http://www.pjbs.org

PJBS

ISSN 1028-8880

Pakistan Journal of Biological Sciences

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Pakistan Journal of Biological Sciences 11 (5): 702-710, 2008
ISSN 1028-8880

The Scaling Technique in Palmer Drought Severity Index; Generalized Calibration and Modification

[1]Ali Reza Soltani Tudeshki, [1]Sefollah Amin Sichani, [1]Saied Mohammad Jafar Nazemossadat,
[2]Mohammad Karamouz and [3]Soheila Javanmard
[1]Department of Agricultural Engineering-Water, Agricultural College, Shiraz University,
Shiraz, Islamic Republic of Iran
[2]Department of Civil Engineering, Engineering College, Tehran University, Tehran, Iran
[3]Department of Atmospheric Sciences and Meteorological Research Center, Pazhuhesh City, Tehran, Iran

Abstract: The scaling technique in calculating Palmer Drought Severity Index (PDSI) has specific properties, which is considered in details, in this study. The Palmer scaling method contains a physically-based weighting factor called climatic characteristic coefficient, K. This factor, is the ratio of average moisture demand to average supply in a regional water balance, whose related coefficients and involved equation parameters should be calibrated according to any special case study. Therefore, in this study, the generalizing procedure of obtaining K-value with no dependency on particular area, in addition to some modifications in the process was analytically developed. The generalized procedure has an appropriate potential for various purposes such as; correctly identifying analytical K-formula, simplifying its application, recognizing its limitations and moreover it can be used in other researches for developing its advantages. The proposed procedure and its modifications also applied for a case study (e.g., Maharlue catchment, Fars province, Iran). The outputs of the application validated the suggested modifications; therefore, the obtained K-values can be used for other studies in the region.

Key words: Drought quantification, drought indices, scaling factors, classifying, PDSI, climatic characteristic coefficient

INTRODUCTION

In order to obtain drought indices for any region, generally several stages should be followed, includes: determining the parameters type and their scale appropriate to the desirable goal, calculating the moisture departures based on an assumed comparison value, scaling the departures and finally classifying them in a predefined categories. Among drought indices, Palmer Drought Severity Index, PDSI (Palmer, 1965), in a way, between the drought indices, has been a landmark in the development of drought indices, even though it is not without limitation (Heim, 2002). Therefore, a review of the PDSI will be valuable, in the beginning, which can be divided in two parts:

Initially, the actual and potential values of four parameters i.e., evapotranspiration (ET), moisture loss (L), soil water recharge (RE) and runoff (RO) are estimated. Then, the average ratio of the actual factors to the corresponding potential values, are calculated, named water balance coefficients (α, β, γ, δ). At last, the climatically appropriate precipitation for the existing conditions, Pr_C, is approximated (Guttman, 1998):

$$Pr_C = \alpha \times ETp + \beta \times REp + \gamma \times RO_p - \delta \times Lp \qquad (1)$$

Then, the moisture anomaly, Z, is calculated as difference of the actual precipitation, Pr and Pr_C, multiplied by climatic characteristics coefficient, K (Wells, 2002):

$$Z = (Pr - Pr_C) \times K = d \times K \qquad (2)$$

where, d is moisture departure (with length dimension) and K is a weighting factor that allows comparisons of deviations to be made between locations and months.

The moisture anomalies at any time scale (i), then, changes to a classified form, X, on the bases of its previous time step, X_{i-1} (Alley, 1984):

$$X_i = 0.9\, X_{i-1} + 0.3\, Z_i \qquad (3)$$

The coefficients of this equation derived by Palmer (1965) in his special study and should be adjusted for any case study. In the classification process, three different X are applied and the appropriate index is selected by picking one of them according to a set of rules (called Backtracking). Using this method, the historical

Corresponding Author: Sefollah Amin Sichani, Department of Agricultural Engineering-Water, Agricultural College, Shiraz University, Shiraz, Islamic Republic of Iran Tel/Fax: +98 711-228 6130

perspective of the index or its Inherent Memory (that is: an inherent time window over which it evaluates the climate trend), reaches only to the start of the current spell (Wells, 2002). However, the backtracking is more or less complex and needs separate studies.

Based on the subject of the study, the following text turns to «the generalizing procedure of the Climatic Characteristic Coefficient»:

The K-formula had been initially developed by Palmer (1965) for a limited set of data from nine climate divisions, which do not represent the average climate of entire world (Wells, 2002). Hence, many researchers like Akinremi *et al*. (1996), Toraabi (2002) and Quiring and Papakryiakou (2003) implied that the K-values should be calibrated for any case study. So, they revised the original values of K, though in some other study they are used by their initial equations. In order to calibrate the K-values for any case study, several steps should be tracked:

