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Aridity and drought indices

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ARIDITY AND DROUGHT INDICES

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Why aridity indices????

To delineate zones prone to desertification

Those areas characterized by low rainfall and by high summer temperatures, so that the vegetation has little opportunity to restore after destruction by human impact or prolonged droughts.

---- desertification????

---- aridity????

---- droughts????

DESERTIFICATION

- The Earth Summit (UNCED, Rio de Janeiro, 1992) defined and
  The General Assembly of UN (UNCED, Paris, 1994) approved the *definition of DESERTIFICATION* :

'Desertification is land degradation in arid, semi-arid and dry sub-humid areas resulting from climatic variations and human activities'

DESERTIFICATION = drylands

- Drylands = arid , semi-arid, (dry)sub-humid
- 40 % of earth's surface
- 20% of earth's population
- Drylands are susceptible to 'human-induced soil degradation' and 'degradation of vegetation'

Global extent of desertification

3 assessments
(mainly for political reasons)
Map 1/25.000.000 by FAO, UNESCO, WMO

1. UNCOD (1977):

United Nations Conference on Desertification

Total area susceptible to desertification: 5281 Mha
Total area affected by desertification : 3970 Mha

Global extent of desertification

- **2. GAP I (1984):**
  General Assessment of Progress
  (Plan of action to combat desertification)

  questionnaire to 91 countries →failure
  UNEP used consultants

Distinction between: rainfed & irrigated cropland
rangeland

→ STILL NO METHODOLOGY!!!!!!!!!

Global extent of desertification

- **3. GAP II (1992)**

  Used the Soil Data Base of GLASOD

  (Global Assessment of Soil Degradation)

  Human induced soil degradation:

  - **Degraded irrigated lands: 43 Mha**
  - **Degraded rainfed croplands: 216 Mha**
  - **Degraded rangelands: 757 Mha**

  Rangelands with degraded vegetation: **2576 Mha**

  total 3592 Mha

Global extent of desertifiation

- Example of Africa

16% of surface:	water erosion
45% of surface:	wind erosion
25% of surface:	salinisation
61% of surface:	animal pressure
45% of surface:	population pressure

ARIDITY VERSUS DROUGHT

- **ARIDITY**

Permanent pluviometric deficit
(long-term climatic phenomenon)
Linked to specific climatic data:

- strong insolation
- elevated temperatures
- low air humidity
- strong evapotranspiration

ARIDITY VERSUS DROUGHT

- **DROUGHT**

Temporary pluviometric deficit
(short-term phenomenon)

Below average availibility of natural water

physical aspect: below the long-term mean (normal)

social aspect: below expected volume to satisfy needs
for agriculture, livestock, domestic use

DROUGHT is also: - annual/seasonal/monthly rainfall less than normal
- reduced river flow

DESERTIFICATION is commonly related to DROUGHT

DROUGHT

- Drylands are affected in an irregular manner by droughts

Types of drought

- meteorological drought
- hydrological drought
- agricultural drought
- edaphic drought

Meteorological drought

- Annual precipitation < average for one or several successive years

example: Sahel 1960s, 1970s, 1980s

BUT!!! ***Average*** is misleading because rain can be scattered or dry periods can alternate with periods of excessive rains.

Hydrological drought

- Water resources used for industry, human, and animal consumption or support of agriculture (irrigation) is low.

Agricultural drought

- Related to *rainfed agriculture*
- Related to ***soil moisture deficit*** during growing season

Soil moisture deficit can be determined by:

- precipitation
- PET
- soil moisture
- crop coefficient (moisture requirements)

Absolute annual or seasonal deficit of precipitation is not a good indicator →→better: rainfall distribution

Edaphic drought

- →→decrease of infiltrability of the soil
- →→increase in runoff and erosion

DELINEATING ARIDITY ZONES

- Based on INDEX OF MOISTURE DEFICIT

or

ARIDITY INDEX $AI = P/PET$

DETERMINATION OF PET

- 1) direct measurements using lysimeters

  ⇨ **NO STANDARDIZATION**

  2) empirical formulas

  Penman & Penman Monteith

  ⇨ **NEEDS LOT OF DATA**: solar radiation, wind velocity, relative humidity, temperature

  3) relation between measured PET and two parameters

  ex. *Thornthwaite:* mean monthly temperature and average number of daylight-hours/month

