Characterization of Drought across Climatic Spectrum

By Victor M. Ponce,[1] Rajendra P. Pandey,[2] and Sezar Ercan[3]

Abstract: A conceptual model of drought characterization across the climatic spectrum is formulated. The model is particularly suited to subtropical and midlatitudinal regions. Drought duration, intensity, and recurrence interval are expressed in terms of the ratio of mean annual precipitation to annual global terrestrial precipitation. The model is useful as a framework for the systematic analysis of droughts and the assessment of changes in drought characteristics due to climatic changes.

INTRODUCTION

A drought at a given location or region is a period of time, lasting weeks, months, or years, during which the actual moisture supply consistently falls short of the climatically expected moisture supply. Droughts are better documented in semiarid and subhumid regions, where humans tend to concentrate. Drought data in extremely arid regions is scant, since very few people are actually affected. Likewise, droughts in very humid regions go largely unnoticed, since the supply of water usually exceeds the actual demand. Here, the writers relate drought characteristics to climatic parameters across the climatic spectrum. The latter is defined in terms of mean annual precipitation and cross-referenced to annual potential evapotranspiration.

Coping with droughts is possible through proper forecasting and planning. To reduce the impact of drought, it is necessary to develop the capability to forecast its characteristics, i.e., its duration (How long will it last?), its intensity (How severe will it be?), and its recurrence interval (How often will it recur?).

CLIMATIC SPECTRUM

Droughts are cyclical and regional in nature; their occurrence is related to prevailing climatic parameters. A readily available climatic parameter is mean annual precipitation, which depends on: (1) latitude; (2) orographic factors; (3) mesoscale ocean currents; (4) atmospheric wind circulation; (5) proximity to oceans and large lakes; (6) atmospheric pressure; (7) character of the Earth's surface, including color and texture; and (8) presence of atmospheric particulates, both natural and human-induced. Closely related to mean annual precipitation is annual potential evapotranspiration, which is a function of: (1) net solar radiation; (2) vapor-pressure deficit; (3) surface roughness; and (4) leaf-area index.

For our purposes, the writers define the climatic spectrum solely in terms of mean annual precipitation, an approach that is particularly useful for subtropical and midlatitudinal regions. The writers characterize the climatic spectrum in terms of the ratio of mean annual precipitation P_{ma} to annual global terrestrial precipitation P_{agt}.

The amount of moisture stored in the atmosphere is a function of latitude and climate, varying typically from 2–15 mm in polar and arid regions to 45–50 mm in humid regions (*World* 1978). A global terrestrial mean value of 25 mm is assumed for the purpose of estimating annual global terrestrial precipitation. The atmospheric moisture recycles every eleven days on the average, for a total of 33 cycles per year (L'vovich 1979), which results in the annual global terrestrial precipitation P_{agt} = 825 mm. Here, the writers assume a round number, P_{agt} = 800 mm.

Globally, the middle of the climatic spectrum, i.e., the division between semiarid and subhumid climates, corresponds to $P_{ma}/P_{agt} = 1$. Regions with $P_{ma}/P_{agt} < 1$ have less-than-average moisture; conversely, regions with $P_{ma}/P_{agt} > 1$ have greater-than-average moisture. Mean annual terrestrial precipitation varies typically in the range of 100–6,400 mm, with a few isolated cases falling outside this range. This enables the division of the climatic spectrum in subtropical and midlatitudinal regions into the following eight types:

1. Superarid, with $P_{ma}/P_{agt} < 0.125$
2. Hyperarid, with $0.125 \le P_{ma}/P_{agt} < 0.25$
3. Arid, with $0.25 \le P_{ma}/P_{agt} < 0.5$
4. Semiarid, with $0.5 \le P_{ma}/P_{agt} < 1$
5. Subhumid, with $1 \le P_{ma}/P_{agt} < 2$
6. Humid, with $2 \le P_{ma}/P_{agt} < 4$
7. Hyperhumid, with $4 \le P_{ma}/P_{agt} < 8$
8. Superhumid, with $P_{ma}/P_{agt} \ge 8$

Table 1 shows the climate types with mean annual precipitation P_{ma} and corresponding P_{ma}/P_{agt} ratios. To determine suitable E_{ap}/P_{ma} ratios, the writers have approximately estimated potential evapotranspiration across the climatic spectrum, for subtropical and midlatitudinal regions. For instance, the writers estimate E_{ap} = 3,000 mm at the limit between superarid and hyperarid regions. Corresponding estimates for other regions led to the E_{ap}/P_{ma} ratios shown in Table 1.