At the beginning, for the first approximation of coefficients, it is assumed that the driest periods were of nearly equal significance locally (Palmer, 1965). So for the average departures of the driest (or wettest) period with a length of $n\,(\bar{d} = \sum_{j=1}^{n} d_j / n)$, at different locations in the study region (R), the following relation can be written:

$$\bar{K}_1 \times \bar{d}_1 = \bar{K}_2 \times \bar{d}_2 = \bar{K}_3 \times \bar{d}_3 = \cdots = \bar{K}_R \times \bar{d}_R \qquad (4)$$

where, $\bar{K}_R$ represents the average weighting factor for different locations and apply to the driest (or wettest) periods as a whole, rather than to each month individually (Palmer, 1965). Equation 4 can be rewritten as a ratio mode for each pair regions:

$$\bar{K}_{R1} / \bar{K}_{R2} = \bar{d}_{R2} / \bar{d}_{R1} \qquad (5)$$

From the Eq. 5, it is noticeable that since the average moisture demand in the two places is roughly the same, the constants ($\bar{K}_{R1}$ and $\bar{K}_{R2}$) may depend on the average moisture shortage (or excess) in two places. In other words, the less the supply in relation to the demand, the greater the significance of a given shortage (Palmer, 1965). Therefore, the average weighting factor can be estimated from a demand-supply ratio: PE, RE and RO as the representative of the moisture demand and Pr with the previously stored moisture (or expected moisture loss, L) as the moisture supply indicators (Palmer, 1965):

$$k = \frac{\text{Moisture demand}}{\text{Moisture supply}} = \frac{f(\overline{ET}, \overline{RE}, \overline{RO})}{f(\overline{Pr}, \bar{L})} \qquad (6)$$

In this equation, k is the first approximation of $\bar{K}$ and the upper-lines represent average values of the parameters, described before. However, it is necessary to develop an appropriate relation between k and the engaged parameters. Based on the above-mentioned principles, various equations were offered in Table 1. The first two equations in the table were proposed by Palmer (1965), the third by Toraabi (2002) and the others have been suggested in our study. Palmer (1965) showed that his first combination (i) did not work well in some climates and finally he proposed the second form (ii) and implied that different equations had to be checked for any case study. So, the ranges of each equation in Table 1 are calculated, for dry and wet situations obtained by substituting the equivalent parameters. It is expected that the values of k be larger at dry condition than wet situations. This is because, in dry time-steps (such as summer), the absolute values of d are usually less than in wet time-steps. The ranges show that some of equations, like (*v*), do not obey the converse trend between k and d (Eq. 5).

Table 1: Various equations for first approximated coefficient of the climatic characteristic

		Ranges of the equations for the dry and wet conditions:	
No.	Proposed equation	Δ = Pr-ETp<0 (ET = Pr+L, RE and RO = 0)	Δ = Pr-ETp≥0 (ET = ETp, L = 0, RO = Pr-ETp+RE)
(i)	$k_i = \frac{\overline{ETp}_i + \overline{RE}_i}{\overline{Pr}_i + \bar{L}_i}$	$k = \frac{ETp + 0}{Pr + L} \geq 1$	$k = \frac{ETp + RE}{Pr + 0} \leq 1$
(ii)	$k_i = \frac{\overline{ETp}_i + \overline{RE}_i + \overline{RO}_i}{\overline{Pr}_i + \bar{L}_i}$	$k = \frac{ETp + 0 + 0}{Pr + L} \geq 1$	$k = \frac{ETp + RE + (Pr - ETp - RE)}{Pr + 0} = 1$
(iii)	$k_i = \frac{\overline{ET}_i + \overline{RE}_i + \overline{RO}_i}{\overline{Pr}_i + \bar{L}_i}$	$k = \frac{(Pr + L) + 0 + 0}{Pr + L} = 1$	$k = \frac{ETp + RE + (Pr - ETp - RE)}{Pr + 0} = 1$
(iv)	$k_i = \frac{\overline{ET}_i + \overline{RE}_i}{\overline{Pr}_i + \bar{L}_i}$	$k = \frac{(Pr + L) + 0}{Pr + L} = 1$	$k = \frac{ETp + RE}{Pr + 0} \leq 1$
(v)	$k_i = \frac{\overline{RE}_i + \overline{RO}_i - \bar{L}_i}{\overline{Pr}_i - \overline{ETp}_i}$	$k = \frac{0 + 0 - L}{Pr - ETp} \leq 1$	$k = \frac{RE + (Pr - ETp - RE) - 0}{Pr - ETp} = 1$
(vi)	$k_i = \frac{\overline{RE}_i + \overline{RO}_i - \bar{L}_i}{\overline{Pr}_i - \overline{ET}_i}$	$k = \frac{0 + 0 - L}{Pr - (Pr + L)} = 1$	$k = \frac{RE + (Pr - ETp - RE) + 0}{Pr - ETp} = 1$

However, after selecting suitable equations, k is used to produce first estimation of the moisture anomaly index, z (Palmer, 1965):

$$\mathrm{z} = \mathrm{d} \times \mathrm{k} \tag{7}$$

Now, the first guessed values of k can be revised. The re-evaluation of the weighting factor is done in two stages:

Stage 1: Obtaining a new annually mean weighting factor, $\overline{\mathrm{K}}'$, inspiring from the reversed form of Eq. 7 (Palmer, 1965):

$$(\overline{\mathrm{K}'})_{\mathrm{w}} = (\sum_{\mathrm{i}=1}^{12} \mathrm{z}_{\text{ex-i}})_{\mathrm{w}} / (\sum_{\mathrm{i}=1}^{12} \mathrm{d}_{\text{ex-i}})_{\mathrm{w}} \quad \text{for wet spells} \tag{8}$$

$$(\overline{\mathrm{K}'})_{\mathrm{d}} = (\sum_{\mathrm{j}=1}^{12} \mathrm{z}_{\text{ex-i}})_{\mathrm{d}} / (\sum_{\mathrm{j}=1}^{12} \mathrm{d}_{\text{ex-i}})_{\mathrm{d}} \quad \text{for drought events} \tag{9}$$

where, w and d are related to the wet spell or drought events and $\sum_{\mathrm{i}=1}^{12} \mathrm{d}_{\text{ex-i}}$ is sum of d for the annually driest (or wettest) period, which is assumed that represents extreme drought (or wet spell) in any area of study (Palmer, 1965; Akinremi *et al.*, 1996):

$$(\sum_{\mathrm{i}=1}^{12} \mathrm{d}_{\text{ex-i}})_{\mathrm{w}} = \mathrm{Max}(\sum_{\mathrm{i}=0}^{12-1} \mathrm{d}_{-\mathrm{i}}) \quad \text{for wet spells} \tag{10}$$

$$(\sum_{\mathrm{i}=1}^{12} \mathrm{d}_{\text{ex-i}})_{\mathrm{d}} = \mathrm{Min}(\sum_{\mathrm{i}=0}^{12-1} \mathrm{d}_{-\mathrm{i}}) \quad \text{for drought events} \tag{11}$$