  ⇨ **OVERESTIMATES** PET FOR **DRY** CONDITIONS

  ⇨ **UNDERESTIMATES** PET FOR MOIST AND **COLD** CONDITIONS

GLOBAL EXTENT OF ARIDITY ZONES

	Aridity Index AI= P/PET	Million (ha)	% world land area
1.Cold	> 0.65	1765.0	13.6
2.Humid	> 0.65	5100.4	39.2
3.Dry sub-humid	0.50-0.65	1294.7	9.9
4.Semi-arid	0.20-0.50	2305.3	17.7
5.Arid	0.05-0.20	1569.1	12.1
6.Hyper-arid	< 0.05	978.2	7.5
Drylands (3+4+5+6)	< 0.65	6147.3	47.2
Susceptible Drylands (3+4+5)	0.05-0.65	5169.1	39.7

World drylands (Mha)

	Africa	Asia	Australia	Europe	North America	South America	World Total	%
Hyper - arid	672	277	0	0	3	26	978	16
Arid	504	626	303	11	82	45	1571	26
Semi-arid	514	693	309	105	419	265	2305	37
Dry sub-humid	269	353	51	184	232	207	1296	21
Total	1959	1949	663	300	736	543	6150	100
% World Total	32	32	11	5	12	8	100	
% Total Global Land Area	13.1	13.0	4.4	2.0	4.9	3.6	41.0	
% Continent Area	66	46	75	32	34	31	41	

DRYLAND ZONES

- Based on climate and environmental attributes
  - BUT!!!! Dryland boundaries are neither static nor abrupt because of:
  - **1. high inter-annual variability in mean rainfall**
- **2. occurrence of drought which may last for several years.**

⇨ Individual aridity zones do not represent homogeneous climates, either in the long term or during a particular time band

⇨ Dryland boundaries may not be defined in terms of natural vegetation or soil type because of human induced processes.

DRYLAND ZONES

Hyper-arid zones (environments)

Arid zones

Semi-arid zones

Dry sub-humid zones

Hyper-arid areas

Very limited rainfall

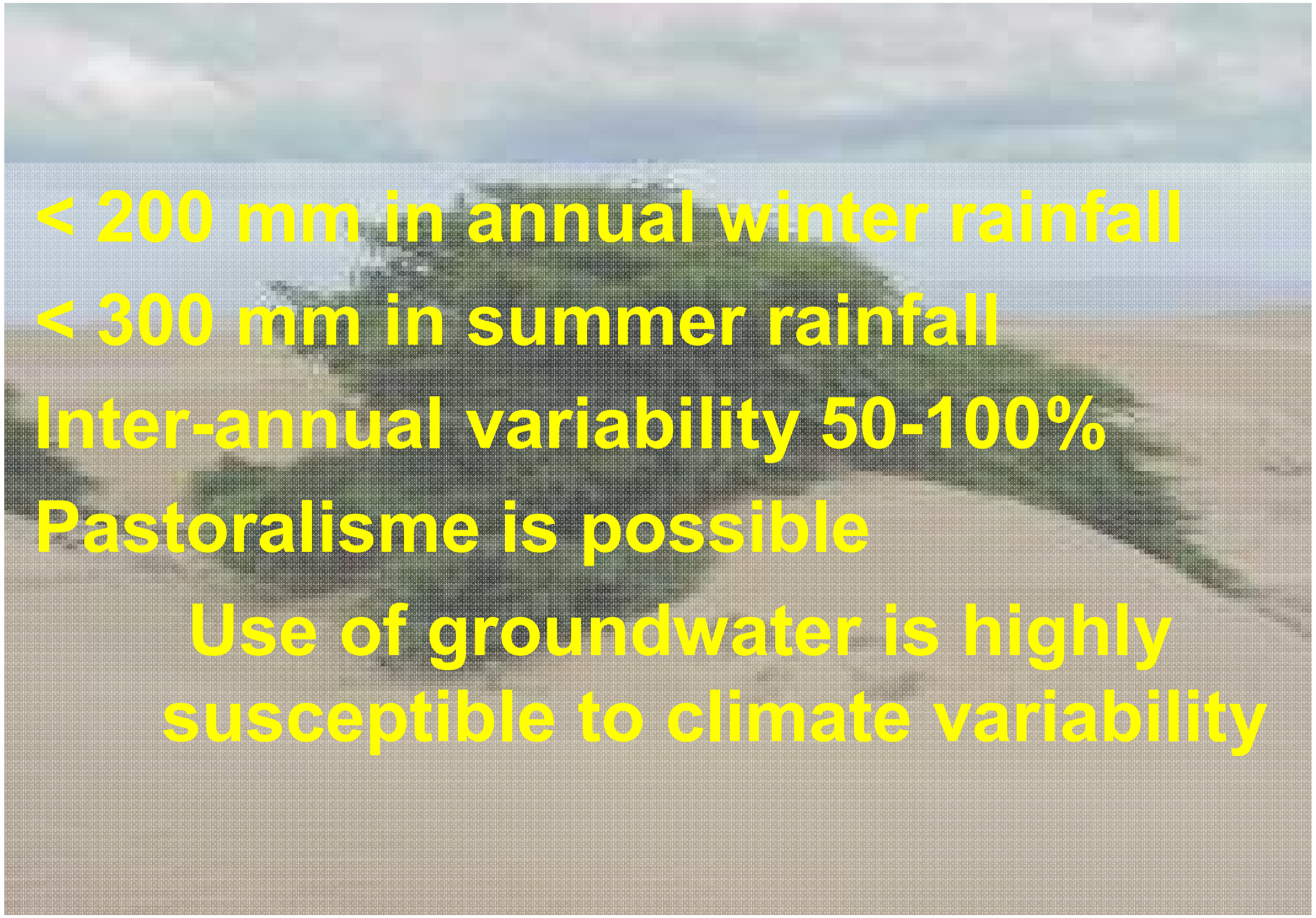
Highly variable rainfall: inter-annualy (100%), monthly

