Civil and Environmental Research
ISSN 2224-5790 (Paper) ISSN 2225-0514 (Online)
Vol.8, No.12, 2016

Development of One Day Probable Maximum Precipitation (PMP) and Isohyetal Map for Bale Zone, Oromiya Region, Ethiopia

Asrat Fikre[1*] Shoeb Quraishi[2] Bahilu Bezabih[3]
1.Water Resources Research Center, Institute of Technology, Arba Minch University, Ethiopia
2.School of natural resource and environmental engineering, Haramaya University, Ethiopia
3.Department of Natural Resource Management, Jimma University, Ethiopia

Abstract
Effective use of land and water is fundamental to growth and sustainable development, however uncontrollable amounts of water can adversely affect the survival of living things. Development of one day probable maximum precipitation and isohyetal map for bale zone using daily extreme values of 18 stations by statistical method to estimate point PMP and to develop one day PMP isohyetal map has been developed. Missing data were reconstructed and inconsistency was checked using inverse distance weighing and double mass curve analysis, respectively. Frequency factor values varied from 2.24 to 5.09 and PMP varied from 51.43mm to 234.81mm with an average 118.92mm. Using Arc GIS interpolation approach PMP grid values were varied 80.0- 180.0 mm.
Keywords: Extreme rain fall, Flood, PMP, Isohyetal map

1 Introduction

Natural environment has a crucial importance for social and economic diversification. Water is a prime requirement for the existence of life; however uncontrollable amounts of water can adversely affect the survival of living beings (Wanniarachchi and Wijeseke, 2012). Extreme environmental events, such as floods, rainstorms, high winds and droughts, have severe consequences on human beings. Extreme rainfall events could cause significant damage to agriculture, ecology and infrastructure, disruption to human activities, injuries and loss of lives (Einfalt, 1998). Ethiopia has a lot of rugged and mountainous topography with altitudes ranging from 4650 meters above sea level to 420 meters below sea level and the rainfall also varies from place to place (EPA, 2003). Flooding is common in Ethiopia during rainy season between June and September and the major types of floods are flash floods and river floods (FDPPA, 2006). Flash floods are mainly linked with isolated and localized intense rainfall. It is a short duration event caused by high peak discharge (Few, 2006). This type of flood could pose a big damage to human life and property because they occur suddenly with very high intensity (Greenough et al, 2001). There were flash floods in many parts of Ethiopia at different times (FDPPA, 2007). The evidence of recent flooding coupled with the IPCC prediction makes Ethiopia more vulnerable than ever. Therefore, flood hazard in Ethiopia may continue as a result of increasing population that intensifies the flood damage due to increasing land and forest degradation, encroachment of people to settle in close proximity to the flood prone areas. Ethiopia should look forward efficient, cost effective adaptation mechanism to cope with the future flood ravage.

Estimating the probability of extreme precipitation and characterizing the uncertainty of the estimates are crucial too, for instance, structural design, public safety alerts, evacuation management, and loss mitigation (Hongwei *et al*., 2011). In current engineering practice, the estimation of extreme rainfalls is accomplished based on statistical frequency analysis of maximum precipitation records where available sample data could be used to calculate the parameters of a selected frequency distribution. The fitted distribution is then used to estimate event magnitudes corresponding to return periods greater than or less than those of the recorded events, hence accurate estimation of extreme rainfall could help to alleviate the damage caused by storms and can help to achieve more efficient design of hydraulic structures.

Hence, knowledge on extreme rainfall and probable maximum precipitation would be the basis in engineering practices for designing hydraulic structures and set up measures for reducing the impact of the disaster. In Bale zone need for irrigation and hydroelectricity has become the primary motivation in large-scale water resource projects. Studies of one day PMP over a catchment area or a zone is essential for the planning and designing of hydraulic structures such as check dams, storage reservoirs and earthen dams although the probability analysis of annual maximum daily rainfall for different returns have been suggested. Thus estimation of probable maximum precipitation and PMP isohyetal maps, which could be an input for estimation of probable maximum flood for water resources planning and designing in the zone where there are no gauging stations. It also provides reliable and quick information on the PMP values in the zone. Objective of the study is to estimate point PMP and to generate the corresponding isohyetal PMP map, which is often needed for proper planning, management and designing of different types of water resource projects.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

The study was carried out in Bale zone of Oromia National Regional State, Ethiopia. It is located between 5011'03" – 8009'27"N Latitude and 38012'04" – 42012'47"E longitude. Physically, the zone is bounded by Genale River to the west and south and Wabe Shabele River on east and north. The lowest and highest altitude of the zone is extended from 300 m to 4377 m above sea level, respectively. The maximum and minimum temperatures are 25^{0}C and 10^{0}C, respectively. The zone has two types of rainfall regime, long rainy season and the short rainy season. The mean annual rainfall varies from 400mm on extreme lowland up to 1200mm on highlands.