In addition, $\sum_{\mathrm{i}=1}^{12} \mathrm{z}_{\text{ex-i}}$ is especial Σz (comes from Eq. 7) that can be assumed as extreme drought (or wet spell) over a 12-months period. Determining what Σz should be the extreme values, needs special route: in which, the varying periods represented the maximum rate of Σz in different area of study were selected. Then, the picked values (individually for dry and wet spells) are plotted verses their length and fitted by an envelope line (Palmer, 1965; Akinremi *et al.*, 1996):

$$\sum_{\mathrm{t}=1}^{\mathrm{i}} \mathrm{Z}_{\mathrm{t}} = \mathrm{m} \times \mathrm{i} + \mathrm{b} \tag{12}$$

where, m and b are coefficients of the fitted line and i is drought or wet spell length. $\sum_{\mathrm{i}=1}^{12} \mathrm{z}_{\text{ex-i}}$ now, is calculated from the regression lines:

$$(\sum_{\mathrm{i}=1}^{12} \mathrm{z}_{\text{ex-i}})_{\mathrm{w}} = \mathrm{m}_{\mathrm{w}} \times 12 + \mathrm{b}_{\mathrm{w}} \quad \text{for wet spells} \tag{13}$$

$$(\sum_{\mathrm{i}=1}^{12} \mathrm{z}_{\text{ex-i}})_{\mathrm{d}} = \mathrm{m}_{\mathrm{d}} \times 12 + \mathrm{b}_{\mathrm{d}} \quad \text{for drought events} \tag{14}$$

Stage 2: Determining K as a function of its relative aspects: Palmer (1965) supposed that the K-values depend on the water balance parameters (Eq. 6), as well as vary inversely with the mean of the absolute values of d for the total length of n year $(\overline{\overline{\mathrm{D}}})$:

$$\overline{\overline{\mathrm{D}}}_{\mathrm{w}} = \sum_{\mathrm{i}=1}^{12} \overline{\mathrm{D}}_{\mathrm{i}} / 12 = \sum_{\mathrm{i}=1}^{12} (\sum_{\mathrm{j}=1}^{\mathrm{n}} \mathrm{d}_{\mathrm{j}} / \mathrm{n})_{\mathrm{i}} / 12 \quad \text{for } \mathrm{d} \geq 0 \tag{15}$$

$$\overline{\overline{\mathrm{D}}}_{\mathrm{d}} = \sum_{\mathrm{i}=1}^{12} \overline{\mathrm{D}}_{\mathrm{i}} / 12 = \sum_{\mathrm{i}=1}^{12} (\sum_{\mathrm{j}=1}^{\mathrm{n}} |\mathrm{d}_{\mathrm{j}}| / \mathrm{n})_{\mathrm{i}} / 12 \quad \text{for } \mathrm{d} \leq 0 \tag{16}$$

So, after some experimenting with various empirical relationships, the semi-logarithmic plot shown in Fig. 1 was developed by Palmer (1965). The generalized form of Palmer equation can be expressed as:

$$(\overline{\mathrm{K}'})_{\mathrm{w}} = \lambda_{\mathrm{w}} \times \mathrm{Log}\left[\frac{\overline{\mathrm{k}} + \theta_{\mathrm{w}}}{\overline{\overline{\mathrm{D}}}_{\mathrm{w}}}\right] + \mu_{\mathrm{w}} \quad \text{for wet spells} \tag{17}$$

$$(\overline{\mathrm{K}'})_{\mathrm{d}} = \lambda_{\mathrm{d}} \times \mathrm{Log}\left[\frac{\overline{\mathrm{k}} + \theta_{\mathrm{d}}}{\overline{\overline{\mathrm{D}}}_{\mathrm{d}}}\right] + \mu_{\mathrm{d}} \quad \text{for drought events} \tag{18}$$

where, $\overline{\mathrm{K}'}$ is annually mean weighting factor (Eq. 8 or 9), λ, θ and μ are the calibrated coefficients (equal to 1.5, 2.8 and 0.5 in Palmer study which are derived only for dry conditions and via inch unit of parameters). $\overline{\mathrm{k}}$ in these equations are annually average of k in each study region, that for a selected form of Table 1, such as Eq. (ii), is written as:

$$\overline{\mathrm{k}} = \frac{\overline{\overline{\mathrm{ETp}}} + \overline{\overline{\mathrm{RE}}} + \overline{\overline{\mathrm{RO}}}}{\overline{\overline{\mathrm{Pr}}} + \overline{\overline{\mathrm{L}}}} \tag{19}$$

In this equation, the double-bars represent annually average values of the parameters, which were described before. For example, for Pr it can be described as:

$$\overline{\overline{\mathrm{Rr}}} = \sum_{\mathrm{i}=1}^{12} \overline{\mathrm{Pr}}_{\mathrm{i}} / 12 \tag{20}$$