Year-long periods without rainfall

⇒ true deserts ⇒ not prone to desertification

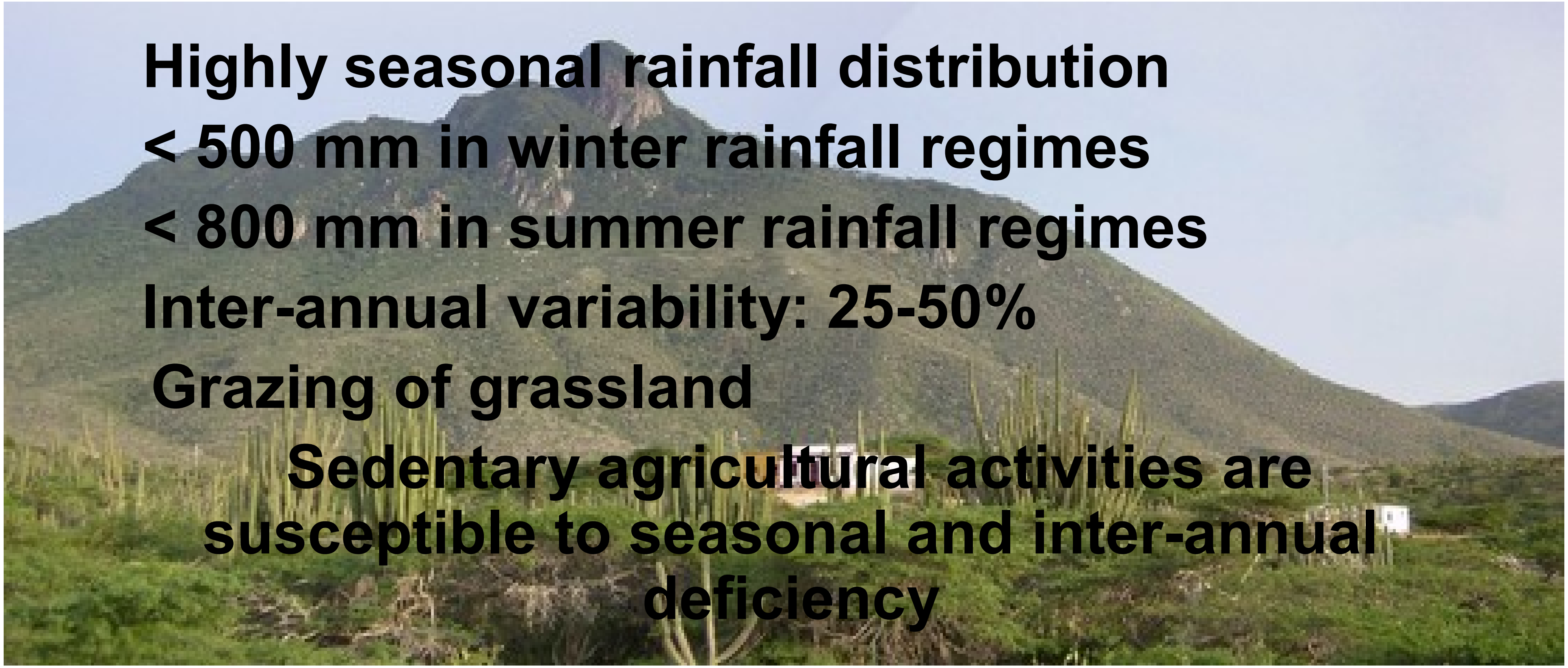
⇒ very low biological productivity

Arid zones



- < 200 mm in annual winter rainfall
- < 300 mm in summer rainfall
- Inter-annual variability 50-100%
- Pastoralisme is possible
  - Use of groundwater is highly susceptible to climate variability

Semi-arid zones



Highly seasonal rainfall distribution

< 500 mm in winter rainfall regimes

< 800 mm in summer rainfall regimes

Inter-annual variability: 25-50%

Grazing of grassland

Sedentary agricultural activities are susceptible to seasonal and inter-annual deficiency

Dry sub-humid zones

High seasonal rainfall regimes

< 25% inter-annual variability

Rainfed agriculture

→ susceptible to degradation enhanced by seasonal rainfall, drought periods and increasing intensity of human use.

