We are IntechOpen,
the world's leading publisher of
Open Access books
Built by scientists, for scientists

4,800
Open access books available

122,000
International authors and editors

135M
Downloads

Our authors are among the

154
Countries delivered to

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

CLARIVATE ANALYTICS

BOOK CITATION INDEX

INDEXED

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

The Evapotranspiration in Climate Classification

Antonio Ribeiro da Cunha and Edgar Ricardo Schöffel
São Paulo State University - Superior School Agronomic Sciences
Federal University of Pelotas - Superior School Eliseu Maciel Agronomy
Brazil

1. Introduction

1.1 Climate

Climate is the average atmospheric condition of a particular place or region, ranging from months to millions of years, being 30 years the classical period defined by the World Meteorological Organization (WMO). It's represents different weather conditions prevailing at a site or region, considering the analysis of a large amount of data, affecting the majority of human activities, mainly in agriculture.

Several researchers have defined the climate word, such as: Köppen (1936) – "the sum of the atmospheric conditions that make a place the earth's surface more or less habitable for humans, animals and plants"; Trewartha (1937) - "the mean or normal condition over a long period, such as 20, 30 and 100 years"; Blair (1942) - "the summation of weather conditions in historical time" or "climate is the summary of all the manifold weather influences"; Thornthwaite (1948) – "the interaction of meteorological factors that contribute to give the place its character and individuality"; Miller (1959) -"the science that discusses the weather condition of the earth surface"; Oliver (1981) - "climate is the aggregate of weather at a given area for a given time period"; and Anwar (1993) - "the generalized picture of weather is called climate".

1.2 Climatological series

For thousands of years, historians recorded information about the weather, but most were based on reports with no reliability. With the creation of weather records in the first half of the 20th century, these manuscripts had extreme events, which were a cause proud of the observation and recording of such information, because the stamp or the signature of the person which recorded allowed reliability - personal source history. After the establishment of WMO was standardized the forms and procedures regarding records in national archives of meteorology.

Thom (1966) defined climatological series as "a sample of a population of data of one same location within the observation period, in days or months", for example, the average temperatures of 30 January in 30 years of observation. The analysis of climatological data involves verifying the story of a weather station. The displacement of the weather station, a change in the observation period or of instrumentation, discontinuity in the measurements, a change in the environment immediately around the station, such as buildings, can invalidate the climatological series; in addition, tests should be made for consistency data.

Recommendations and criteria are defined by WMO to promote the detection of the usual problems of discontinuity, non-representativeness and data inconsistency.

The data record should be consistent (have no changes in location, instruments, observation practices, etc.; these are identified here as "exposure changes") and have no missing values so a normal will reflect the actual average climatic conditions. This ensures the homogeneity of climatologically series, because that way, the observed variations are caused only by conditions of weather and climate. Another problem is related to the mesh to collect weather data that is still insufficient, affecting the representativeness and damaging the climate studies in a region.

After the end of the 20th century, the weather information has been transmitted digitally, due to advances in computer technology, and with that, it the collection, transmission, processing and storage of meteorological data have been facilitated. This is due to the use of data loggers that reduced the errors of reading, interpreting and typing, providing quality and standardization of data collected.

1.3 Climatological normals

From 1956 to 1989, WMO guided to update the weather data the every 10 years. As of 1989, it's established the general procedures for calculating the monthly and annual averages, which provided an opportunity for the climatological normal standard and provisional (WMO, 2009).

The WMO defines normal as "period averages computed for a relatively long period of at least three consecutive decades", i.e. "mean climatological data computed for the following consecutive periods of 30 years: 1 January 1901 to December 31 , 1930, 1 January 1931 to December 31, 1960, etc" (WMO, 1984).

There is a coordinated international effort to compile data standard - the global standard - every 30 years to monitor climate change that may occur, the latter being obtained for the period 1961-1990.

The use of meteorological allows comparisons between regions through different climate elements, analyzing the changes monthly throughout the year and during the fall-winter and spring-summer, the energy transfer from soil to atmosphere by evapotranspiration and water availability (climatic water balance).

1.4 Climatic classification system

The climate classifications are intended the organize large amount of information to facilitate the rapid retrieval and communication, grouping items according to their similarities to provide an estimate of the climatic resources of a particular place or region, serving for various purposes. They simplify the climatic data of a place or region, provides a concise description of climate factors in terms of real assets (the which creates the local climate), provides a means by which the climatic regions can be accurately identified and can be used in global, local or micro scale, being the starting point for analyzing the causes of climate variations.

The climate classifications provide relevant information to the different types of cultures: allow the interrelationship between the local climate with the productive potential of a given species, the identification of abnormal conditions or agricultural practice, the quantification of water stress levels that the culture is subject, estimate rates of aridity and productivity losses for different locations, identify the conditions conducive or anomalous

for the agricultural practices, choose plant varieties most suitable for a region, providing the best sowing time, management recommendations, cultural practices and harvesting, and other information critical to the agroclimatic zoning.

It is difficult to create a suitable climate classification system, because it is defined according to each climatologist and their own criteria, being some more complex systems and other simpler.

According to Trewartha (1968) "classification of climate is a process basic to all sciences, consisting of recognizing individuals with certain important characteristics in common and grouping them into a few classes or types". Griffiths (1978) defined it as, "climatic classification is merely a method of arranging various climatic parameters either singly or grouped into ranks or sets, so, as both to simplify the mass of data and to identify analogies", i.e. "there are no two places in the world that experience exactly the same climate; but it is possible to identify areas with similar climate; this grouping or analogue method is referred to as climate classification".

Classification sistems different are known, such as those of Amend for Supan (1879), Köppen (1936), Kendrew (1941), Blair (1942), Thornthwaite (1948), Flohn (1950), Kazi (1951), Geiger (1953), Miller (1959), Nasrullah (1968), Terjung & Louie (1972), Griffiths (1978), Johnson (1979), Shamshad (1988), Raja & Twidal (1990), F.K. Khan (1991) and J.A. Khan (1993). In which case, we gave priority to two more classifications used throughout the world, Köppen (1936) and Thornthwaite (1948).

The Köppen climate classification is relatively simple and very popular. It associates vegetation types with climate prevailing in the regions, taking into account the temperature and precipitation. Already the Thornthwaite classification is based on two major climate indices, moisture content and the annual potential evapotranspiration.

2. Köppen's versus Thornthwaite's climatic classification

The main difficulty in climate classification is related to the inadequacy of climatic data available, both in terms of surface coverage as in terms of duration and reliability. The climatic elements most frequently used to characterize the climate are the mean values of temperature and precipitation, beyond of other climate elements for a better classification.

The Köppen climate classification contains information more suited to geographical and climatological studies than of agrometeorological, simplifying complex situations of the relationship of climate to the productivity of agricultural crops (Burgos, 1958). Rolim et al. (2007) does not recommend it for the determination of agrometeorological zones because it is efficient only for the macro scale, has a low capacity for the separation of types of climates, and lost in details, since it does not differentiate very well the climatic types (Cunha et al. 2009).

It is inconceivable that Köppen could have produced his original classification and map without using other landscape signals of climate (particularly vegetation) since there would have been so little observed climate data available at that time. In the light of this, the persistence of his scheme of classification is even more remarkable (Peel et al., 2007). The use of Köppen's classification is not confined to teaching, because many researchers routinely use it for their own particular research purposes (McMahon et al., 1992; Peel et al., 2004, 2007). In this sense, Lohmann et al. (1993) state that the Köppen classification is easier to use and is still a useful tool to estimate the ability of climate models to reproduce the present climate and indicate the impact of climate change on the biosphere.