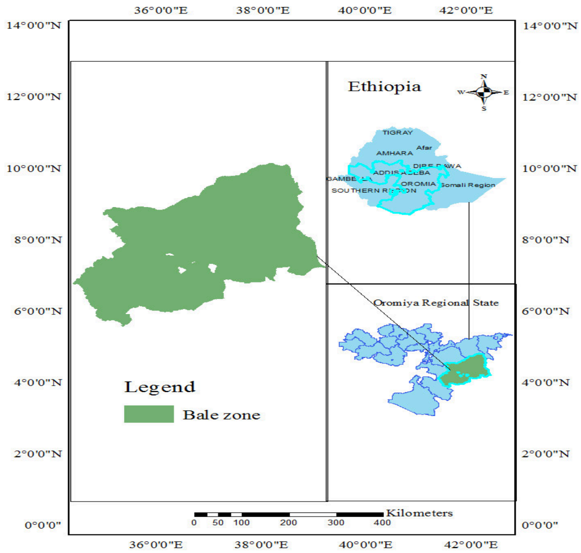

Fig.1. Map of study area

2.2. Data Evaluation and Analysis

All of the studied stations were active during the data collection season and have maximum record length of 44 years, minimum record length of 14 years with average of 26.22 years. Data were analyzed using Advanced excel sheet and Arc GIS 10 software. Before using data for analysis missing value were corrected then consistency was checked and all stations were consistent.

To estimate the missed rainfall values, the Inverse Distance Weighting method (Simanton and Osborn, 1980).

$$\theta_m = \frac{\sum_{i=1}^{n} \theta_i d_{m,i}^{-k}}{\sum_{i=1}^{n} d_{m,i}^{-k}} \qquad (1)$$

The consistency of the data set of the given stations was checked by the double mass-curve method.

$$P_a = \frac{M_a}{M_o} P_o \qquad (2)$$

Hershfield (1961, 1965) considered that, for PMP estimation there is a value of frequency factor that will not exceed, say Km. He then modified Chow's equation as:

$$X_{PMP} = \bar{X}_n + S_n K_m \qquad (3)$$

The maximum frequency factor (Km) was calculated using equation given by Hershfield (1961, 1965), as:

$$K_m = \frac{X_1 - \bar{X}_{n-1}}{\sigma_{n-1}} \qquad (4)$$

3. RESULTS AND DISCUSSION

3.1. Derivations of HOR, $\bar{X}_{N-1}$ σ_{N-1} and Km for stations

The maximum frequency factor for the stations was derived by using equation 4 and presented in Table 1. Based on the result, the maximum frequency values varied from a maximum (5.09) observed at Robe and Sofumor stations and the minimum (2.24) at Bidre station with an average of 3.53 and CV of 24.97%. This variability was due to climatic variation within the stations in the zone.

Table 1. The values of HOR, $\overline{X}_{N-1}, \sigma_{N-1}$ an d Km of stations

Station name	Average annual rainfall	HOR	$\overline{X}_{N-1}$	σ_{N-1}	Km
Abissa	732.56	84.9	45.69	10.67	3.67
Agarfa	1103.47	142.8	61.66	22.64	3.58
Angetu	853.41	86.9	51.23	11.6	3.07
Belle	902.04	88.8	35.84	11.85	4.47
Beletu	823.78	90.4	40.68	12.19	4.08
Bidre	874.34	94.0	60.38	15.04	2.24
D/Mena	1007.66	109.3	58.38	17.13	2.97
D/sebro	1199.63	141.5	55.28	23.38	3.69
Dinsho	1332.39	88.4	46.98	14.48	2.86
Gassera	1122.17	108.1	54.93	20.09	2.65
Ginir	1036.59	200.0	69.15	26.47	4.94
Goro	894.36	83.0	50.52	11.71	2.77
Jara	982.58	120.0	49.95	20.02	3.5
Rira	737.18	48.0	27.43	8.66	2.38
Robe	819.17	112.3	44.7	13.29	5.09
Sewena	939.52	90.9	40.04	18.2	2.79
Sinana	894.24	85.5	42.94	11.66	3.65
Sofumor	661.10	106.0	49.64	11.07	5.09
Mean					3.53
Sd					0.88