→ **Dry sub-humid zones are included in the definition of desertification**

ARIDITY INDICES

- Problem??

- - Data collection
- - The more parameters, the more errors

EVALUATION AND CLASSIFICATION OF CLIMATIC INDICES FOR YAZD REGION (IRAN)

- Mohammad Zare Ernani and Donald Gabriels

- Department of Soil Management and Soil Care, International Centre for Eremology, Ghent University, Belgium

PURPOSE:

- This study aims at comparing different climatic indices for evaluating the aridity and the rain aggressivity and rain distribution based on climatic data from 21 weather stations in the Yazd-Ardakan basin (Iran) and this for 5 to 48 successive years.

- Five aridity indices were used to assess the aridity in the basin:
  - De Martonne Aridity Index
  - Emberger Aridity Index
  - UNEP Aridity Index
  - Thornthwaite Classification
  - Gaussen-Bagnouls Classification.
- For rain distribution and rain concentration
  - Modified Fournier Index (MFI)
  - Precipitation Concentration Index (PCI)

ARMENIA
AZERBAIJAN
Baku
TURKEY
CASPIAN SEA
TURKMENISTAN
Ashkhabad
Khvoy
Tabriz
Ardabil
Sabalān 15,783 ft.
Orumiyeh
Lake Urmia
Rasht
ELBURZ MTS.
GOLESTĀN NATIONAL PARK
Atrek
KOPET-DAG
Quchan
Mashhad
Irbil
Mahābād
Zanjān
Āmol
Sari
Gorgān
Mount Damāvand 18,934 ft.
Kirkūk
Sanandaj
Hamadān
Tehran
Qom
Harirud
Herāt
Bakhtarān
Arāk
Baghdad
Tigris
Khorramābād
ZAGROS
AFGHANISTAN
Dezfūl
IRAQ
YAZD
Ahvāz
SĪSTĀN
Euphrates
Behbehān
KUWAIT
Kāzerūn
PAKISTAN
Kuwait
Būsh
13,261 ft.
Persian Gulf
Bandar Abbās
BALUCHISTAN
SAUDI ARABIA
QESHM
Hāmūn-e Jaz Mūriān
Strait of Hormuz
BAHRAIN
Al-Manāmah
QATAR
Abu Dhabi
Doha
OMAN
Gulf of Oman
U.A.E.
0 150 300 mi
0 150 300 km
©2001, Encyclopædia Britannica, Inc.

1. Aridity index of De Martonne

$$I_M = \frac{P}{t + 10}$$

P = Annual average rainfall in mm.

t = Annual average temperature in degrees centigrade.

Climate Type	Aridity Index
Arid	0-10
Semi-arid	10-20
Mediterranean	20-24
Semi-humid	24-28
Humid	28-35
Very Humid	35-55
Extremely Humid	>55

2. Aridity index of Emberger

$$I_E = \frac{100 \times P}{M^2 - m^2}$$

M = Average temperature of the hottest month in degrees centigrade.
m = Average temperature of the coldest month in degrees centigrade.
P = Annual average rainfall in mm.

3. UNEP aridity index (P/ETP)

- **ETo = 16 x Nm ((10 x Tm) / I)^a**

$$I = \sum_{1}^{12} (Tm/5)^{1.514}$$

- Tm = mean monthly temperature
- Nm = adjustment factor related to hours of daylight
- Heat Index or I = Sum (Tm / 5)1.514 for m = 1 12
- a = $6.75 \times 10^{-7} \times I^3 - 7.71 \times 10^{-5} \times I^2 + 1.792 \times 10^{-2} \times I + 0.49239$

Index	Class
P/ETP < 0.03	hyper-arid zone
0.03 < P/PET <0.2	arid zone
0.2< P/PET <0.5	semi-arid zone
P/PET >0.5	humid zone

4. Thornthwaite classification

$$PEindex = \sum_{1}^{n=12} 115 \times \left(\frac{P}{T-10}\right)^{10/9}$$

- P = monthly precipitation in inches;
- T = temperature in °F; and n = months = 12.