The Köppen classification compensates for its shortcomings because have wide acceptance (Stern et al., 2000), and remains the best known scheme for the climatic zoning, according to Hudson & Brown (2000).

Sunkar (2008) says "the differentiation between the wet and the dry seasons provides adequate information to properly evaluate the potential of agricultural land, when using the Köppen classification system".

Thornthwaite considers the moisture as factor truly active, using it as a basis for identifying the most of its major climatic types, except for three areas of cold in which it analyzes the temperature as active factor or critical. It considers the vegetation is a physical means by which it is possible to transport water from the soil into the atmosphere, defining a type of climate as wet or dry depending on the water requirements of vegetation (Trewartha, 1954). Undoubtedly this is one of the great virtues of Thornthwaite classification, consider the potential evapotranspiration as an essential element in determining of other indexes. Thornthwaite's introduced the concept of potential evapotranspiration which was improved over time on several occasions. The potential evapotranspiration is one opposite process of precipitation it refers to "water used by an extensive vegetated surface in active growth, completely covering the ground, unrestricted and soil water " (Thornthwaite, 1946). The comparison between precipitation and potential evapotranspiration obtained from in the climatic water balance indicate deficiencies and excesses of moisture throughout the year or in season of crop growth (Pereira et al., 1997). The potential evapotranspiration is estimated by the temperature, due to the difficulty in obtaining information from other climatic elements to use a more accurate method (Pereira et al., 2002).

Climatic classification Thornthwaite presents a detailed climate, generating more information a local called of climatic subtype, which favors local studies. According to Balling (1984), this methodology has brought a much greater sensitivity in the definition of climates, and allows separated efficiently climates in topoescala, summarize to efficiently the information generated by normal water balance and the ability to determine agroclimatic zones (Rolim et al., 2007). This classification takes into account temperature, precipitation and evapotranspiration, and presents in detail the period of deficit and hidric surplus of a local (Rolim et al., 2007; Cunha et al., 2009). The Köppen classification associate the vegetation with temperature, while the Thornthwaite classification with the moisture factor (Essenwanger, 2001). For all this, Thorthwaite classification is considered a more refined method than that of Koppen for agricultural applications, since it takes into account the evapotranspiration (Trewartha, 1954).

The most important contribution to the modeling of vegetation and climate is the idea of potential evaporation proposed by Thornthwaite (Hudson & Brown, 2000) and the Thornthwaite map that includes the clear divisions of wetter and drier regions (Logan, 2006). By comparing maps generated by the Köppen and Thornthwaite methods, Doerr (1962) says the Thornthwaite classification is more accurate and helpful to describe the climate of a place. Most geographers readily admit that the Thornthwaite climate classification represents a major step forward in terms of conceptual sophistication about the Köppen system (Malmström, 1969).

3. Climatologic water balance

When relate evapotranspiration with the rain, taking into account the storage of water in the soil, periods of deficit and surplus are revealed, allowing a more critical analysis and

appropriate a place or region. This allows quantification of the levels of water stress to which he is subjected a particular culture, and also estimate indexes of drought and reduced productivity.

According to Thornthwaite (1948), deficiencies and surpluses of water over one year affects the climate of a region amending the conditions of humidity. Excess water in the rainy season, in large part does not solve the drought in the dry season, but may soften, especially if the plants have broad and deep root system. Would be better if the rain was always greater than evapotranspiration, which always occurs to small soil water surplus, provided that no surface flow (runoff), thereby ensuring a water storage in soil under conditions of field capacity, this means that actual evapotranspiration is close to potential evapotranspiration.

The climatic water balance calculations depend on average monthly temperature data, monthly precipitation, potential evapotranspiration and water retention characteristics of soil-water site. The depth of soil layer defines the ability of water available for plants, the greater the depth of soil the greater the water holding capacity and the root system tends to be more superficial. When there is low water availability in the soil, the plants develop more their root system.

Calculations of water stress and evapotranspiration potential and real that participate in the water balance are needed to quantify levels of water stress to which that finds a culture, as well as estimating the productive potential of different locations. For this, the climatic water balance should represent the water availability of a place or region and must be made from time series uninterrupted, consistent and homogeneous, at least 30 years.

In 1948, Thornthwaite proposed the climatic water balance monthly as a simple method, using average monthly air temperature and precipitation accumulated, as well as the storage capacity of soil water, assuming that the soil is considered a reservoir, and that all the water available to the soil first will contribute to the evapotranspiration demand. Still, defines the potential evapotranspiration, as the transfer of water to the atmosphere of a large area with dense vegetation, with active growth covering the entire surface (bahiagrass) and under soil conditions without water restriction - more appropriate concept for climatological studies (Varejão-Silva, 2006).

Thornthwaite & Mather (1955) developed a climatic water balance monthly to monitor the variation of soil water storage throughout the year. By accounting for the supply of water to the soil - precipitation, and the atmospheric demand - potential evapotranspiration, and with a maximum storage - available water capacity, the water balance provides estimates of actual evapotranspiration, of deficit and water excess and soil water storage (Pereira et al., 2002).

4. Methodology

This study used climatologically normal data (1961-1990) published by Brazil's National Institute of Meteorology (INMET, 2009): data of monthly mean air temperature and cumulative monthly rainfall. The locations used to evaluate the effect of altitude: Campos do Jordão (SP) and Santos (SP), the effect of latitude: Boa Vista (RR) and Santa Maria (RS), the effect of longitude: João Pessoa (PB) and Porto Velho (RO) and the effect of ocean currents: Angra dos Reis (RJ) and Cabo Frio (RJ). Geographic coordinates of the locations used in the study (Table 1).

District	State	Latitude	Longitude	Altitude
Campos do Jordão	SP	22° 45′ S	45° 36′ W	1,642.0
Santos	SP	23° 56′ S	46° 20′ W	13.5
Boa Vista	RR	02° 49′ N	60° 39′ W	90.0
Santa Maria	RS	29° 42′ S	53° 42′ W	95.0
João Pessoa	PB	07° 06′ S	34° 52′ W	7.4
Porto Velho	RO	08° 46′ S	63° 55′ W	95.0
Angra dos Reis	RJ	23° 01′ S	44° 19′ W	3.0
Cabo Frio	RJ	22° 59′ S	42° 02′ W	7.0

Table 1. Geographic coordinates of the locations used in the study.

With these normal climatologically data were used two classification systems climate, Köppen and Thorntwaite, aiming to evaluate the role of evapotranspiration.

4.1 Description of criteria and symbols by Köppen (1936) method

The "**1st letter**", it was considered P = annual precipitation (cm) and T = average annual temperature (°C); analyzing the conditions:

Condition (1): winter precipitation: 70% of total annual precipitation occurs during the six coldest months of the year;

Condition (2): summer precipitation: 70% of total annual precipitation occurs during the six hottest months of the year;

Condition (3): when does not apply any of the above conditions.