The next step is to apply the empirical coefficients (λ, θ and μ) and Eq. 17 and 18 (derived for all of regions

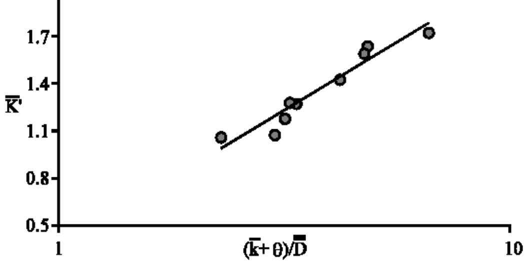

Fig. 1: The extracting of K-value from driest 12 months in Palmer's (1965) study

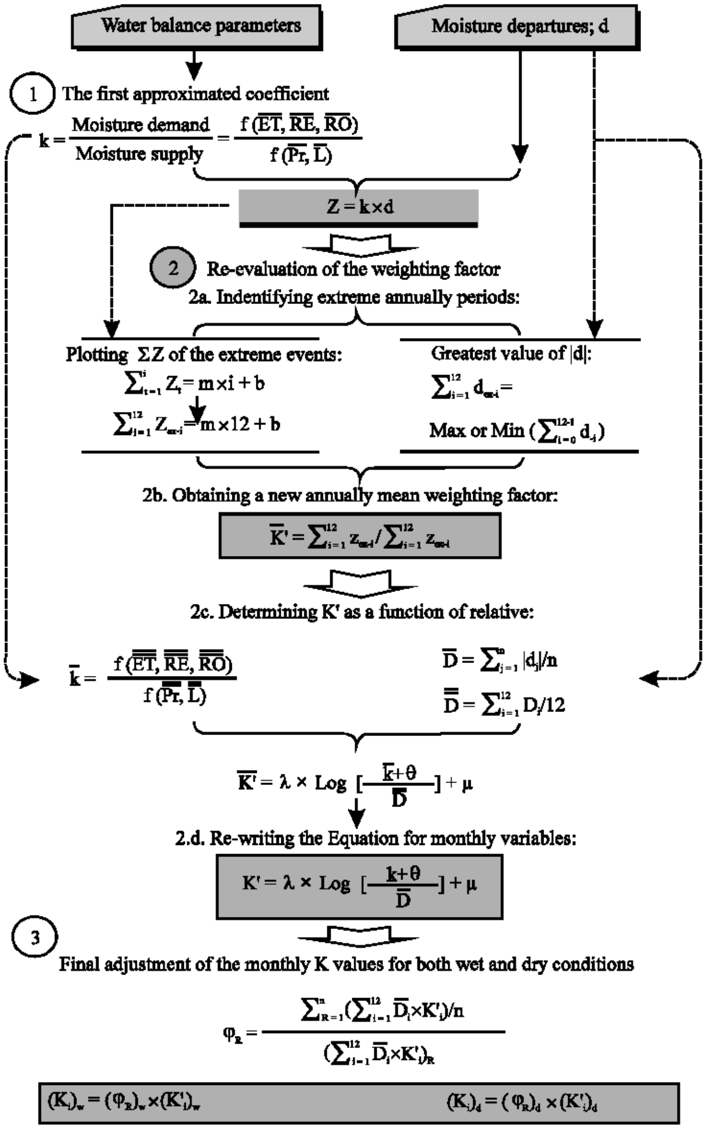

Fig. 2: Flowchart of calibrating the climatic characteristic coefficient in PDSI

in a study), to each of the 12 calendar months and thereby deriving the 12 K'-values for each place:

$$(K')_w = \lambda_w \times \text{Log}\left[\frac{k+\theta_w}{\bar{D}_w}\right] + \mu_w \quad \text{for wet spells} \tag{21}$$

$$(K')_d = \lambda_d \times \text{Log}\left[\frac{k+\theta_d}{\bar{D}_d}\right] + \mu_d \quad \text{for drought events} \tag{22}$$

where, k is approximated from the selected equation in Table 1 and $\bar{D}$ is computed as implied at Eq. 15 and 16.

Stage 3: As final adjustment of the monthly K-values, coming back to Eq. 4, it is expected that the average annual sum of the weighted average departures $(\sum_{i=1}^{12}\bar{D}_i \times K_i')$ should be about the same for all study area. So, if all weighting factors are adjusted so that all of the annual sums of $\sum_{i=1}^{12}\bar{D}_i \times K_i'$ equals to an average of all regions, i.e., $\sum_{R=1}^{n}(\sum_{i=1}^{12}\bar{D}_i \times K_i')_R/n$, then drought (or wet spell) analysis results should be more comparable. The adjustment factor, φ, can be obtained by:

$$\varphi_R = \frac{\sum_{R=1}^{n}(\sum_{i=1}^{12}\bar{D}_i \times K_i')_R/n}{(\sum_{i=1}^{12}\bar{D}_i \times K_i')_R} \tag{23}$$

And the final equation of K would be, as;

$$(K)_w = (\varphi_R)_w \times (K')_w \quad \text{for wet spells} \tag{24}$$

$$(K)_d = (\varphi_R)_d \times (K')_d \quad \text{for drought events} \tag{25}$$

Afterward, it is necessary to rebuild the envelop line (Eq. 12) using Z-values comes from the following equations (although Palmer did not change its initial envelop line):

$$Z_i = (K_i)_w \times d_i \qquad \text{if } d_i > 0 \quad \text{for wet spells} \tag{26}$$

$$Z_i = (K_i)_d \times d_i \qquad \text{if } d_i < 0 \quad \text{for drought events} \tag{27}$$

The aforementioned process is summarized in Fig. 2, which can help the user to understand and apply it straightforward.