PE Index	Climate
More than 128	Wet
64-127	Humid
32-63	Sub-Humid
16-31	Semi-arid
Less than 16	Arid

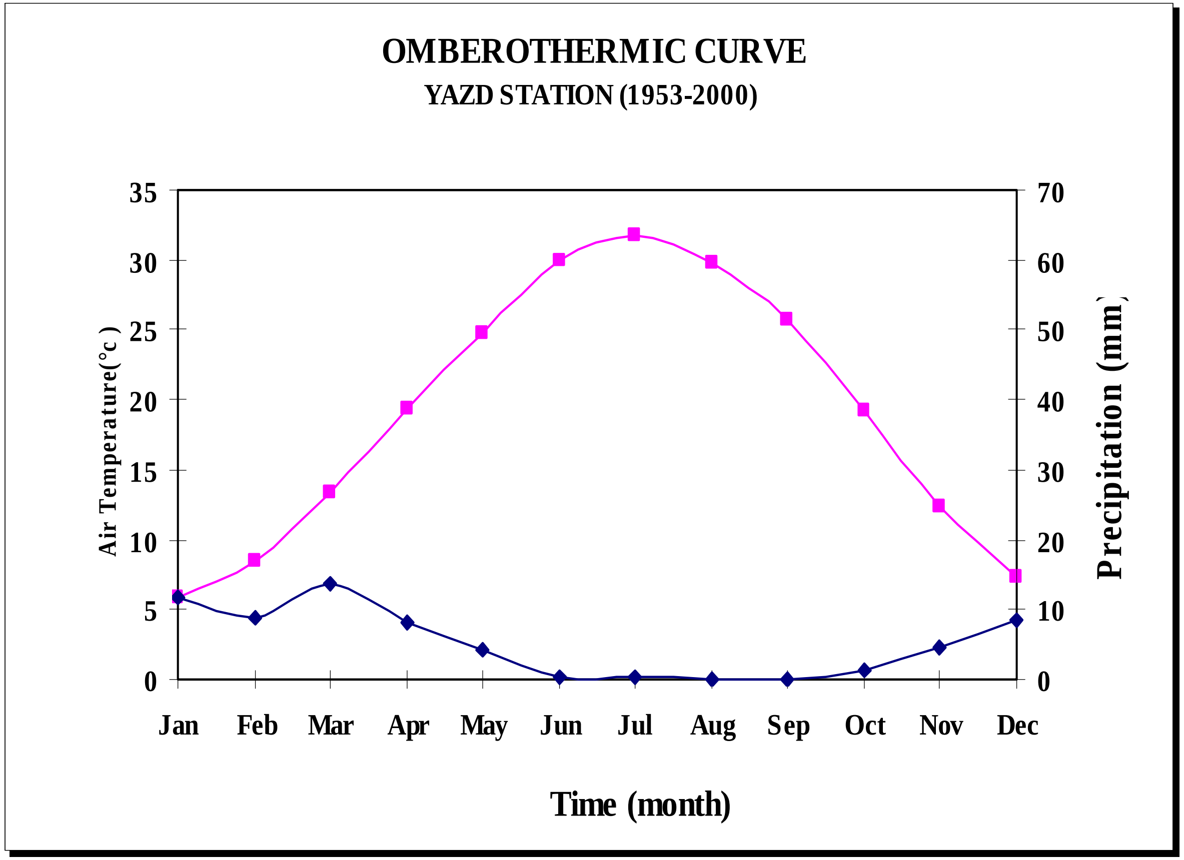
5. Gaussen-Bagnouls classification method