Condition (1) true:

$P > 2T \Rightarrow$ climate is **A**, **C** or **D**

$2Q < P < T \Rightarrow$ climate is **BS** (steppe)

$P < T \Rightarrow$ climate is **BW** (desert)

Condition (2) true:

$P > 2 (T +14) \Rightarrow$ climate is **A**, **C** or **D**

$(T +14) < P < 2 (T +14) \Rightarrow$ climate is **BS** (steppe)

$P < (T +14) \Rightarrow$ climate is **BW** (desert)

Condition (3) true:

$P > 2 (T + 7) \Rightarrow$ climate is **A**, **C** or **D**

$(T + 7) < P < 2 (T + 7) \Rightarrow$ climate is **BS** (steppe)

$P < (T + 7) \Rightarrow$ climate is **BW** (desert)

Therefore, according to the average temperature, the "**1st letter**" can be:

A: tropical, temperature of the coldest month is above 18 °C;

B: dry climates, limits determined by the temperature and precipitation;

C: temperate climate, temperature of the coldest month between 18 and -3 °C;

D: cold weather, temperature of the warmest month above 10 °C and temperature of the coldest month below -3 °C;

E: polar climates: temperature of the warmest month is below 10 °C;

F: the hottest month is below 0 °C;

G: mountain weather;

H: high altitude climates.

The "**2nd letter**" is obtained as a function of precipitation:

Af: no dry season - the driest month precipitation is greater than 6 cm; **Am**: the driest month precipitation shows higher or equal to (10 - P/25); **Aw**: when the previous conditions do not apply and the driest period occurs in winter;

BS; **BW**: see the previous conditions (1), (2) and (3);

Cs; **Ds**: when the precipitation is winter and the wettest month of winter precipitation has equal or greater than three times that of the driest month; **Cw**; **Dw**: the wettest month of summer precipitation has greater than or equal to 10 often the driest month; **Cf**; **Df**: moist, do not apply when sewing;

EF: displays all months of the year with average temperatures below 0 °C; **ET**: when the warmest month has temperature between 0 and 10 °C; **EB**: perpetual snow or tundra.

The "**3rd letter**"is obtained as a function of temperature:

a. hot summer, is the hottest month temperature is above 22 °C;
b. moderately warm summer, the temperature of the warmest month is below 22 °C and at least four months have temperatures above 10 °C;
c. short summer and moderately cold, less than 4 months has a temperature higher than 10 °C;
d. very cold winter, the coldest month has temperatures below -38 °C;

OBS: For arid local (**BS** or **BW**):

BSh' or **BWh'**: very warm, with average annual temperatures over 18 °C and warmest month with temperatures above 18 °C;

BSh or **BWh**: warm, with average annual temperatures over 18 °C and warmest month temperatures below 18 °C;

BSk or **BWk**: cold, with average annual temperature below 18 °C and warmest month with temperatures above 18 °C;

BSk' or **BWk'**: very cold, with average annual temperature below 18 °C and warmest month temperatures below 18 °C.

4.2 Description of criteria and symbols by Thornthwaite (1948) method

The calculation of potential evapotranspiration was done according to the Thornthwaite (1948) method:

$$ET = 16\left(\frac{10.Tn}{I}\right)^{a} \text{ to } 0 \leq Tn < 26.5°C \tag{1}$$

$$ET = -415.85 + 32.24Tn - 0.43Tn^2 \text{ to } Tn \geq 26.5°C \tag{2}$$

Where "Tn" is the average temperature of the month "n", in °C, "n" ranges from 1 to 12 (January through December); "I" index that expresses the level of heat available in the region, according to the equation:

$$I = \sum_{n=1}^{12}(0.2Tn)^{1.514} \tag{3}$$

The exponent of the equation (1) is a function of "I", calculated by the equation:

$$a = 6.7510^{-7}I^3 - 7.7110^{-5}I^2 + 1.791210^{-2}I + 0.49239 \tag{4}$$

The value of "ETp" is a standard condition: evapotranspiration that occurs in a month for 30 days with a photoperiod of 12 hours, dependent on thermal conditions, and therefore needs correction.

$$ETp = ET\left(\left(\frac{d}{30}\right)\left(\frac{N}{12}\right)\right) \tag{5}$$

Where "d" is the number of days of the month and "N" photoperiod of the month in question.

The calculating the climatic water balance was done by the Thornthwaite & Mather (1955) method, assuming the available water capacity of the soil equal to 100 mm for comparative purposes.

The estimation indexes of humidity (Ih), aridity (Ia) and moisture (Im) were calculated according to Thornthwaite (1948):

$$Ih = \frac{EXC}{ETP}100 \tag{6}$$

$$Ia = \frac{DEF}{ETP}100 \tag{7}$$

$$Im = Ih - 0,6(Ia) \tag{8}$$

Where "EXC" is water excess and "DEF" is water deficit, comings from the climatic water balance (mm); "ETP" is potential evapotranspiration (mm).

The following tables that contains the sort keys: Table 2 (1st key), Table 3 (2nd key), Table 4 (3rd key) and Table 5 (4th key).

Climatic types	Moisture index (Im)
A – perhumid	$100 \leq Im$
B_4 – humid	$80 \leq Im < 100$
B_3 – humid	$60 \leq Im < 80$
B_2 – humid	$40 \leq Im < 60$
B_1 – humid	$20 \leq Im < 40$
C_2 – moist subhumid	$0 \leq Im < 20$
C_1 – dry subhumid	$-20 \leq Im < 0$
D – semiarid	$-40 \leq Im < -20$
E – arid	$-60 \leq Im < -40$

Table 2. Climatic types. 1st key based on the moisture index.

Moist climates (A, B$_4$, B$_3$, B$_2$, B$_1$ e C$_2$)	Aridity index (Ia)	Dry climates (C$_1$, D e E)	Humidity index (Ih)
r – little or no water deficiency	0 ≤ Ia < 16.7	d – little or no surplus water	0 ≤ Ih < 10
s – moderate summer water deficiency	16.7 ≤ Ia < 33.3	s – moderate winter water surplus	10 ≤ Ih < 20
w – moderate winter water deficiency	16.7 ≤ Ia < 33.3	w – moderate summer water surplus	10 ≤ Ih < 20
s$_2$ – large summer water deficiency	33.3 ≤ Ia	s$_2$ – large winter water surplus	20 ≤ Ih
w$_2$ – large winter water deficiency	33.3 ≤ Ia	w$_2$ – large summer water surplus	20 ≤ Ih

Table 3. Climatic types. 2nd key based on the aridity indexes and humidity.

Climatic types	Thermal index (It) (ET$_P$ anual)
A′ – megathermal	1,140 ≤ ET$_P$
B′$_4$ – mesothermal	997 ≤ ET$_P$ < 1,140
B′$_3$ – mesothermal	855 ≤ ET$_P$ < 997
B′$_2$ – mesothermal	712 ≤ ET$_P$ < 855
B′$_1$ – mesothermal	570 ≤ ET$_P$ < 712
C′$_2$ – microthermal	427 ≤ ET$_P$ < 570
C′$_1$ – microthermal	285 ≤ ET$_P$ < 427
D′ – tundra	142 ≤ ET$_P$ < 285
E′ – frost	142 > ET$_P$

Table 4. Climatic types. 3rd key based on the thermal index and annual potential evapotranspiration.

