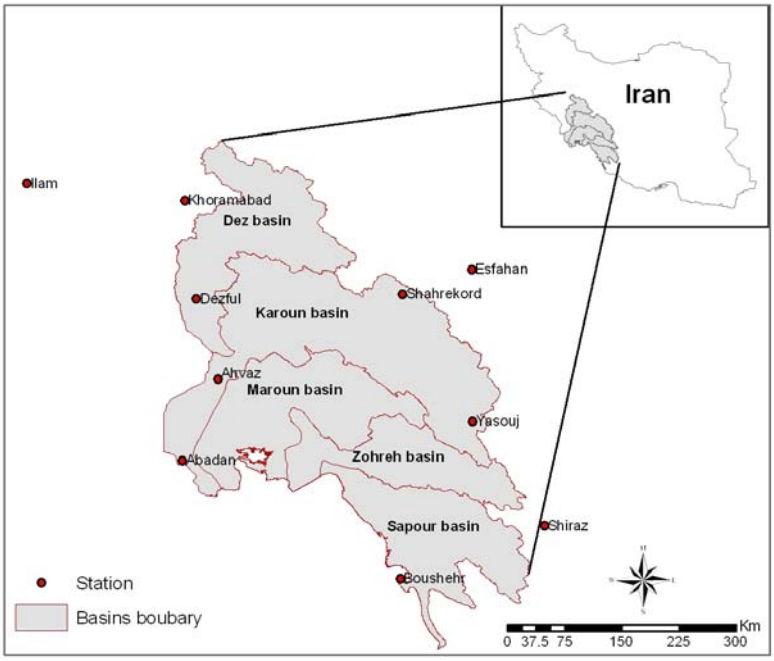

Fig. 1. Location of the study area

After selection of storms and estimation of mean rainfall depth for each sub-basin, it is necessary to estimate maximum humidity source in order to maximize selected storms. Storm moisture maximization factor was determined by using of surface dew point temperature in conjunction with an assumed saturated atmosphere above surface level. Surface dew point is used as a critical measure of moisture potential for severe storms. Maximum dew point for any location is chosen as the highest value persisting for 12-hour duration. In this study surface dew point data in 7 stations are considered as representative of inflow humidity source. Therefore, to calculate the maximum inflow humidity into storm, study of maximum persisting 12-hour dew point duration for the period under study in 7 stations and also dew point values of the stations at storm event are required. For an investigating of the maximum persisting 12-hour dew point duration in the period, 10-day recorded data for each year were extracted. Then maximum persisting 12-hour dew point values for each 10-day period were fit to normal distribution and the values of 100-year return period were calculated. By converting mean monthly pressure data at each station to 1000 millibar pressure level, the effect of topography can be ignored. Dew point temperature and maximum 12-hour persisting condition at the stations during all storm events were calculated and reduced to equivalent mean sea level (MSl, i.e.1000 millibar pressure level). For a reduction of dew point temperatures to 1000 millibar level, Figure 2 was applied.

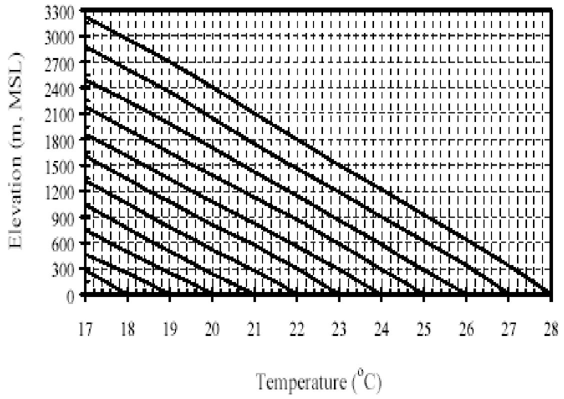

Fig. 2. Pseudo-adiabatic graph for dew point reduction to 1000 millibar

In the next step, variation of 10-day maximum 12-hour duration dew point data with 50-year return period (at the level of 1000 millibar) in each station were selected as corresponding to typical curves. Then the selected data were plotted and then by reading points from those curves, the humidity coefficients were estimated (Figure 2). Usually recorded dew points of a 12-hour period, in stormy days with the biggest values, were selected. Then the smallest of these values during storm event were used as maximum persisting 12-hour duration of dew point.

These values were also transferred to 1000 millibar level by using air pressures data in the stations during storm event to become comparable with each other. Then, by using equation (1) humidity coefficients were calculated:

$$FM = Wm/Ws \quad (1)$$

Where: Wm is the maximum precipitable water at 1000 to 200 millibar levels which can be obtained on the basis of maximum 12-hour duration dew point with 100-year return period in a simultaneous period with storm.

Ws is the maximum precipitable water at 1000 to 200 millibar levels which can be obtained on the basis of maximum 12-hour duration dew point simultaneous with storm.