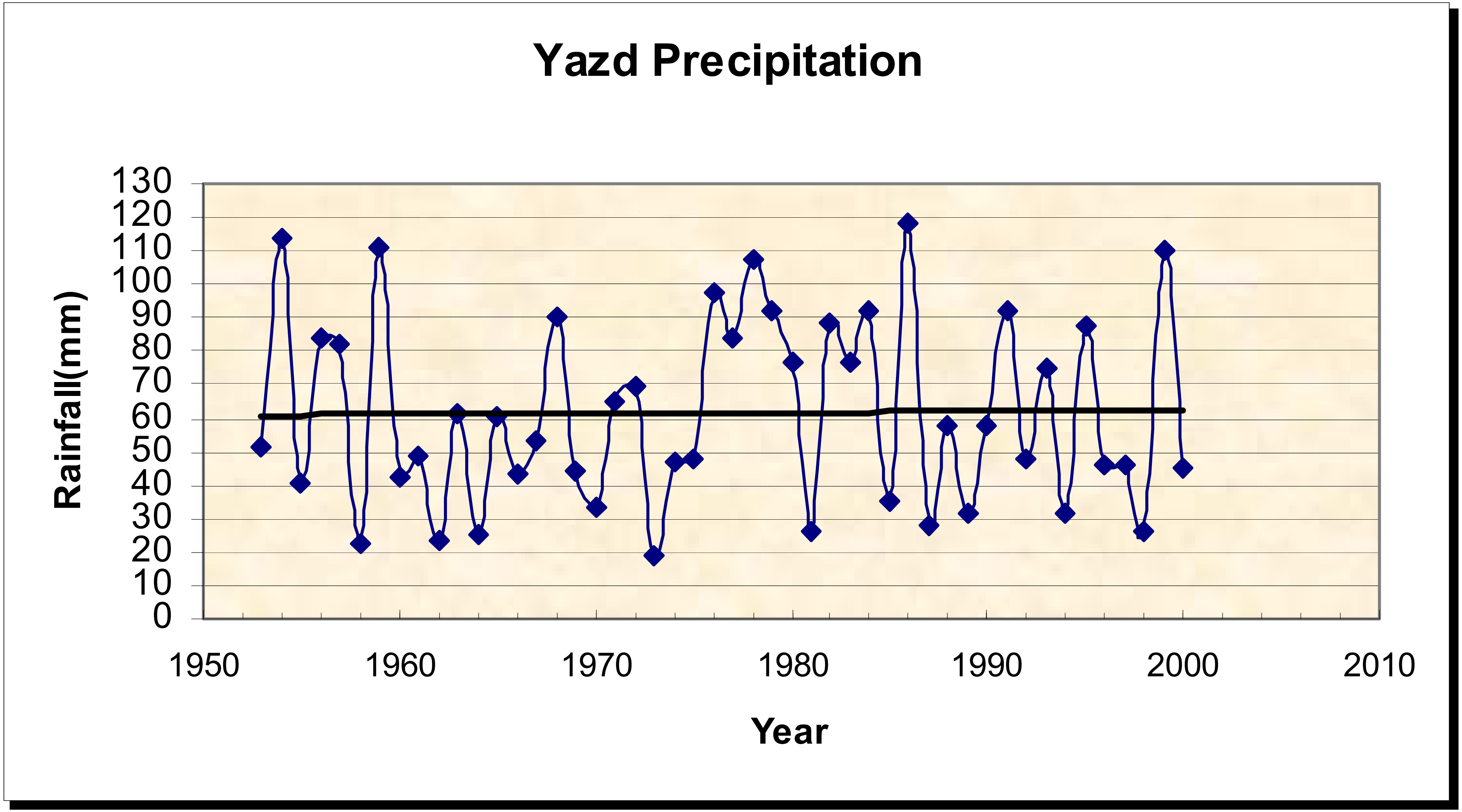
- combination of average monthly temperature and total rainfall
- gives more precise climatic classification
- easily climatic identification by determining separately the numbers of dry and wet months