Climatic subtypes	Concentration of ET$_P$ in summer (%)
a′	ET$_s$ < 48%
b′$_4$	48.0 ≤ ET$_s$ < 51.9
b′$_3$	51.9 ≤ ET$_s$ < 56.3
b′$_2$	56.3 ≤ ET$_s$ < 61.6
b′$_1$	61.6 ≤ ET$_s$ < 68.0
c′$_2$	68.0 ≤ ET$_s$ < 76.3
c′$_1$	76.3 ≤ ET$_s$ < 88.0
d′	88.0 ≤ ET$_s$

Table 5. Climatic subtypes. 4th key based on the relationship summer/annual potential evapotranspiration in % (ET$_s$).

5. Examples of application

5.1 Different altitude

In Tables 6 and 7 following information regarding the climatologic water balance (Thornthwaite & Mather, 1955) to Campos do Jordão and Santos, respectively. They were required to Thornthwaite climatic classification.

Months	T (ºC)	P (mm)	ET_P (mm)	$P-ET_P$ (mm)	NEG (mm)	GW (mm)	ALT (mm)	ET_A (mm)	DEF (mm)	EXC (mm)
J	17.3	306.1	82.5	223.7	0.0	100.0	0.0	82.4	0.0	223.7
F	17.5	265.6	76.4	189.4	0.0	100.0	0.0	76.2	0.0	189.4
M	16.7	193.5	75.7	117.8	0.0	100.0	0.0	75.7	0.0	117.8
A	14.7	98.9	57.7	41.2	0.0	100.0	0.0	57.7	0.0	41.2
M	11.9	79.3	41.8	37.5	0.0	100.0	0.0	41.8	0.0	37.5
J	10.1	51.4	30.7	20.6	0.0	100.0	0.0	30.8	0.0	20.6
J	9.5	42.1	28.9	13.2	0.0	100.0	0.0	28.9	0.0	13.2
A	11.3	58.5	38.1	20.4	0.0	100.0	0.0	38.1	0.0	20.4
S	13.4	91.6	49.5	42.1	0.0	100.0	0.0	49.5	0.0	42.1
O	14.9	159.3	62.9	96.3	0.0	100.0	0.0	63.0	0.0	96.3
N	15.9	205.9	70.4	135.5	0.0	100.0	0.0	70.4	0.0	135.5
D	16.6	300.1	79.9	220.2	0.0	100.0	0.0	79.9	0.0	220.2
Ann	14.2	1,852.3	694.5	1,157.8		1,200.0	0.0	694.5	0.0	1,157.8

Table 6. Climatologic water balance according to Thornthwaite and Mather (1955) for the period 1961 to 1990. Campos do Jordão, SP, Brazil, INMET (2009). (T = temperature; P = precipitation; ETP = potential evapotranspiration; NEG = negative accumulated; GW = ground water; ALT = GWactual –GWprevious; ETA = actual evapotranspiration; DEF = water deficit; EXC = water excess).

To compare two nearby site, with small differences in latitude and longitude, but with a reasonable difference in altitude, and using the methodology of Köppen, Campos do Jordão shows the climatic type **Cfb** (humid temperate climate with moderately warm summer) while Santos shows the climatic type **Afa** (humid tropical climate with hot summers). The two sites are similar with respect to humidity, sites with high rainfall in all months of the year and show no water stress throughout the year. However, Campos do Jordão shows itself as a place colder than Santos due to the influence of altitude on air temperature.

Months	T (°C)	P (mm)	ET$_P$ (mm)	P-ETP (mm)	NEG	GW (mm)	ALT (mm)	ET$_A$ (mm)	DEF (mm)	EXC (mm)
J	28.6	255.9	197.2	58.7	0.0	100.0	0.00	197.2	0.0	58.7
F	28.9	220.3	185.6	34.7	0.0	100.0	0.00	185.6	0.0	34.7
M	28.1	221.1	178.6	42.5	0.0	100.0	0.00	178.6	0.0	42.5
A	26.3	193.6	129.9	63.7	0.0	100.0	0.00	129.9	0.0	63.7
M	24.8	144.3	103.7	40.6	0.0	100.0	0.00	103.7	0.0	40.6
J	23.2	106.2	76.5	29.7	0.0	100.0	0.00	76.5	0.0	29.7
J	22.8	121.6	73.8	47.7	0.0	100.0	0.00	73.9	0.0	47.7
A	22.8	78.4	76.3	2.1	0.0	100.0	0.00	76.3	0.0	2.1
S	22.4	130.2	73.5	56.7	0.0	100.0	0.00	73.5	0.0	56.7
O	24.2	146.0	104.9	41.1	0.0	100.0	0.00	104.9	0.0	41.1
N	25.8	162.0	133.4	28.6	0.0	100.0	0.00	133.4	0.0	28.6
D	27.4	210.9	175.2	35.7	0.0	100.0	0.00	175.2	0.0	35.7
Ann	25.4	1,990.5	1,508.7	481.8		1,200.0	0.00	1,508.7	0.0	481.8

Table 7. Climatologic water balance according to Thornthwaite and Mather (1955) for the period 1961 to 1990. Santos, SP, Brazil, INMET (2009). (T = temperature; P = precipitation; ET$_P$ = potential evapotranspiration; NEG = negative accumulated; GW = ground water; ALT = GWactual – GWprevious; ET$_A$ = actual evapotranspiration; DEF = water deficit; EXC = water excess).

Using the method of Thornthwaite realizes that Campos do Jordão presents the climatic type **ArB'₁a'** (perhumid without water deficit throughout the year, with moderate temperatures and annual potential evapotranspiration of 694.5 mm concentrated in 33.7% in the summer) while Santos presents the climatic type **B₁rA'a'** (humid without water deficit throughout the year, with high temperatures and annual potential evapotranspiration of 1,508.7 mm concentrated in 37.2% in the summer). The district of Santos presents increased evaporative demand due to their higher temperatures, thus the annual water surplus is smaller than in Campos do Jordão, which has a water surplus much higher compared to Santos due to low temperatures which occur along the year, which reduces evapotranspiration.

Comparing the two methods of classification, it is noted which Campos do Jordão is differs of Santos at altitude and relief (Mantiqueira Mountains), which means it has lower values of temperature, and thus, presents a lower demand evapotranspiration. The rainfall in these regions tends to be higher in the rainy season (October-March) in relation to sea level - effect of atmospheric circulation that brings moisture from the Atlantic Ocean. For agricultural activities have thermal constraints for many crops - risk of frost as a limiting factor, however, the natural landscape of these regions offer excellent conditions for ecotourism activities.

Interestingly, the Köppen classification does not differentiate the two sites for moisture content (function of precipitation), considering them as **f** (wet), while the Thornthwaite classification shows the difference between Campos do Jordão and Santos, characterizes them as **A** (perhumid) and **B₁** (humid), respectively, according to the difference in water

surplus. Moreover, the Thornthwaite classification of stands out for identifying the absence of water stress (**r**) and potential evaporation concentrated in the summer (**a'**), being the 3rd letter, according to Thornthwaite classification, identifies the difference between the evapotranspiration demand between the two locations, indicating no need for supplemental irrigation.

5.2 Different latitude

Tables 8 and 9 present information regarding the climatologic water balance (Thornthwaite & Mather, 1955), necessary for climatic classification for districts of Boa Vista and Santa Maria respectively.