Based on these generalized procedure (Fig. 2), which was the main part of this paper objective, a case study was selected to show the procedure via actual data.

MATERIALS AND METHODS

For putting into practice the method of PDSI scaling (weighting factor, K), the data set of Fars province (south part of Iran; Fig. 3) was applied and the results were illustrated step by step based on the aforementioned details. In this way, the outputs led the research to some modifications, which were explained in accompany with the results.

The Maharlue catchment was divided in three areas of study (three sub-basins) and for each one of them, the area equivalent data of monthly rainfall and temperature from the existing stations were calculated for 31 year (which are out of question). However, the obtained moisture departures of these areas were used as the input parameters for this study. The d-values of the first area are presented in Table 2.

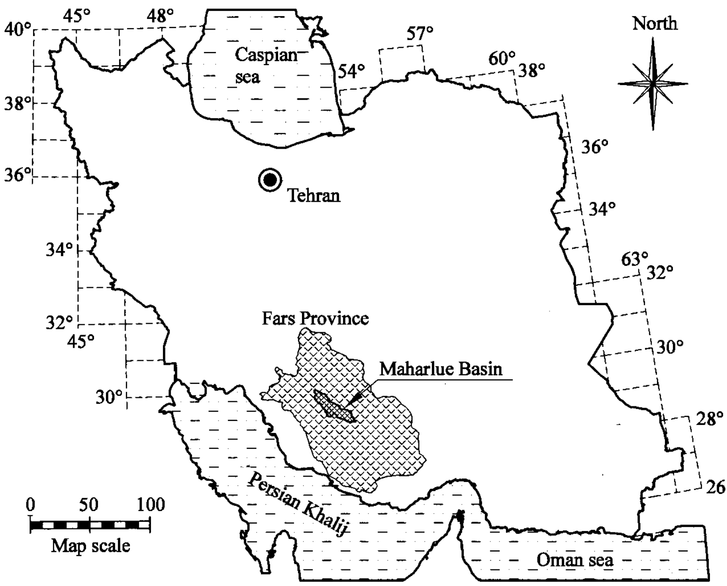

Fig. 3: Location of Maharlue Basin (4270 km^2) in Fars province and the Country of Iran (Software bank of Fars Province Water Organization, 2003)

Table 2: Values of moisture departures in mm at a solar calendar; study location of Maharlue-1

	Time scale; months of water year											
Year	7	8	9	10	11	12	1	2	3	4	5	6
1350	-	-2.3	-17.1	13.4	33.0	57.8	79.0	16.6	23.8	13.9	6.2	1.6
1351	-2.0	-27.4	-36.0	-34.9	-93.9	-0.5	-28.1	-27.5	-23.9	-2.3	-2.7	-0.9
1352	-2.9	-28.0	-83.5	27.7	25.2	-54.3	4.8	-12.3	2.2	-2.6	6.5	2.1
1353	2.2	-28.2	28.8	1.3	-4.3	-47.9	-0.5	75.4	30.1	31.8	11.9	2.1
1354	-1.7	-16.7	13.3	-70.6	93.9	53.9	34.4	12.9	16.7	10.7	11.8	1.6
1355	-1.9	0.3	-73.0	20.6	-61.9	-100.7	27.6	-13.2	0.1	0.8	-3.9	-0.9
1356	-2.8	98.7	-28.5	148.8	-38.6	3.4	-16.2	-5.5	4.2	3.1	3.9	2.4
1357	-1.6	40.3	24.7	-11.0	43.4	-17.4	-17.9	0.6	7.2	3.6	8.6	5.2
1358	-0.3	-25.4	68.2	-12.1	132.7	46.4	-18.3	-15.6	-3.1	-2.6	2.4	1.6
1359	-1.6	-22.2	27.2	-49.1	-28.2	31.2	-12.7	-3.7	11.0	16.3	11.8	6.8
1360	-0.1	-16.1	-82.7	-58.6	21.4	38.0	20.6	-16.2	-5.9	-6.8	-0.2	-0.7