Depth-Area-Duration

An important step in estimating PMP is the analysis of major storms. Through an analysis of the storms, Depth-Area-Duration (DAD) curves as the base for PMP estimates can be obtained. (DAD) is also applied to generalized relations for other areas or other basins with similar climate and topographic characteristics. This analysis includes collection precipitation data from various sources. The first steps in developing DAD relations require the precipitation records for all areas in the storm. Estimation of spatial distribution of rainfall is one of the basic steps in PMP studies. In this study Kriging methods are used for interpolation.

Wind maximization

Wind maximization is most commonly used in orographic regions (WMO, 1986). The wind maximization ratio is simply the maximum average wind speed for some specific duration and critical direction obtained from a long record of observations, e.g. 50 year, to the observed maximum average wind speed for the same duration in the storm being maximized.

Coefficient of maximization wind speed is based on equation (2) as follows:

$$MW = MW1/MW2 \quad (2)$$

Where:

MW is the wind speed maximization factor

MW1 is the maximum wind speed with a 100 year return period.

MW2 is the maximum persisting 12-hour wind speed during the storm.

Selection of intense and widespread storm

Intense and widespread storm is a weather situation that tends to create precipitation in all stations in the basin and even around the basin. Selection of intense and widespread storms was done on the basis of maximum discharge and daily maximum rainfall data with 24, 48, 72 and 96 hours duration during the period under study. Only two cases of these storms are analyses. Preliminary selection of the storm was on the basis of arithmetic average of rainfall at all existing stations in the region. Therefore, precipitations with various durations related to different dates were arranged in descending order and ultimately with accord to flood events the ideal storms were selected.

Statistical Method

Wherever sufficient precipitation data are available, statistical method is employed for estimating probable maximum precipitation. This method is particularly useful for making quick estimate, or where other meteorological data, such as dew point and wind records, are not available. The statistical method is recommended for basins less than 1000 Km^2, but has been used for larger areas with some corrections (WMO, 1986). This method requires annual maximum precipitation series in the region for required storm durations. The statistical method developed by Hershfield (1961) and modified later Hershfield (1965) is based on the general frequency equation (Chow, 1961). Equation (3) shows the general frequency equation

$$Xt = Xn + KSn \quad (3)$$

Where: Xt is the precipitation for return period t; Xn and Sn are respectively the mean and standard deviation of the serie with n annual maxima while K is a common statistical constant which varies with different frequency distributions. This method requires some adjustments, such as adjustment of mean (Xn) and standard deviation (Sn) of annual series for maximum observed precipitation and also adjustment of mean and standard deviation of annual series for length of record.

3. Results and discussion

Moisture and Wind Maximization Factors for a storm which lasted from 23 to 26 November of 1994 are presented in Table (1). This storm was observed in 7 stations. Table (2) shows dew points and maximum wind speed in the second storm which occurred at 30 March of 1998. This storm was observed only in 5 stations.

Results obtained from calculation of PMP values in the region in both physical and statistical method for 24-hour duration have been compared as in Table (3). As indicated in the table, the estimated PMP values in statistical method are more than those of the physical method. This is mainly due to occurrence of very rare events in recorded period. Storm precipitation data affect calculation of mean and standard deviation values. Length of record should be considered too. A long record will yield generally more reliable PMP estimates than will a short record of comparable quality. In other words, frequency distribution of extreme values is generally skewed to the right and therefore, correcting such events is recommended in PMP statistical estimates. Thus estimating PMP by this method can create conspicuous errors in basins under study. By considering the recommendations of WMO (1986), in case of availability of meteorological data, physical method yields in better results than the statistical method.

Table 1. Moisture and Wind Maximization Factors for Some Selected Storms For 23-26 November 1994

Synoptic Station	MPD[1] (°c)	SPW[2] (mm)	MPD[3] (°c)	EPW[4] (mm)	Moisture factor	MPW[5] (knot)	MPW[6] (knot)	Wind Factor	PMP Factor
Abadan	20.1	52.0	22.0	62.0	1.2	18.0	21.0	1.16	
Ahvaz	17.4	41.6	21.1	57.5	1.38	21	23.5	1.2	
Bushehr	17.1	40.4	21.2	58.0	1.43	15	26.1	1.74	
Mahshar	19	48	20.9	56.5	1.18	18	31.4	1.74	
Omidyeh	17.2	40.8	23.4	64.4	1.57	17	21.8	1.28	
Bushehr Coastal	19.6	50.4	21.8	61	1.21	20	32.5	1.62	
Aghajari	17.7	42.8	22.4	64.4	1.5	21	24.4	1.16	
Average					1.35			1.41	1.90

Table 2. Moisture and Wind Maximization Factors for Some Selected Storms For 30 Mar 1998

Synoptic Station	MPD (°c)	SPW (mm)	MPD (°c)	EPW (mm)	Moisture factor	MPW (knot)	MPW (knot)	Wind Factor	PMP Factor
Abadan	16.9	39.6	19.4	49.6	1.25	18.0	21.6	1.2	
Ahvaz	15.7	35.1	20.9	55.6	1.58	18	26.1	1.45	
Mahshar	14.8	32.4	19.1	48.4	1.26	22	31.4	1.42	
Omidyeh	16.6	38.4	19.1	48.4	1.26	18	20.5	1.14	
Dezful	17	40	20.4	53.6	1.34	18	20.8	1.15	
Average					1.34			1.27	1.70