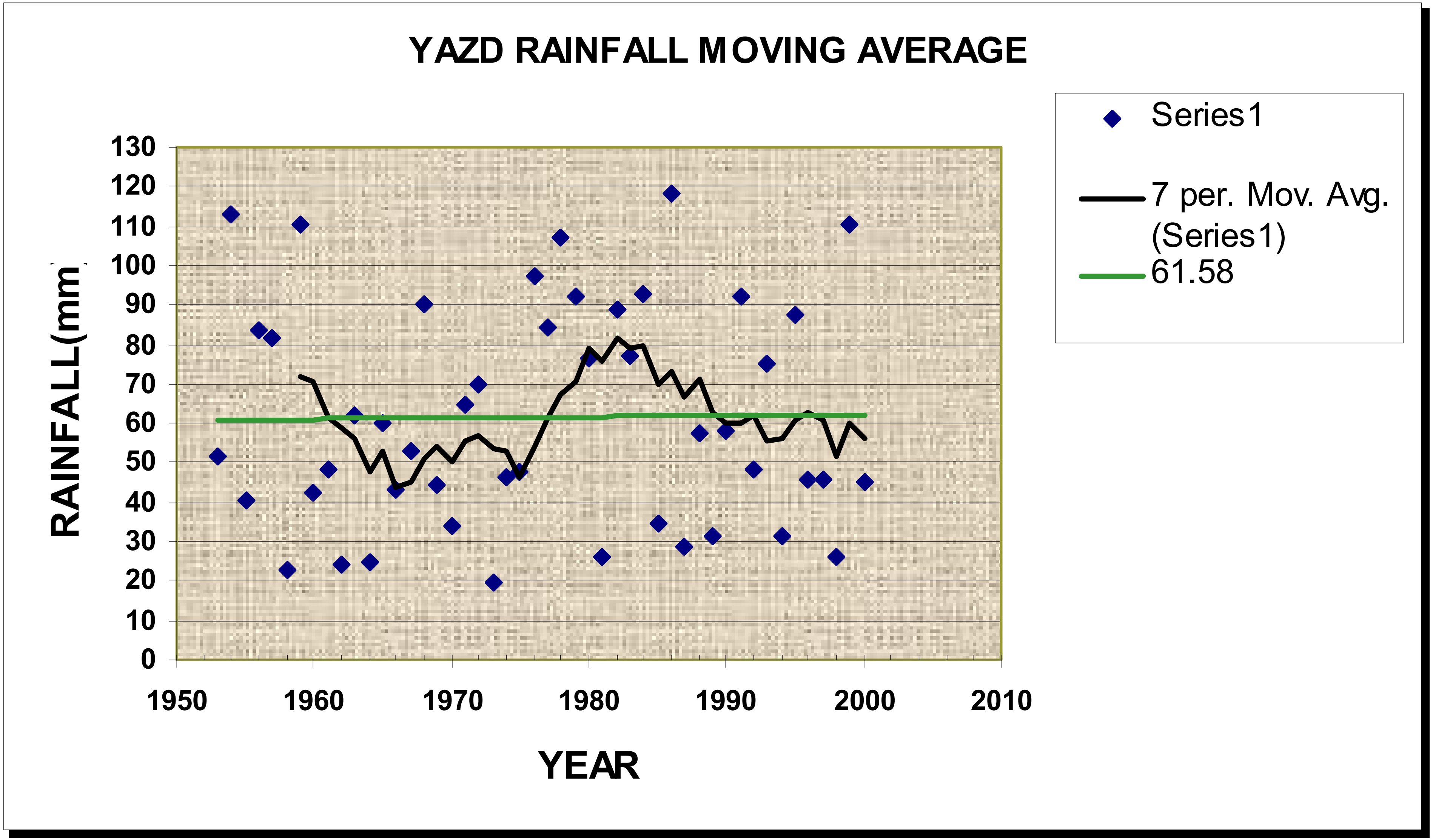
P > 3T → Humid

3T>P>2T → Semi-humid

P<2T → Arid




Yazd Precipitation
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Rainfall(mm)
1950
1960
1970
1980
1990
2000
2010
Year



YAZD RAINFALL MOVING AVERAGE
RAINFALL(mm)
YEAR
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1950
1960
1970
1980
1990
2000
2010
Series1
7 per. Mov. Avg. (Series1)
61.58

6. Precipitation concentration index

- to estimate the temporal variability of monthly rainfall

$$PCI = 100\frac{\sum p_i^2}{P^2}$$

p = monthly precipitation
P = annual precipitation

PCI	Concept
8.3 – 10	uniform
10 – 15	Moderately seasonal
15 – 20	seasonal
20 – 50	Highly seasonal
50 – 100	Irregular

Station	PCI_1	PCI_2	P_{mean}	PERIOD
ABARKUH	29.87	14.3	60.1	1967-1995
ARDEKAN	28.36	16.54	55.56	1966-1990
ASHKZAR	24.98	16.07	67.65	1978-1995
BAJGAN	26.66	15.05	235.61	1966-1995
DEHSHIR	26.67	14.34	95.87	1967-1995
GHOTROOM	23.87	15.62	140.8	1966-1995
HAJIABAD	26.66	14.2	77.36	1966-1995
KHARANAGH	22.05	14.98	129.82	1966-1995
KHOOR BIABANAK	28.43	16.61	88.02	1986-1995
MAZRAEH NOW	28.21	16.21	98.54	1967-1995
NASRABAD	21.01	15.22	211.97	1967-1995
ROBATPOSHTE	25.15	15.55	131.75	1967-1989
TAFT	23.57	15.75	131.68	1966-1994*
VARZANEH	28.21	13.76	73.01	1958-1995
ANAR	29.64	16.16	84.90	1986-2000
BAFGH	30.15	18.44	58.10	1993-2000
HOJATABAD	21.33	15.74	155.48	1967-1985
KAVIR SIYAHKOOH	31.59	19.62	73.70	1988-2000
NAEEN	25.88	14.74	99.95	1969-2000
SAGHAND	28.23	15.74	67.94	1967-2000
YAZD	29.80	15.29	61.58	1953-2000

Dry and humid periods

LP_D* = N° of dry months = *$P < 0,5\ ET_0$

***LP_R*= N° of rainy months= $P > 0,5\ ET_0$**

where: : **LP_D:** length of the water shortage period
LP_R: length of the water surplus period

Water shortage

$$DH = \sum_{1}^{12} \left(P - ET_0 \right)$$

DH = yearly water shortage (mm)
P = monthly precipitation (mm)