Table 2: Continued

Year	7	8	9	10	11	12	1	2	3	4	5	6
	Time scale; months of water year											
1361	3.4	72.6	-5.7	-12.6	-55.5	29.6	-1.6	-12.8	0.2	-3.6	-2.3	-0.9
1362	-2.7	-28.2	-82.3	-122.8	-110.6	-59.6	9.2	29.3	-15.9	-7.0	-1.6	-0.6
1363	-2.2	26.3	-25.8	25.6	8.6	-69.4	-47.8	8.0	-3.5	-3.7	-3.3	-0.5
1364	-2.8	2.8	21.8	-57.5	-70.2	-34.8	-1.8	4.9	6.4	5.3	2.0	1.2
1365	-2.2	31.3	269.7	-31.7	-68.7	18.5	28.2	-18.7	-5.7	-5.3	2.6	0.0
1366	-2.5	-12.3	-76.9	101.4	29.5	13.2	-20.0	39.8	22.0	10.4	4.4	1.4
1367	-2.3	-29.8	-37.3	-20.8	-71.6	-33.8	-16.1	-2.0	-1.3	-8.1	-5.2	-1.2
1368	-3.0	27.4	53.2	6.8	129.5	-70.1	-33.5	-21.1	-18.3	-13.4	-6.2	-2.1
1369	-3.3	-28.1	-74.5	24.9	54.5	42.8	-20.1	-18.1	-7.7	-1.8	-2.9	-1.2
1370	5.9	-30.6	50.9	23.3	6.9	9.3	1.5	41.9	26.9	33.8	7.4	1.8
1371	-1.9	-30.0	65.4	158.3	19.9	136.7	-8.6	7.0	15.5	8.7	1.2	0.3
1372	-2.9	-10.3	-93.9	-144.2	-99.5	7.8	-53.3	9.0	-36.7	-23.6	-10.5	-3.2
1373	0.1	104.8	46.9	8.1	101.6	-40.6	-0.5	45.7	32.9	34.4	7.6	1.2
1374	29.5	-30.6	67.2	110.3	15.2	42.8	79.9	-15.0	4.3	-3.2	-0.1	-0.2
1375	5.6	-29.0	-83.2	-99.3	-85.8	-39.2	61.0	2.8	12.2	2.7	-3.3	-2.4
1376	-3.4	-0.4	76.2	8.1	144.5	13.1	37.4	-11.8	0.9	-1.6	-6.0	-2.2
1377	-2.5	-30.4	-99.7	-26.0	24.5	170.7	-45.8	-25.1	-27.7	-24.1	-10.5	-2.3
1378	-3.9	-24.0	-60.6	-7.3	-18.1	-78.9	-67.3	-37.9	-43.2	-32.7	-12.2	-3.7
1379	7.5	61.5	21.7	-41.6	-51.9	-55.4	-40.6	-21.7	-24.7	-22.3	-10.9	-3.4
1380	-3.8	-16.1	125.7	121.6	-25.7	-12.6	67.1	-15.6	0.9	-10.7	-6.4	-3.0

(Note: the solar year 1350, month 7 related to the 10th month of 1971)

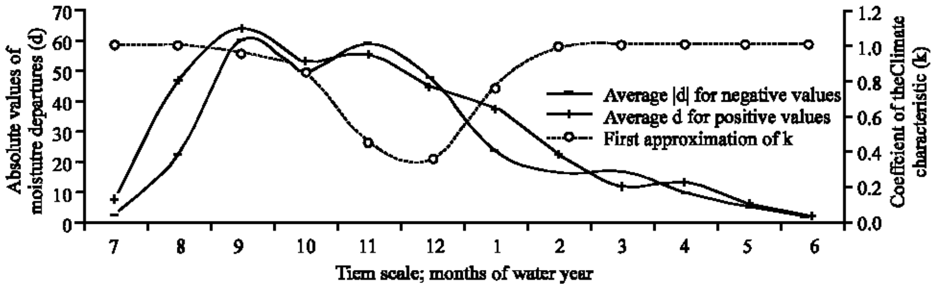

Fig. 4: The changes of selected k-equation via absolute values of d, in the study region

RESULTS

At first, due to pre-calculated d for the study-region, different k-equations in Table 1 were evaluated and then, the (iv) equation was distinguished more appropriate, because of its converse trends to the absolute values of the moisture departures (Fig. 4), as it is expected (Eq. 5).

Then the selected k-coefficients, were applied (using Eq. 7) to calculate initial moisture anomalies, z. Subsequently, in order to obtain the enveloped line of extreme dry and wet spells, the varying periods represented the maximum rate of Σz in different areas of study, were scanned from the z-time series. Figure 5 shows the results, from which the following equations were obtained for dry and wet spells:

$$\sum_{j=1}^{i} Z_j = m_w \times i + b_w = 23 \times i + 280 \quad \text{for wet spells} \tag{28}$$

$$\sum_{j=1}^{i} Z_j = m_d \times i + b_d = -24 \times i - 185 \quad \text{for drought events} \tag{29}$$

Now, the annually mean weighting factor, $\overline{K'}$ for each region (Eq. 8 and 9) can be obtained form extreme drought (or wet spell), which were calculated from Eq. 28 and 29 (by i = 12) and Eq. 10 and 11. Table 3 shows the results. However, determining the relationships between $\overline{K'}$, $\overline{\overline{D}}$ and $\overline{k}$ (Eq. 17 and 18) showed that following the explained procedure will be encountered with unacceptable values (negative coefficients for the slope of Eq. 17 and 18, also negative $\overline{K'}$). This can be interpreted as the effect of significant vacillations in the monthly distribution of parameters (especially d), whose annual averages do not reflect them.

Therefore, the aforesaid procedure was re-tracked in the month scale (Table 4, Fig. 6). It should be noted that in the new proposed method, Eq. 17 and 18 (with annual scale) are not derived and Eq. 21 and 22 are directly obtained using monthly parameters.

At the end Stage, the final values of K were obtained by the fitted equations (Fig. 6) and adjusting coefficients (Table 5). Now, these weighting factors (K_w and K_d for

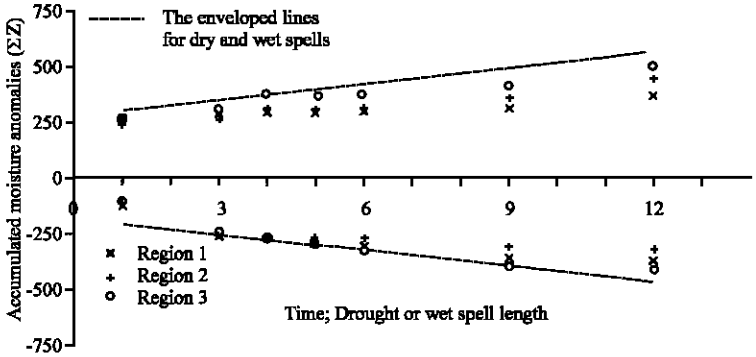

Fig. 5: Driving the drought severity equations using extreme events, (from the three study regions of Maharlue)