Months	T (°C)	P (mm)	ET_P (mm)	$P-ET_P$ (mm)	NEG	GW (mm)	ALT (mm)	ET_A (mm)	DEF (mm)	EXC (mm)
J	27.5	25.1	151.0	-125.9	-513.2	0.6	-1.5	26.6	124.4	0.0
F	28.0	18.1	152.2	-134.1	-647.2	0.1	-0.4	18.5	133.6	0.0
M	28.4	30.9	179.4	-148.5	-795.7	0.0	-0.1	31.0	148.4	0.0
A	28.0	88.5	165.0	-76.5	-872.2	0.0	-0.0	88.5	76.5	0.0
M	26.9	213.0	145.8	67.2	-39.8	67.2	67.2	145.8	0.0	0.0
J	25.9	321.3	121.6	199.7	0.0	100.0	32.8	121.6	0.0	166.9
J	25.8	267.8	123.8	144.0	0.0	100.0	0.0	123.8	0.0	144.0
A	26.6	188.0	139.6	48.4	0.0	100.0	0.0	139.6	0.0	48.4
S	27.7	99.4	158.3	-58.9	-58.9	55.5	-44.5	143.9	14.4	0.0
O	28.2	63.5	174.8	-111.3	-170.2	18.2	-37.2	100.7	74.1	0.0
N	28.0	60.8	163.3	-102.5	-272.7	6.5	-11.7	72.5	90.8	0.0
D	27.6	44.0	158.5	-114.5	-387.2	2.1	-4.5	48.5	110.0	0.0
Ann	27.4	1,420.4	1,833.3	-412.9		450.0	0.0	1,061.1	772.2	359.3

Table 8. Climatologic water balance according to Thornthwaite and Mather (1955) for the period 1961 to 1990. Boa Vista, RR, Brazil, INMET (2009). (T = temperature; P = precipitation; ET_P = potential evapotranspiration; NEG = negative accumulated; GW = ground water; ALT = GWactual – GWprevious; ET_A = actual evapotranspiration; DEF = water deficit; EXC = water excess)

Located in the Northern Hemisphere, but very close to the equator, Boa Vista introduces climatic type **Awa** (tropical climate with dry season in winter and warm all year round), second the methodology of Köppen. The low latitude of Boa Vista question influence in the definition of the seasons because the summer no presents the highest temperatures. On the other hand, the district of Santa Maria is located further south of the Tropic of Capricorn, and shows the climatic type **Cfa** (humid temperate and hot summer).
These two sites were similar with respect to high temperatures in summer (**a**), however, the air temperature is higher during the year, which explains the high values of evapo-

transpiration. Regarding precipitation, the two sites have high values, but the monthly distribution is different. Boa Vista has dry and rainy season well defined, while in Santa Maria the precipitation is uniform throughout the year.

Second the method of Thornthwaite, Boa Vista presents the climatic type $C_1dA'a'$ (dry subhumid with little excess water during June, July and August, high temperatures and annual potential evapotranspiration of 1,833.3 mm concentrated in 26.3% in the summer). Already, Santa Maria has the climatic type $B_4rB'_3a'$ (humid without water deficit, with moderate temperatures and annual potential evapotranspiration of 896.5 mm concentrated in 38.7% in the summer).

Months	T (°C)	P (mm)	ET_P (mm)	$P-ET_P$ (mm)	NEG (mm)	GW (mm)	ALT (mm)	ET_A (mm)	DEF (mm)	EXC (mm)
J	24.2	163.0	130.7	32.3	0.0	100.0	0.0	130.7	0.0	32.3
F	23.9	127.2	115.0	12.2	0.0	100.0	0.0	115.0	0.0	12.2
M	21.9	136.2	101.1	35.1	0.0	100.0	0.0	101.1	0.0	35.1
A	18.4	121.4	64.0	57.4	0.0	100.0	0.0	64.0	0.0	57.4
M	15.9	127.5	45.8	81.7	0.0	100.0	0.0	45.8	0.0	81.7
J	13.9	139.3	31.9	107.4	0.0	100.0	0.0	31.9	0.0	107.4
J	14.1	144.9	33.6	111.3	0.0	100.0	0.0	33.6	0.0	111.3
A	14.2	142.1	35.5	106.6	0.0	100.0	0.0	35.5	0.0	106.6
S	16.5	124.3	50.0	74.3	0.0	100.0	0.0	50.0	0.0	74.3
O	18.6	128.2	70.8	57.4	0.0	100.0	0.0	70.8	0.0	57.4
N	21.0	120.5	93.6	26.9	0.0	100.0	0.0	93.6	0.0	26.9
D	23.3	142.2	124.4	17.8	0.0	100.0	0.0	124.4	0.0	17.8
Ann	18.8	1,616.8	896.5	720.3		1,200.0	0.0	896.5	0.0	720.3

Table 9. Climatologic water balance according to Thornthwaite and Mather (1955) for the period 1961 to 1990. Santa Maria, RS, Brazil, INMET (2009). (T = temperature; P = precipitation; ET_P = potential evapotranspiration; NEG = negative accumulated; GW = ground water; ALT = GWactual – GWprevious; ET_A = actual evapotranspiration; DEF = water deficit; EXC = water excess).

Analyzing the 1st letter of the climate type, Boa Vista has the highest average monthly temperatures in relation to the humid climate of Santa Maria, which increases the demand for evapotranspiration. The climate of Santa Maria (humid) is associated with lower levels of temperature due to the mountainous regions, which requires less evapotranspiration. These conditions are confirmed by the 2nd letter, which indicates **d** (small excess of water) and **r** (no drought) to Boa Vista and Santa Maria, respectively, and also the 3rd letter **A'** (high temperatures associated with high evapotranspiration). Both classifications show that in

monthly scale there is no need for irrigation of agricultural crops in Santa Maria. While in Boa Vista the classification of Thornthwaite specifies more appropriately through of high aridity index (Ia = 42) and of negative moisture index (Im =- 6), showing the need for the use of irrigation during the months September to April.

5.3 Different longitude

The climatologic water balance (Thornthwaite & Mather, 1955) for districts of João Pessoa and Porto Velho can be found in Tables 10 and 11, respectively.

According to the methodology of Köppen, João Pessoa and Porto Velho present the same climatic type **Ama** (tropical climate with a dry season and hot summer).

Months	T (°C)	P (mm)	ET$_P$ (mm)	P-ET$_P$ (mm)	NEG	GW (mm)	ALT (mm)	ET$_A$ (mm)	DEF (mm)	EXC (mm)
J	27.1	75.8	151.1	-75.3	-439.0	1.2	-1.4	77.2	74.0	0.0
F	27.2	108.4	141.8	-33.4	-472.4	0.9	-0.3	108.8	33.1	0.0
M	27.0	252.2	150.9	101.3	0.0	100.0	99.1	150.9	0.0	2.2
A	26.7	349.8	137.9	211.9	0.0	100.0	0.0	137.9	0.0	211.9
M	26.0	307.3	127.5	179.8	0.0	100.0	0.0	127.5	0.0	179.8
J	25.2	346.1	109.1	237.0	0.0	100.0	0.0	109.1	0.0	237.0
J	24.2	346.2	97.3	248.9	0.0	100.0	0.0	97.3	0.0	248.9
A	24.3	183.5	99.5	84.0	0.0	100.0	0.0	99.5	0.0	84.0
S	25.1	87.2	109.8	-22.6	-22.6	79.7	-20.2	107.4	2.4	0.0
O	26.3	35.4	136.4	-101.0	-123.6	29.0	-50.7	86.1	50.3	0.0
N	26.7	24.9	141.6	-116.7	-240.3	9.0	-20.0	44.9	96.7	0.0
D	26.9	28.5	151.8	-123.3	-363.7	2.6	-6.4	34.9	116.9	0.0
Ann	26.1	2,145.3	1,554.9	590.4		723.0	0.0	1,181.6	373.3	963.7

Table 10. Climatologic water balance according to Thornthwaite and Mather (1955) for the period 1961 to 1990. João Pessoa, PB, Brazil, INMET (2009). (T = temperature; P = precipitation; ET$_P$ = potential evapotranspiration; NEG = negative accumulated; GW = ground water; ALT = GWactual – GWprevious; ET$_A$ = actual evapotranspiration; DEF = water deficit; EXC = water excess).