According to Hershfield (1961) the frequency factor Km was independent of rainfall magnitude. However its magnitude varies inversely with mean daily annual maximum and annual total rainfall. But result of this study showed 50% of stations confirm to Hershfiled and the rest were different. This is due variability of maximum annual series of stations. Graphs were drawn for the estimated maximum frequency factors (Km) against mean daily annual maximum rainfall depths to observe the trend. As it could be observed from Figure 2, the trend line shows a random relation. This revealed that Km depends on the characteristics of the data.

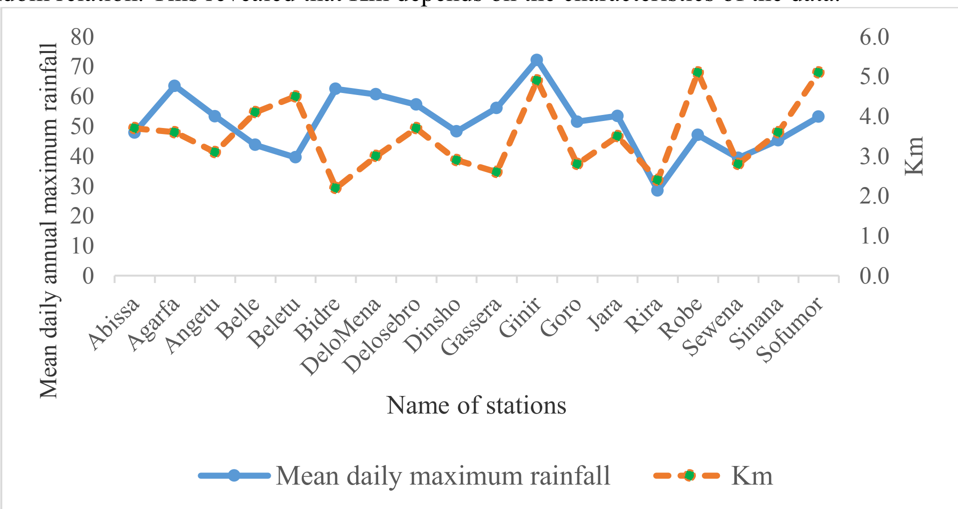

Fig. 2. Trend of mean daily annual maximum rainfall and Km

3.2. Derivations of 1-day PMP and PMP to HOR ratio for stations

The derived PMP showed that the maximum value was 234.81 mm at Ginir station and minimum 51.43 mm at Rira station and the average had been estimated as 118.92 mm with coefficient of variability 32.42%. Normally, the highest PMP estimate corresponding to stations having higher variability was reported from dry areas. However, in this study it was observed due to that station that has dry conditions and largest variability for rainfall record, as compared to a station with the highest observed variability.

Table 2. Derivation of one day PMP and PMP to HOR ratio

Station name	mean	Sn	HOR	CV (%)	PMP	PMP:HOR
Abissa	47.87	13.70	84.9	28.70	98.27	1.16
Agarfa	63.5	25.50	142.8	40.20	154.89	1.08
Angetu	53.33	14.20	86.9	26.60	96.92	1.12
Belle	43.78	16.86	90.4	38.50	112.54	1.24
Beletu	39.62	17.79	88.8	44.90	119.11	1.34
Bidre	62.48	16.25	94	26.00	98.81	1.05
D/Mena	60.69	19.90	109.3	32.80	119.95	1.10
D/sebro	57.24	26.50	141.5	46.30	155.01	1.10
Dinsho	48.27	16.00	88.4	33.20	94.09	1.06
Gassera	56.14	21.41	108.1	38.10	112.81	1.04
Ginir	72.19	32.90	200	45.60	234.81	1.17
Goro	51.53	12.90	83	25.00	87.24	1.05
Jara	53.46	25.00	120	46.80	140.92	1.17
Rira	28.51	9.65	48	33.80	51.43	1.07
Robe	47.11	18.26	112.3	38.80	139.97	1.25
Sewena	39.37	17.79	90.9	45.20	89.07	0.98
Sinana	45.3	12.60	85.5	27.90	91.44	1.07
Sofumor	53.17	17.69	106	33.30	143.20	1.35
				mean	118.92	1.13
				Sd	38.56	0.10