Table 3: The annually driest (or wettest) moisture anomalies and departures as well as the annually mean weighting factor (study regions of Maharlue)

Area of study	Wettest 12 months periods			Driest 12 months periods		
All	The maximum rates of Σz					
		556.0			-473.0	
Separately:	The greatest and smallest values of d:					
	Max.	2nd	3rd	3rd	2nd	Min.
	--------	--------	--------	--------	--------	--------
Region 1	461.6	451.5	436.4	-457.9	-458.5	-461.5
Region 2	508.6	508.2	496.6	-369.1	-369.5	-393.8
Region 3	535.1	520.7	484.5	-442.9	-444.2	-444.8
Separately:	$\overline{K'} = \sum_{i=1}^{12} z_{ex-i} / \sum_{i=1}^{12} d_{ex-i}$					
Region 1		1.24			1.03	
Region 2		1.10			1.25	
Region 3		1.08			1.07	

Table 4: The requirement parameters for extracting the empirical relationships of K', (for the three study regions of Maharlue)

	Time scale; months of water year											
Variables	7	8	9	10	11	12	1	2	3	4	5	6
Z_{max}	$\Sigma z = m \times i + b =$			+23.0	×i	+280.0	and i = 1 ⇒		$z_{w-max} =$		303	
				-24.0	×I	-185.0			$z_{w-max} =$		-209	
Study region 1												
d_w-max	29.5	104.8	269.7	158.3	144.5	170.7	79.9	75.4	32.9	34.4	11.9	6.8
d_d-min	-3.9	-30.6	-99.7	-144.2	-110.6	-100.7	-67.3	-37.9	-43.2	-32.7	-12.2	-3.7
K'_w	10.3	2.9	1.1	1.9	2.1	1.8	3.8	4.0	9.2	8.8	25.4	44.5
K'_d	53.8	6.8	2.1	1.4	1.9	2.1	3.1	5.5	4.8	6.4	17.1	55.9
k	1.00	1.00	0.95	0.84	0.45	0.35	0.76	0.99	1.00	1.00	1.00	1.00
$\overline{Dw_i}$	7.7	46.6	64.1	53.3	55.3	44.7	37.6	22.6	12.1	13.5	6.3	2.1
$\overline{Dd_i}$	2.4	22.2	60.0	50.0	59.0	47.7	23.7	16.3	16.7	9.7	5.2	1.7
Study region 2												
d_w-max	24.8	91.1	248.9	158.5	134.0	121.1	73.0	62.8	38.8	39.7	17.8	4.1
d_d-min	-2.8	-26.5	-81.8	-130.8	-111.0	-86.0	-60.0	-41.0	-43.8	-26.6	-10.1	-3.0
K'_w	12.2	3.3	1.2	1.9	2.3	2.5	4.1	4.8	7.8	7.6	17.0	74.8
K'_d	74.2	7.9	2.6	1.6	1.9	2.4	3.5	5.1	4.8	7.9	20.6	70.3
k	0.99	1.00	0.96	0.89	0.55	0.39	0.82	1.00	1.00	1.00	1.00	1.00
$\overline{Dw_i}$	7.7	43.4	61.2	44.9	49.5	37.9	31.4	19.1	15.8	14.2	6.1	1.7
$\overline{Dd_i}$	1.8	20.6	50.4	47.9	60.0	46.0	22.7	15.7	16.8	8.9	4.4	1.6
Study region 3												
d_w-max	13.4	59.6	271.2	142.3	114.4	91.2	63.5	60.1	53.4	39.5	27.5	3.2
d_d-min	-2.3	-19.1	-64.4	-99.0	-102.4	-83.0	-56.6	-65.7	-68.0	-36.5	-10.9	-2.2
K'_w	22.6	5.1	1.1	2.1	2.6	3.3	4.8	5.0	5.7	7.7	11.0	94.2
K'_d	89.3	10.9	3.2	2.1	2.0	2.5	3.7	3.2	3.1	5.7	19.2	94.8
k	0.99	1.00	0.97	0.97	0.89	0.73	0.92	1.00	1.00	1.00	1.00	1.00
$\overline{Dw_i}$	9.0	27.0	47.6	39.3	48.5	36.8	23.4	17.2	21.8	13.7	6.1	1.2
$\overline{Dd_i}$	1.3	14.8	44.7	36.9	45.5	44.7	22.0	20.9	34.5	16.7	5.0	1.1

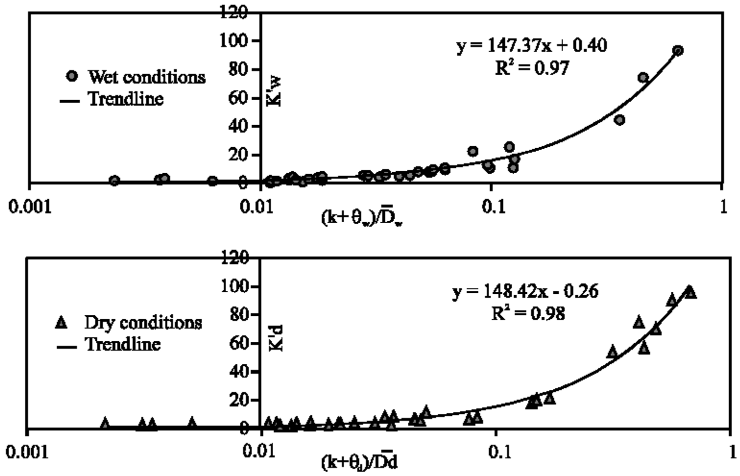

Fig. 6: The empirical equations of K (study region of Maharlue)