Months	T (ºC)	P (mm)	ET_P (mm)	$P\text{-}ET_P$ (mm)	NEG	GW (mm)	ALT (mm)	ET_A (mm)	DEF (mm)	EXC (mm)
J	25.5	320.9	123.9	197.0	0.0	100.0	0.0	123.9	0.0	197.0
F	25.5	316.0	114.5	201.5	0.0	100.0	0.0	114.5	0.0	201.5
M	25.6	273.9	126.4	147.5	0.0	100.0	0.0	126.4	0.0	147.5
A	25.7	251.0	121.4	129.6	0.0	100.0	0.0	121.4	0.0	129.6
M	25.3	126.6	116.6	10.0	0.0	100.0	0.0	116.6	0.0	10.0
J	24.7	49.6	102.5	-52.9	-52.9	58.9	-41.0	90.7	11.8	0.0
J	24.6	24.2	104.1	-79.9	-132.8	26.5	-32.4	56.6	47.5	0.0
A	25.9	36.4	125.5	-89.1	-221.8	10.9	-15.6	52.0	73.4	0.0
S	26.2	119.9	128.7	-8.8	-230.6	10.0	-0.9	120.8	7.9	0.0
O	26.1	192.7	133.8	58.7	-37.6	68.7	58.7	134.0	0.0	0.0
N	26.0	225.2	130.5	94.7	0.0	100.0	31.3	130.5	0.0	63.4
D	25.5	319.1	127.8	191.3	0.0	100.0	0.0	127.8	0.0	191.3
Ann	25.6	2,255.5	1,455.9	799.6		875.0	0.0	1,315.3	140.6	940.2

Table 11. Climatologic water balance according to Thornthwaite and Mather (1955) for the period 1961 to 1990. Porto Velho, RO, Brazil, INMET (2009). (T = temperature; P = precipitation; ET_P = potential evapotranspiration; NEG = negative accumulated; GW = ground water; ALT = GWactual – GWprevious; ET_A = actual evapotranspiration; DEF = water deficit; EXC = water excess).

According to the Thornthwaite method, Porto Velho presents the climatic type **B₃rA'a'** (humid with little water deficit in the months from June to September, high temperatures and annual potential evapotranspiration of 1,455.9 mm concentrated in 25.1% in the summer), while João Pessoa presents the climatic type **B₂sA'a'** (humid with moderate water stress during the months of January, February and from September to December, with high temperatures and annual potential evapotranspiration of 1,554.9 mm concentrated in 29.0% in the summer).

Thornthwaite's method shows differences with respect to temperature monthly. In Porto Velho the variation of monthly temperature range is less while in João Pessoa is higher due to the effect of continentality/ocean. It also differentiates the sites with respect to deficiencies and excess water throughout the year. The proximity of the ocean generates less thermoregulatory effect provided by the moisture present in the interior of the continent, which showed higher temperatures in winter in João Pessoa. The rainfalls are concentrated during summer in Porto Velho and autumn-winter in João Pessoa, showing respectively, deficiencies in winter and spring-summer. The irrigation of cultures is recommended from June to September in Porto Velho, while in João Pessoa is necessary from September to February, once the annual aridity index is high (Ia = 24). The use of the climatologic water balance in the classification of Thornthwaite becomes advantageous because it allows identifying the level of disability and the season when occurs water deficit.

5.4 Ocean currents

Information related to climatologic water balance (Thornthwaite & Mather, 1955), for Angra dos Reis and Cabo Frio, necessary to climatic second classification Thornthwaite are presented in Tables 12 and 13, respectively.

Months	T (°C)	P (mm)	ET_P (mm)	$P-ET_P$ (mm)	NEG	GW (mm)	ALT (mm)	ET_A (mm)	DEF (mm)	EXC (mm)
J	25.9	241.0	143.1	97.9	0.0	100.0	0.0	143.1	0.0	97.9
F	26.4	221.9	137.3	84.6	0.0	100.0	0.0	137.3	0.0	84.6
M	25.7	233.4	135.1	98.3	0.0	100.0	0.0	135.1	0.0	98.3
A	23.8	163.8	99.7	64.1	0.0	100.0	0.0	99.7	0.0	64.1
M	22.1	105.3	79.3	26.0	0.0	100.0	0.0	79.3	0.0	26.0
J	20.7	74.3	61.3	13.0	0.0	100.0	0.0	61.3	0.0	13.0
J	20.2	71.9	58.7	13.2	0.0	100.0	0.0	58.7	0.0	13.2
A	20.8	78.9	65.6	13.3	0.0	100.0	0.0	65.6	0.0	13.3
S	21.4	109.0	72.6	36.4	0.0	100.0	0.0	72.6	0.0	36.4
O	22.3	152.1	89.0	63.1	0.0	100.0	0.0	89.0	0.0	63.1
N	23.5	171.0	105.0	66.0	0.0	100.0	0.0	105.0	0.0	66.0
D	24.9	261.1	131.8	129.2	0.0	100.0	0.0	131.9	0.0	129.2
Ann	23.1	1,883.7	1,178.6	705.1		1,200.0	0.0	1,178.6	0.0	705.1

Table 12. Climatologic water balance according to Thornthwaite and Mather (1955) for the period 1961 to 1990. Angra dos Reis, RJ, Brazil, INMET (2009). (T = temperature; P = precipitation; ET_P = potential evapotranspiration; NEG = negative accumulated; GW = ground water; ALT = GWactual – GWprevious; ET_A = actual evapotranspiration; DEF = water deficit; EXC = water excess).

According with the methodology of Köppen, Angra dos Reis presents the climatic type **Afa** (tropical climate with no dry season and hot summer) while Cabo Frio is climatic type **Awa** (tropical climate with dry season in winter and hot summer). In this case, the difference between the climates is the amount and distribution of rainfall throughout the year, which is much smaller in Cabo Frio. Angra dos Reis presents high rainfall, especially in spring and summer.

When the Thornthwaite method is applied, Angra dos Reis presents the climatic type **B₃rA'a'** (humid without water stress, with high temperatures and annual potential evapotranspiration of 1,178.6 mm concentrated in 35.3% in the summer), while Cabo Frio displays the climatic type **C₁dA'a'** (dry subhumid, with drought in nearly all months of the year, with high temperatures and annual potential evapotranspiration of 1,156.6 mm concentrated in 32.9% in summer). Thus, we find that the differences between these two sites are mainly related to precipitation and water deficit, because as the precipitation is higher there will be less water deficiency in soil. In contrast, the water surplus occurs when rainfall exceeds field capacity.