Table 3. Estimated probable maximum precipitation values based on statistical and Physical methods (mm)

Station	Statistical (Hershfilds) methods	Physically (maximization of storms) method
Abadan	236	92.5
Ahvaz	371	114.7
Mahshahr	362	137.3
Brojerd	277	98
Bushehr	637	145.3
Dezful	418	151.7
Masjed soleiman	516	144
Omidieh	407	93.9
Yasoj	356	134.9

1 . Maximum Persisting 12 hr. Dew point during the storm

2 .Storm Precipitable Water corresponding to the storm dew point temperature (mm)

3 . Maximum Persisting 12 hr. Dew point with 100-yr. return period

4 . Extreme Precipitable Water corresponding to the extreme dew point temperature (mm)

5 . Maximum Persisting 12 hr. Wind speed during the storm

6 . Maximum Persisting 12 hr. Wind speed with 50-yr. return period

4. Conclusion

In this study two different techniques were employed for estimating PMP: statistical and meteorological methods. Statistical procedure was based on the transposition and maximization of historical precipitation (annual maximum precipitation series). Physically oriented method was based on the maximization of the physical factors (dew point and wind). Statistical method resulted in estimating larger values in comparison to the physical method. In addition, it was concluded that physical method can be applied for catchments with areas of 1 to 5000 Km^2 and duration of 24, 48, 72, 96, and 120 and 144 hours, whereas statistical method is used mostly for making quick estimates for basins of no more than about 1000 km^2. A major shortcoming in the statistical method is that it yields only point values of PMP and use of generalized curves based on data from climatically similar regions introduce additional sources of error.

Extreme rainfall amounts of rare magnitude or occurrence, with return periods of 500 or more years, are often found to have occurred at some time during a much shorter period like 30 years. Such a rare event may have an appreciable effect on the mean and standard deviation of the annual series. In other words frequency distribution of rainfall extremes is skewed to the right so adjustment of these extreme events is essential in statistical estimating of PMP and while these adjustments do not apply, estimated PMP shows much great values. Whereas in convergence synoptical model, storm physical features should be consider. These features such as moist and warm air and movement of moist and warm air, on the basis of dew point temperature and wind speed and wind direction of any storm, are identified. Thus estimating of PMP by synoptical model is more precise and reliable and the results of the study show that in order to design water structures, using of synoptical model is recommended.

References

Betlahmy, N., 1984. Long-term hydrologic events from short-term records: J. of Hydrology, 68: 141-148

Bureau of Meteorology, 1985. The estimation of probable maximum precipitation in Australia for short small areas': Bulletin 51, August 1984, AGPS, Canberra. World Meteorological Organization

Collier, C. G., and P. J., Hardaker, 1996. Estimating probable maximum precipitation using a storm model approach: J. of Hydrology, 183: 277-306.

Desa, M.N., Noriah,A.b. and Rakhecha,P.R. 2001. Probable maximum precipitation for 24h duration over southest Asian Monsoon region-Selangor Malaysia. www.Elsevier.com/ocate/atmos.

Douglas, E. M., and A. P., Barros, 2003. Probable maximum precipitation estimation using multifractilals: application in the Eastern United States, J. of Hydrology 4: 1012-1024.

Ghahraman, B. and A. R., Sepaskhah, 1994. Determination of ultimate values of rainfall (PMP) at southern parts of Iran: Nivar, No. – 22

Hershfield, D.M., 1961. Estimating the probable maximum precipitation: J. of the Hydraulic Division, American Society of Civil Engineers, 87: September, 99-116.

Hershfield, D.M., 1965. Method for estimating probable maximum rainfall: J. of American Waterworks Association, 57: 965-972.

Kennedy, M.R., 1982. The estimation of probable maximum precipitation in Australia-past and Current practice. In Proceedings of the Workshop on Spillway Design, Melbourne, 1981. Awrc cont. 26-52.

Burea of Meteorology (1994). The estimation of probable maximum precipitation in Australia: Generalized short-duration method. Bulletin 53, December, AGPS, Canberra.

Paimozd, SH., 2002. Comparison of synoptical and statistical methods of estimating probable maximum precipitation and converse to probable maximum flood, case study: Hormozgan province. Msc. Thesis, Tehran Tarbiat Modares University.

Papalexiou S. M. and D. Koutsoyiannis, 2006. A probabilistic approach to the concept of Probable Maximum Precipitation: Advances in Geosciences, 7: 51-54.

Salehipak, T., 1999. Calculation of probable maximum precipitation, case study: Mamlo basin. Msc. Thesis, Tehran Tarbiat Moalem University.

World Meteorological Organization, 1986. Manual for estimation of probable maximum precipitation: second edition, Operational hydrology report No.1, WMO- No.32, Geneva.

World Meteorological Organization, 1994. Guide to hydrological practices, fifth edition, WMO- No. 168, Geneva.