GLOBAL DATA ON DROUGHTS AND CLIMATE

Droughts in the United States have a tendency to be more persistent in the interior of the country than in areas farther east or west, with durations for moderate and severe droughts varying between 3 and 5 years (Karl 1983). The greater drought persistence in the Great Plains of central North America than in any other part of the United States has been documented by Karl et al. (1987) and Laird et al. (1996). Johnson and Kohne (1993) have shown that drought persistence is greater in the interior of the United States, including the states of Wyoming, Colorado, North Dakota, and Montana. Horn (1989) studied the spatial variability of droughts in Idaho, where the mean annual precipitation varies between 250 and 1,500 mm, with an average of about 800 mm. He concluded that the median drought durations varied between 5.6 and 6.4 years throughout the state.

Klugman (1978) has studied droughts in the Upper Midwest of the United States from 1931 to 1969. His analysis showed that while the 30s and the 50s were decades of drought, the 40s and 60s were wet periods. This indicates a recurrence in-

[1]Prof., Dept. of Civ. and Envir. Engrg., San Diego State Univ., San Diego, CA 92182-1324.

[2]Sci. ''C,'' Nat. Inst. of Hydro., Roorkee, U.P. 247 667 India.

[3]Hydro., State Hydr. Works, Ankara, Turkey; formerly, Grad. Student, Dept. of Civ. and Envir. Engrg., San Diego State Univ., San Diego, CA.

Note. Discussion open until September 1, 2000. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this technical note was submitted for review and possible publication on August 25, 1998. This technical note is part of the ***Journal of Hydrologic Engineering***, Vol. 5, No. 2, April, 2000. ©ASCE, ISSN 1084-0699/00/0002-0222–0224/$8.00 + $.50 per page. Technical Note No. 19096.

TABLE 1. Conceptual Model of Drought Characterization across the Climatic Spectrum

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Climatic Spectrum							
Climate type: Superarid Hyperarid Arid Semiarid Subhumid Humid Hyperhumid Superhumid							
Mean annual precipitation P_{ma} (mm)	100	200	400	800	1600	3200	6400
P_{ma}/P_{agt} [1]	0.125	0.25	0.5	1	2	4	8
Annual potential evapotranspiration E_{ap} (mm)	3000	2400	2000	1600	1200	1200	1200
E_{ap}/P_{ma}	30	12	5	2	0.75	0.375	0.1875
Length of rainy season L (mo)	1	2	3	4	6	9	12
Drought Characteristics							
Drought duration D (yr)	1	2	4	6	4	2	1
Drought intensity I (dimensionless)							
-Moderate	0.25	0.5	1	1.5	1	0.5	0.25
-Severe	0.50	1.0	2	3.0	2	1.0	0.50
-Extreme	0.75	1.5	3	4.5	3	1.5	0.75
Drought recurrence interval T (yr)	2	3	6	12	25	50	100

[1] P_{agt} = annual global terrestrial precipitation.

terval of 20 years for this subhumid region, with a mean annual precipitation of 1,500 mm. Karl and Young (1987) have reported drought recurrence intervals ranging from 20 to 60 years in the southeastern United States. This location includes North Carolina, Georgia, and Tennessee, which have humid climates.

The Indian subcontinent, the northern half of which lies above the tropic of Cancer, has a wide variability of climatic regimes, from superarid to superhumid. High rates of evapotranspiration prevail over hyperarid Rajastan, in western India, with annual rates exceeding 2,500 mm and reaching 3,500 mm in some regions of northwest Rajastan. Conversely, low rates of evapotranspiration prevail over hyperhumid Assam and the Himalayan Bengal, in northeastern India, with annual rates in the range of 1,200–1,500 mm. Over central India, which is semiarid, evapotranspiration rates vary in the range of 1,400–1,800 mm (Abbi 1974). Gregory (1989) has reported that droughts in hyperhumid regions of India such as Assam are very infrequent, with the last documented drought in the region dating back to 1900.

The Australian continent, more than half of which lies below the tropic of Capricorn, has a wide variability in climatic regimes. For instance, in hyperarid William Creek, in South Australia, precipitation is 127 mm and potential evapotranspiration is more than 2,540 mm. In arid Alice Springs, in the Northern Territory, precipitation is 250 mm and potential evapotranspiration is 2,460 mm. In semiarid/subhumid Perth, in Western Australia, precipitation is 890 mm and potential evapotranspiration is 1,670 mm. In subhumid Sydney, in New South Wales, precipitation is 1,200 mm, and evapotranspiration exceeds 1,020 mm (Kendrew 1961). French (1987) has analyzed long-term series of annual rainfall for semiarid Georgetown, in north central South Australia, where the mean annual rainfall is 475 mm. Records from 1874 to 1985 show 20 drought events, i.e., a mean recurrence interval of 5.6 years.