The magnitude of the ratio at an individual station did not exceed three times the highest observed rainfall depth. But in sewena station it was noted that, the highest one-day recorded rainfall values were greater than their respective estimates of point PMP i.e. 0.98 times the highest observed rainfall. This was due to high rainfall variability in the station.

3.3. Development of PMP Isohyetal Map

Isohyetal maps were generated by means of Arc GIS 10 software. Accordingly, PMP grid values were varying between 80.00 mm and 180.00 mm. The high PMP isohyetal values were observed along the Northern and Central Districts and decreases outward to Eastern and Western Districts.

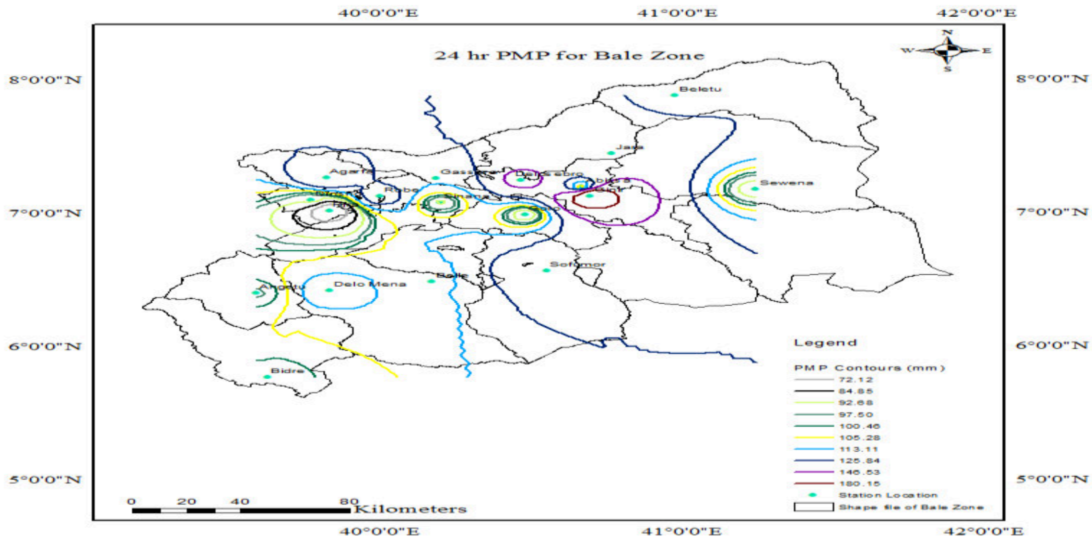

Figure 3. Isohyetal map of one day PMP for Bale Zone

4. CONCLUSION

Appropriate enveloping km curve showing the relationship between the km and the mean annual maximum rainfall for duration of 24 hr had been developed. The maximum frequency factors of individual rain gauge station were found to vary from 2.24 to 5.09 at an average value of 3.53 and coefficients of variability of 24.97%.The enveloping km have a random relation with rainfall magnitude was observed from the trend of Km vis-à-vis mean of daily maximum annual rainfall series and annual rainfall records.

From the results of PMP values return periods were estimated for flood frequencies of 5-10000 years. The estimated PMP is reasonable for designing of hydraulic structures for return periods in the order of 10, 20 and 50 years and stable hydraulic structures for return periods of 5 year.

PMP grid values were varying between 80.00 mm and 180.00 mm. The high PMP isohyetal values were observed along the Northern and Central Districts and decreases outward to Western Districts. This gives information for the designers, planners and decision makers' inorder to conduct hydraulic structures in the study area.

5. REFERENCES

[1] Al-Mamun, A. and A. Hashim. 2004. "General long duration probable maximum precipitation isohyetal map for Peninsula Malaysia." Journal of Spatial Hydrology, 4(1) 20-35.