Months	T (°C)	P (mm)	ET_P (mm)	$P-ET_P$ (mm)	NEG	GW (mm)	ALT (mm)	ET_A (mm)	DEF (mm)	EXC (mm)
J	25.0	74.6	129.8	-55.2	-409.5	1.7	-1.2	75.8	54.0	0.0
F	25.2	37.0	120.7	-83.7	-493.2	0.7	-0.9	37.9	82.8	0.0
M	25.3	58.1	129.4	-71.3	-564.6	0.3	-0.4	58.5	71.0	0.0
A	24.1	78.6	103.4	-24.8	-589.4	0.3	-0.1	78.7	24.8	0.0
M	22.6	74.0	84.7	-10.7	-600.1	0.2	-0.0	74.0	10.6	0.0
J	21.6	47.9	69.3	-21.4	-621.5	0.2	-0.0	47.9	21.4	0.0
J	21.1	47.1	66.6	-19.5	-641.0	0.2	-0.0	47.1	19.5	0.0
A	21.0	37.6	67.8	-30.2	-671.2	0.1	-0.0	37.6	30.1	0.0
S	21.2	58.1	71.0	-13.0	-684.1	0.1	-0.0	58.1	12.9	0.0
O	22.0	90.6	86.1	4.5	-307.6	4.6	4.5	86.1	0.0	0.0
N	23.3	92.7	102.8	-10.2	-317.7	4.2	-0.5	93.1	9.7	0.0
D	24.4	88.3	124.8	-36.5	-354.3	2.9	-1.3	89.6	35.2	0.0
Ann	23.1	784.6	1,156.6	-372.0		16.0	0.0	784.6	372.0	0.0

Table 13. Climatologic water balance according to Thornthwaite and Mather (1955) for the period 1961 to 1990. Cabo Frio, RJ, Brazil, INMET (2009). (T = temperature; P = precipitation; ET_P = potential evapotranspiration; NEG = negative accumulated; GW = ground water; ALT = GWactual – GWprevious; ET_A = actual evapotranspiration; DEF = water deficit; EXC = water excess).

These differences between the two local are restricted to the effect of ocean currents on the Atlantic coast, the Brazilian coast, influencing the precipitation regime. As the ocean current is warmer near Angra dos Reis, this presents higher values rainfall throughout the year, especially during the hottest periods of the year.

The climatic classifications of Köppen and Thornthwaite suggest that in Angra dos Reis is not necessary the use of irrigation for local agriculture, but to Cabo Frio, the differences between the two classifications are important. According to Köppen classification the use of irrigation be essential in the winter, however hides the water deficit that occurs in the remainder of the year in Cabo Frio, a fact that is detected by the Thornthwaite classification, which stresses the use of irrigation throughout the years, except in October.

Therefore, in general, to Köppen sees only a greater quantity of rain, but not how it is distributed, nor whether it is sufficient to avoid water deficit. Thus, the Thornthwaite classification is more appropriate because it allows not only see the differences in rainfall, as well as other pertinent differences and coming from the water balance, such as evapotranspiration, water deficiencies and excesses throughout the year, important in the planning of an agricultural region. Thus, Köppen loses in details when the need is for agricultural use, being recommended the Thornthwaite's method.

6. Conclusion

It is difficult to find a climate classification that can be considered perfect, because each classification has its own merits, limitations and failures. Despite the differences between climatic classifications, either for one reason or another, knowledge of the climate of a place (region) allows a better orientation to agriculture.

The Köppen classification is still the most widely used despite its limitations, since it only depends on temperature and precipitation. The Thornthwaite classification seems more appropriate in the scope of its subdivisions and other climatic types according to temperature, precipitation and evapotranspiration (moisture factor), featuring more detail for a place or region, even using the estimated potential evapotranspiration according to the annual temperature variation and photoperiod, is still a more complete and comprehensive. Currently, it is not possible to use bolder methods for estimating evapotranspiration due to failure to obtain sufficient data for this, beyond poor spatial distribution of meteorological stations in several countries, as in Brazil, being recommended using the original method for calculating potential evapotranspiration suggested by Thornthwaite (1948).

The use of the water balance by the classification of Thornthwaite enriches the basis of classification based on the amounts of rainfall and temperature, allowing to identify a place or region by the characteristics: the changes in air temperature and cumulative monthly and annual rainfall, the deficit and water excess throughout the year, the potential evapotranspiration monthly and annual, the seasons drought and rainy - the distribution of rainfall seasonally and the index of aridity. This will allow identifying periods where there is need for irrigation.

Through the classification of Thornthwaite, when analyzing the deficiency or excess moisture, the concentration of thermal efficiency or potential evapotranspiration during the summer, allows climatic information more detailed from location - climate subtype, showing that Thornthwaite (1948) improved the climate classification system when introduced the water factor as a function of evapotranspiration and water balance.

7. Acknowledgements

## 8. References

Anwar, M.M. (1993). *A geography of Pakistan*, Book-World Islamabad and Lahore, pp. 20-60.

Balling, R.C. (1984). Classification in climatology, *in* Gaile, G.L. & Willmott, C.J. (ed.), *Spatial statistics and models*, Dordrecht: Reídel Publishing, Hingham, pp. 81-108.

Blair, T.A. (1942). *Climatology, general and regional*, Prentice-Hall, INC., New York. pp. 484.

Burgos, J.J. (1958). *Agroclimatic classifications and representations: report of the applications value of climatic and agroclimatic classification for agricultural purposes*, Comission for Agricultural Meteorology, WMO, Varsovia.

Cunha, A.R. & Martins, D. (2009). Climatic classification for the districts of Botucatu and São Manuel, SP, *Brazilian Journal of Irrigation and Drainage* Vol. 14 (No. 1): 1-11.

Doerr, A.H. (1962). Thornthwaite's original climatic classification and Oklahoma's climate, *Proceedings of the Oklahoma Academy of Science* Vol. 42 (No. 1): 231-235.

Essenwanger, O.M. (2001). Classification of climates, *World Survey of Climatology* Vol. 1C, General Climatology. Elsevier, Amsterdam, pp. 102.

Flohn, H. (1950). Neue auschavgen über die allgemeinen zirkulation der atmosphare und ihre klimatische bedeutung, *Erdkunde* Vol. 4 (No. 1): 141-162.

Geiger, R. (1953). Eine neue Weltkarte der Klimagebiete der Erde, *Erdkunde* Vol. 8 (No.1/2): 58-60.

Griffiths, J.F. (1978). *Applied climatology*. An Introduction, 2nd Edition, Oxford University Press London, pp. 136.

Hudson, J.C. & Brown, D.A. (2000). *Rethinking grassland regionalism*.

URL://www.geog.umn.edu/Faculty/brown/grasslands/RGR1.htm

INMET - National Institute of Meteorology. (2009). *Climatological Normals of Brazil 1961-1990*, *in* Ramos, A.M., Santos, L.A.R., Fortes, L.T.G. pp. 465.

Johnson, B.L.C. (1979). *Pakistan*, Heinemann, London, pp. 51-59.

Kazi, S.A. (1951). Climatic regions of west Pakistan, *PGR* Vol. 6 (No. 1): 1-39.

Kendrew, W.G. (1941). *Climates of the continents*, Oxford University Press London, pp. 608.