Russian experience shows that over the past 1,000 years, catastrophic droughts have occurred with a frequency of 8–12 per century (every 10 years on the average). In Kazakhstan, which is mostly hyperarid and arid (Zonn et al. 1994), around 35 severe droughts have occurred in the last 100 years, i.e., every 3 years on the average. In the Ukraine, where climate and soils are more favorable for agricultural production, droughts affect the area every 4–5 years (Kogan 1997).

Ponce (1995a) has documented the drought events in the drought polygon of northeastern Brazil during the twentieth century. The polygon contains a diversity of biogeographical regions, ranging from arid to semiarid to subhumid to humid. The data suggests a recurrence interval from 4 to 12 years, with an average value of about 10 years. The drought duration varied between 1 and 5 years.

Ponce (1995b) has reported that hydrological droughts in the Upper Paraguay river basin, in central western Brazil, recur every 28–30 years on the average and last 3–6 years. The mean annual precipitation in the Upper Paraguay river basin varies between 900 and 2,000 mm, with an average of 1,380 mm.

CONCEPTUAL MODEL OF DROUGHT CHARACTERIZATION

Our conceptual model deals specifically with meteorological droughts lasting at least one year, with an emphasis on subtropical and midlatitudinal regions. Persistence is the property of a drought event to last more than one year. For a given drought event, intensity refers to the extent of the precipitation deficit. To determine drought intensity, the moisture deficiency is accumulated over the drought duration. Therefore, the longer the duration, the greater the intensity. Since dry periods are generally followed by corresponding wet periods, it follows that the recurrence interval is always greater than the duration. Thus, for meteorological droughts lasting at least one year, the recurrence interval is at least two years.

The preceding concepts of drought intensity and duration resemble those of Dracup et al.'s severity, duration, and magnitude, wherein magnitude is defined as the ratio of severity over duration (Dracup et al. 1980). In our case, intensity is akin to severity; therefore, intensity is equal to magnitude times duration.

A conceptual model works in the mean; i.e., it describes general trends and not necessarily specific events. It is meant to aggregate the deterministic and stochastic components of the precipitation anomalies. Its value is that it provides a conceptual framework for interpreting the regional variability of drought phenomena.

Given a drought year with precipitation P, where $P < P_{ma}$, the precipitation deficiency may be classified into three types: (1) moderate, with $P/P_{ma} = 0.75$; (2) severe, with $P/P_{ma} = 0.5$; and (3) extreme, with $P/P_{ma} = 0.25$ (National Institute of Hydrology 1990). The writers define drought intensity as the ratio of the deficit $(P_{ma} - P)$ to the mean (P_{ma}). For a drought lasting more than one year, intensity is defined as the summation of the annual intensities

$$I = \sum \frac{P_{ma} - P}{P_{ma}} \quad (1)$$

in which I = drought-intensity index.

Therefore, average annual drought intensity is the total drought intensity divided by the duration. Average annual drought intensity has been referred to as drought magnitude by Dracup et al. (1980) and as run intensity by Frick et al. (1990).

The writers base their conceptual model of drought characterization on the following premises, amply supported by observations:

1. Drought duration varies across the climatic spectrum, reaching a maximum around the middle and decreasing toward the extremes.
2. Since drought intensity is directly related to duration, intensity also reaches a maximum around the middle of the climatic spectrum and decreases toward the extremes.
3. The drought recurrence interval increases gradually from the dry to the wet side of the climatic spectrum.

Table 1 summarizes the writers' conceptual model of drought characterization. For drought duration, the expected values vary between 1 and 6 years, with larger values toward the middle of the climatic spectrum (6 years), decreasing toward either extreme (1 year). The longer durations toward the middle of the climatic spectrum are due to greater interannual precipitation variability within the semiarid and subhumid regions. Within these regions, drought duration is likely to be the longest, approaching 4–6 years. The shorter durations toward both extremes of the climatic spectrum are justified because of smaller interannual precipitation variability. In superarid regions, variability is reduced because the precipitation amounts are small; in superhumid regions, variability is reduced because of the length of the rainy season, which approaches 12 months.