[2] Alemayew Dame and Semu Ayalew, 2010. Development of regional probable maximum precipitation for probable maximum flood development and application in design flood hydrograph:case study of Blue Nile basin, Ethiopia. The 2010 Conference on Water Resources in Ethiopia, Addis Ababa, 12-16 January 2010, Ministry of Water Resources.

[3] Chow, V. T., D.R Maidment and L.W. Mays, 1988. Applied Hydrology, McGraw Hill, New York.

[4] Chow, V.T. 1952. A general formula for hydrologic frequency analysis. Trans. Am. Geophys. Union, vol 32:173-188.

[5] Desa, M.M. and P.R. Rakhecha, 2006. Probable maximum precipitation for 24 hr duration over an equatorial region: Part 2-Johor, Malaysia. Humid Tropics Centre Kuala Lumpur, Department of Irrigation and Drainage, Malaysia.

[6] Durbude, D.G. 2008. Estimation of Probable Maximum Precipitation for planning soil and water conservation structure. Journal of soil and water conservation, 17: 31-35.

[7] Einfalt, T. 1998. Correction and preparation of continuously measured rain gauge data: a standard method in North Rhine-Westphalia, Water Science and Technology, 37(11) 12-22.

[8] Environmental Protection Authority (EPA), 2003. The Sate of Environment Report of Ethiopia, Addis Ababa, Ethiopia.

[9] Ewemoje, T.A. and O.S. Ewemoojee, 2011. Best distribution and plotting positions of daily maximum flood estimation at Ona River in Ogun-oshun river basin, Nigeria. Agricultural Engineering International: CIGR Journal, Vol.13, Manuscript No. 1380.

[10] FDPPA. 2006. Joint Government and Humanitarian Partners Flash Appeal for the 2006 Flood Disaster in Ethiopia, Addis Ababa, Ethiopia.

[11] FDPPA. 2007. Regional summary of Multi-Agency Flood Impact assessment of 2006, Addis Ababa, Ethiopia.

[12] Few, R. 2006. Flood Hazards, Vulnerability and Risk Reduction, In Few R. and Matthies F. (ED). Flood Hazards and Health: Responding to present and future risks, London.

[13] Ghahraman, B. 2008. Determination of ultimate values of rainfall (PMP) at southern parts of Iran. Nivar Journal of Iran Meteorological Organization, 22: 24-37.

[14] Greenough, G. M., McGeehin, S. Bernard, J. Trtanj, J. Riad and D. Engelberg, 2001. The Potential Impacts of Climate Variability and Change on Health Impacts of Extreme Weather Events in the United States. Environmental Heath Perspective, 109(2).

[15] Hershfield, D.M. 1961. Estimating the probable maximum precipitation. J. Hydraul. Div., American Society of Civil Engineers, Vol.87, (HY5), pp. 99-116.

[16] Hershfield, D.m. 1962. Rainfall frequency Atlas of the United State for durations from 30 mins to 24 hours and return periods from 1 year to 100 years. Tech. Paper no. 40, U.S. Department of Commerce, Washington, D.C.

[17] Hershfield, D.M. 1965. Method for estimating the probable maximum precipitation. J.Am. Water Works Assoc., Vol.57, pp.965-972.

[18] Hongwei Shang, Jun Yan1, Mekonnen Gebremichael, and Semu M. Ayalew, 2011. Trend Analysis of Extreme Precipitation in the Northwestern Highlands of Ethiopia with a Case Study of Debre Markos.

[19] Simanton, J. R. and H. B. Osborn, 1980. Reciprocal-distance estimate of point rainfall. Journal of Hydraulic Engineering, Div. 106 (HY7), 1242–1246.

[20] Tao, D.Q, V.T. Nguyen, and A. Bourque, 2002. On selection of probability distributions for representing extreme precipitations in Southern Quebec. Annual Conference of the Canadian Society for Civil Engineering. 5th -8th June 2002. pp 1-8.

[21] Wanniarachchi and Wijesekera, 2012. Using SWMM as a Fool for Flood plain Management in Unguaged Urban Watershed. Journal of the institution of Engineers, SRILANKA VOL: XXXX V, No. 01.