Khan, F.K. (1991). *A geography of Pakistan*, Oxford University Press Karachi, Pakistan, pp. 245.

Khan, J.A. (1993). *The climate of Pakistan*, Rahber Publishers Karachi, pp. 79.

Köppen, W. (1936). Das geographische system der climate, *in* Köppen, W. & Geiger, R. (ed.), *Handbuch der Klimatologie*, CG Borntrager, Berlin. pp. 46.

Logan, B. (2006). *A Statistical Examination of the Climatic Human Expert System, The Sunset Garden Zones for California*, Masters of Science in Geography, Faculty of the Virginia Polytechnic Institute & State University, pp. 144.

Lohmann, U., Sausen, R., Bengtsson, L., Cubasch, U., Perlwitz, J. & Roeckner, E. (1993). The Köppen climate classification as a diagnostic tool for general circulation models, *Climate Research* Vol. 3 (No. 3): 177–193.

Malmström, V.H. (1969). A new approach to the classification of climate, *The Journal of Geography* Vol. 68 (No. 6): 1-12.

McMahon, T.A., Finlayson, B.L., Haines, A.T., & Srikanthan, R. (1992). *Global runoff – continental comparisons of annual flows and peak discharges*, Catena Verlag, Cremlingen, pp. 166.

Miller, A.A. (1959). *Climatology*, Mehtewn London and E.P. Dulton and Co. INC., New York, pp. 313.

Nasrullah, K. (1968). Climate of West Pakistan according to Thornthwaite system of classification of climates, *PGR* Vol. 23 (No. 1): 12-25.

Oliver, J.E. (1981). *Climatology, Selected Applications*, Great Britain, Richard Clay Ltd, Bungay, Suffolk, p. 260.

Peel, M.C., Finlayson, B.L. & McMahon, T.A. (2007). Updated world map of the Köppen-Geiger climate classification, *Hydrology and Earth System Sciences* Vol. 11 (No. 5): 1633–1644.

Peel, M.C., McMahon, T.A. & Finlayson, B.L. (2004). Continental differences in the variability of annual runoff – update and reassessment, *Journal of Hydrology* Vol. 295 (No. 1-4): 185–197.

Pereira, A.P, Villa Nova, N.A. & Sediyama, G.C. (1997). *Evapotranspiration*. Piracicaba: Fealq. pp. 183.

Pereira, A.P, Angelocci, L.R. & Sentelhas, P.C. (2002). *Agrometeorology: fundamentals and practical applications*, Lavras: Agricultural. pp. 478.

Raja, I.A. & Twidal, J.W. (1990). Distribution of global insulation over Pakistan, *Journal of Solar Energy* Vol. 44 (No. 2): 21-29.

Rolim, G.S., Camargo, M.B.P., Lania, D.G. & Moraes, J.F.L. (2007). Climatic classification of Köppen and Thornthwaite sistems and their applicability in the determination of agroclimatic zonning for the state of São Paulo, Brazil, *Bragantia* Vol. 66 (No. 4): 711-720.

Shamshad K.M. (1988). *The meteorology of Pakistan. Climate and Weather of Pakistan*, Royal Book Company Karachi Pakistan, pp. 313.

Stern, H., De Hoedt, G. & Ernst, J. (2000). Objective classification of Australian climates, *Australian Meteorological Magazine* Vol. 49 (No.1): 87–96.

Sunkar, A. (2008). *Sustainability in karst resources management: the case of the Gunung Sewu in Java*, Thesis of Doctor of Philosophy, The University of Auckland, pp. 230.

Supan, A. (1879). Die Temperaturzonen der Erde, *Petermanns Geography Mitt* Vol. 25 (No. 1): 349-358.

Terjung, W.H. & Louie, S. (1972). Energy input output climates of the world: a preliminary attempt, *Archiv für Meteorologie Geophysik und Bicklimatologie* Vol. 2: 129-166.

Thom, H.C.S. (1966). *Some methods of climatological analysis*, Technical note no. 81. WMO, Geneva, Switzerland, pp. 53.

Thornthwaite, C.W. (1946). The moisture factor in climate, *American Geophysical Union Transactions* Vol. 27 (No. 1): 41-48.

Thornthwaite, C.W. (1948). An approach toward a rational classification climate, *Geographical Review* Vol. 38 (No. 1): 55-94.

Thornthwaite, C.W. & Mather, J.R. (1955). The water balance, *Drexel Institute of Tecnology* Vol. 8 (No. 1): 1-14.

Trewartha G.T. (1937,1954). *An introduction to climate*, 3rd Edition, Mc Grawhill Book Company. INC, pp. 395.

Trewartha G.T. (1968). *An introduction to climate*, 4th Edition, Mc Grawhill Kogakusha, LTD, pp. 408.

Varejão-Silva, M.A. (2006). *Meteorology and climatology*. Digital Version 2. Recife, Pernambuco, pp. 463.

WMO - World Meteorological Organization (1984). *Technical Regulations*, Vol. I. WMO Publication No. 49. Geneva, Switzerland.

WMO - World Meteorological Organization No. 100 (2009). *Guide to climatological practices*, 3rd ed. pp. 180.
URL://www.wmo.int/pages/prog/wcp/ccl/guide/guide_climat_practices.html
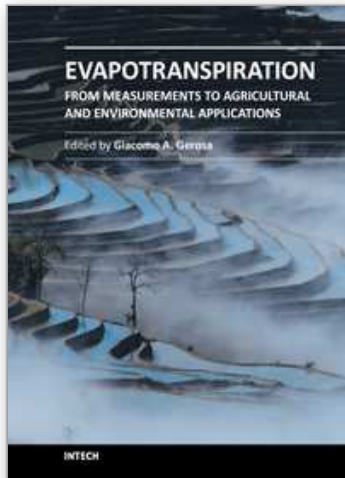
Evapotranspiration - From Measurements to Agricultural and Environmental Applications

Edited by Dr. Giacomo Gerosa

ISBN 978-953-307-512-9

Hard cover, 410 pages

Publisher InTech

Published online 09, November, 2011

Published in print edition November, 2011

This book represents an overview of the direct measurement techniques of evapotranspiration with related applications to the water use optimization in the agricultural practice and to the ecosystems study. Different measuring techniques at leaf level (porometry), plant-level (sap-flow, lysimetry) and agro-ecosystem level (Surface Renewal, Eddy Covariance, Multi layer BREB), are presented with detailed explanations and examples. For the optimization of the water use in agriculture, detailed measurements on transpiration demands of crops and different cultivars, as well as results of different irrigation schemes and techniques (i.e. subsurface drip) in semi-arid areas for open-field, greenhouse and potted grown plants are presented. Aspects on ET of crops in saline environments, effects of ET on groundwater quality in xeric environments as well as the application of ET to climatic classification are also depicted. The book provides an excellent overview for both, researchers and student,s who intend to address these issues.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Antonio Ribeiro da Cunha and Edgar Ricardo Schöffel (2011). The Evapotranspiration in Climate Classification, Evapotranspiration - From Measurements to Agricultural and Environmental Applications, Dr. Giacomo Gerosa (Ed.), ISBN: 978-953-307-512-9, InTech, Available from: http://www.intechopen.com/books/evapotranspiration-from-measurements-to-agricultural-and-environmental-applications/the-evapotranspiration-in-climate-classification