The drought recurrence interval varies between 2 years on the extreme dry side and about 100 years on the extreme wet side, increasing in an approximate geometric progression. Since recurrence interval decreases from wet to dry climates, and since it must always exceed duration, it follows that duration must decrease toward the dry side of the climatic spectrum (Table 1). Thus, in hyperarid regions, droughts are short and recur once every 2–3 years; in semiarid and subhumid regions, droughts are long and recur once every 6–25 years; in hyperhumid regions, droughts are short and recur once every 50–100 years.

SUMMARY

The writers have formulated a conceptual model of drought characterization across the climatic spectrum, primarily suited to subtropical and midlatitudinal regions. The model estimates expected values of drought duration, intensity, and recurrence interval as a function of the ratio of mean annual precipitation to annual global terrestrial precipitation.

Drought duration varies between 1 and 6 years across the climatic spectrum, and reaches a maximum toward the middle. Intensity varies directly with duration, and recurrence interval increases approximately in a geometric progression, from 2 years on the extreme dry side to about 100 years on the extreme wet side. Comparison of the conceptual model with drought data from several countries throughout the world shows that the model may be suitable as a framework for drought analysis and planning.

APPENDIX. REFERENCES

Abbi, S. D. S. (1974). ''Hydrometeorological studies in India. *Preprints, Int. Tropical Meteorology Mtg*., American Meteorological Society–East African Meteorological Department–World Meteorological Organization, Nairobi, Kenya.

Dracup, J. A., Lee, K. S., and Paulson Jr., E. G. (1980). ''On the statistical characteristics of drought events.'' *Water Resour. Res*., 16(2), 289–296.

French, R. J. (1987). ''Adaptation and adjustments in drought-prone areas: an overview–South Australian Study.'' *Planning for drought, toward a reduction of societal vulnerability*, D. A. Wilhite et al., eds., Westview Press, Boulder, Colo.

Frick, D. M., Bode, D., and Salas, J. D. (1990). ''Effect of drought on urban water supplies. I: Drought analysis.'' *J. Hydr. Engrg*., ASCE, 116(6), 733–753.

Gregory, S. (1989). ''The changing frequency of drought in India, 1871–1985.'' *The Geographical J*., 155(3), 322–334.

Horn, D. R. (1989). ''Characteristics and spatial variability of droughts in Idaho.'' *J. Irrig. and Drain. Engrg*., ASCE, 115(1), 111–124.

Johnson, W. K., and Kohne, R. W. (1993). ''Susceptibility of reservoirs to drought using Palmer index.'' *J. Water Resour. Plng. and Mgmt*., ASCE, 119(3), 367–387.

Karl, T. R. (1983). ''Some spatial characteristics of drought duration in the United States.'' *J. Climate and Appl. Meteorology*, 22(8), 1356–1366.

Karl, T., Quinlan, F., and Ezell, D. S. (1987). ''Drought termination and amelioration: its climatological probability.'' *J. Climate and Appl. Meteorology*, 26, 1198–1209.

Karl, T. R., and Young, P. J. (1987). ''The 1986 Southeast drought in historical perspective.'' *Bull. Am. Meteorological Soc*., 68(7), 773–778.

Kendrew, W. G. (1961). *The climates of the continents*. Oxford University Press, London.

Klugman, M. R. (1978). ''Drought in the Upper Midwest, 1931–1969.'' *J. Appl. Meteorology*, 17(10), 1425–1431.

Kogan, F. N. (1997). ''Global drought watch from space.'' *J. Am. Meteorological Soc*., 78(4), 621–636.

Laird, K. R., Fritz, S. C., Maasch, K. A., and Cumming, B. F. (1996). ''Greater drought intensity and frequency before AD 1200 in the northern Great Plains, USA.'' *Nature*, 384(12), 552–554.

L'vovich, M. I. (1979). *World water resources and their future*. American Geophysical Union, Washington, D.C.

National Institute of Hydrology. (1990). ''Hydrological aspects of drought, up to 1987–88.'' *Rep. CS-37*, Roorkee, U.P. India.

Ponce, V. M. (1995a). ''Management of droughts and floods in the semiarid Brazilian northeast: the case for conservation.'' *J. Soil and Water Conservation*, 50(5), 422–431.

Ponce, V. M. (1995b). ''Hydrologic and environmental impact of the Paraná-Paraguay waterway on the Pantanal of Mato Grosso, Brazil: a reference study.'' Dept. of Civ. and Envir. Engrg., San Diego State University, San Diego.

World water balance and water resources of the earth. (1978). UNESCO, Paris.

Zonn, I., Glantz, M. H., and Rubinstein, A. (1994). ''The Virgin lands scheme in the former Soviet Union.'' *Drought follows the plow*, M. H. Glantz, ed., Cambridge University Press, Cambridge, U.K.