Table 5: The coefficients of climate characteristics, K (study regions of Maharlue)

	Time scale; months of water year												
Variables	7	8	9	10	11	12	1	2	3	4	5	6	Avg.
$\bar{D}_i \times K'_i$													
Study region 1													
	113.6	129.0	129.2	108.7	51.3	32.8	90.2	118.2	115.3	115.9	113.0	111.4	102.39
	110.7	105.5	88.9	75.1	14.2	2.8	69.6	105.8	106.9	108.8	110.0	110.9	84.10
													φ
$(K_i)_w$	15.3	2.9	2.1	2.1	1.0	0.8	2.5	5.5	10.0	9.0	18.7	55.3	1.04
$(K_i)_d$	50.3	5.1	1.6	1.6	0.3	0.1	3.1	6.9	6.8	12.0	22.7	68.6	1.07
Study region 2													
	112.0	127.7	128.4	112.4	64.2	36.0	96.7	118.1	116.8	116.2	112.9	111.2	104.39
	109.2	105.9	91.8	82.7	29.3	9.2	78.9	107.2	106.9	109.0	110.2	110.9	87.60
													φ
$(K_i)_w$	14.9	3.0	2.1	2.6	1.3	1.0	3.1	6.3	7.6	8.4	19.1	68.7	1.02
$(K_i)_d$	62.2	5.3	1.9	1.8	0.5	0.2	3.6	7.0	6.5	12.5	25.9	73.4	1.03
Study region 3													
	113.0	121.2	125.2	121.2	113.5	85.7	108.6	117.4	119.2	116.0	113.0	111.0	113.74
	109.8	107.4	95.4	96.7	83.1	59.9	94.3	105.9	102.3	107.0	110.0	111.0	98.57
													φ
$(K_i)_w$	11.8	4.2	2.5	2.9	2.2	2.2	4.4	6.4	5.1	7.9	17.4	88.8	0.94
$(K_i)_d$	76.8	6.6	2.0	2.4	1.7	1.2	3.9	4.6	2.7	5.9	20.0	92.2	0.91

each of the 12 calendar months) are capable to be employed as the climatic characteristics coefficients for three regions of the case study, in order to calculate moisture anomaly or Z-values (Eq. 26, 27).

DISCUSSION

At the operational part of this research, the average of $\sum_{i=1}^{12}\bar{D}_i \times K'_i$ in all study regions (the numerator of Eq. 23) were obtained 107 and 90 separately for wet and dry periods (Table 5); while Palmer (1965) was calculated it 17.7 without separating the periods. Also, in some other study, different value has been found for this coefficient ($\sum_{R=1}^{n}(\sum_{i=1}^{12}\bar{D}_i \times K'_i)_R / n$), like 14.2 by Akinremi *et al.* (1996) in the Canadian prairies and 264.3 by Toraabi (2002) in Zayande-Rood basin (Isfahan-IR of Iran). Comparison of these results shows that K-values should be calibrated for any case study and moreover, it may be significant calculating K-coefficients separately for dry and wet periods.

However, the generalized procedure of the climatic coefficient, represented in this study, can be considered as a reference text for any case study. It also can be helpful for other researches related to the K-developing or modification, such as the monthly modified procedure, proposed in this study. So, it can be take into account as a turning point in the Palmer scaling method.

The «monthly modified procedure» in this study, also confirmed the problem, implied by Alley (1984), who stated: deriving monthly K-values (Eq. 21, 22) using data on the annual level (Eq. 17, 18), may not yield the desired result of comparability of the index values between months.

Consequently, it is recommended that the generalized process, for any case of study that needs to quantify drought severity by PDSI, was followed step by step in accompany with the monthly modification method. Afterward their results should be compared to decide that which one could be obtained better outputs.

REFERENCES

Akinremi, O.O., S.M. McGinn and A.G. Barr, 1996. Evaluation of the palmer drought index on the Canadian prairies. J. Clim., 9 (5): 897-905.

Alley, W.M., 1984. The Palmer drought severity index: Limitations and assumptions. J. Clin. Applied Meteor., 23: 1100-1109.

Guttman, N.B., 1998. Comparing the palmer drought index and the standardized precipitation index. J. Am. Water Resour. Assoc., 34 (1): 113-121.

Heim, Jr. R.R., 2002. A review of twentieth-century drought indices used in the United States. Bull. Am. Meteor. Soc., 83 (8): 1149-1165.

Palmer, W.C., 1965. Meteorological drought. Research Paper No. 45, U.S. Department of Commerce Weather Bureau, Washington DC., pp: 58.

Quiring, S.M. and T.N. Papakryiakou, 2003. An evaluation of agricultural drought indices for the Canadians prairies. Agric. For. Meteor., 118: 49-62.

Toraabi, P.S., 2002. Drought Management; Analysis and Predicting of droughts and its effect on water supply management. Ph.D Thesis. Civil Engineering College of Amir-Kabir University of Technology, pp: 325.

Wells, N., 2002. Documentation for the PDSI Information. Used in the National Agriculture Decision Support System, NADSS. Computer Science and Engineering, University of Nebraska, Lincoln (http://nadss.unl.edu/info/pdsi_doc/, Accessed in 2003).