MAP of Aridity Zones in Latin America

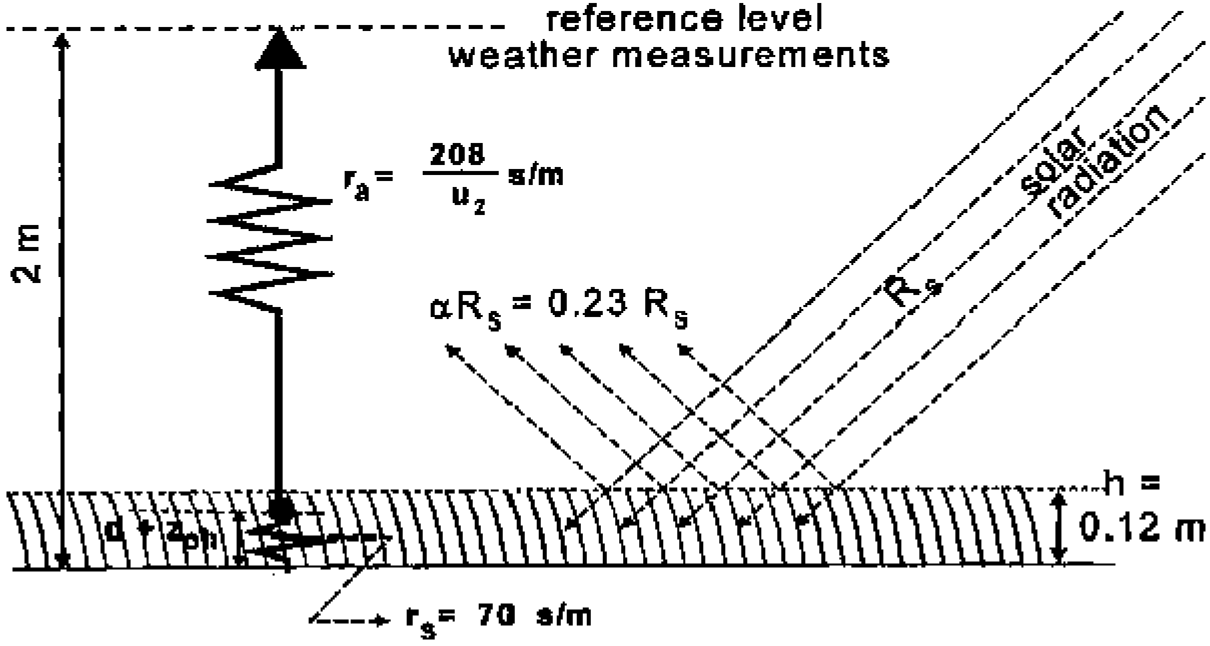
Project CAZALAC

(Centro del Agua para Zonas Áridas y Semiáridas de América LAtina y El Caribe), La Serena, Chili

Penman-Monteith-FAO

Tm, monthly mean temperature (°C)
RS, solar radiation in calcm-2d-1
HR, monthly mean relative humidity (%)
U2, wind speed in ms-1

Characteristics of a hypothetical reference crop (green grass of 0.12 m high with an albedo of 0.23)



r_a: aerodynamic resistance
r_s : surface resistance of the green grass = 70 s/m

Penman-Montheith-FAO

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)}$$

Where:
ET_0 baseline evapotranspiration [mm day-1],
Rn net radiation on the crop surface [MJ m-2 day-1],
G heat flow density in the soil [MJ m-2 day-1],
T average daily temperature at a 2 m height [°C],
u_2 wind speed at a 2 m height [m s-1],
e_s saturation vapor pressure [kPa],
e_a current vapor pressure [kPa],
e_sγ- e_a saturation vapor pressure gap [kPa],
Δ slope of the saturation vapor pressure line in function of temperature [kPa °C-1],
psychrometric coefficient [kPa °C-1].

Protocol to calculate the baseline Evapotranspiration by using the FAO/Penman-Monteith equation

Step 1. Calculation of Net Radiation, Rn (MJ/m2 day) from global solar radiation, RG (Cal/cm2 day)

Rn = RG * .0419 * .8

Factor 0.0419 converts cal/cm2 day into MJ/m2 day

Factor 0.8 is the Rn/RG quotient for a vegetated area with a good water supply

Step 2. Calculation of air vapor pressure at saturation, es (kPa)

es = =0.707 * EXP(.05979 * Ta)

Ta is the average air temperature (°C)

Step 3. Calculation of air saturation shortage Ds(kPa)

Ds = es * (1 - HR/ 100)

HR is relative humidity in %

Step 4. Calculation of the saturation vapor pressure curve slope, Δ (kPa/°C)

TETA = (Ta + 237.3) ^ 2

ALFA = 17.27 * Ta / (Ta + 237.3)

Δ = 4098 * (.6108 * EXP(ALFA)) / TETA

Step 5. Calculation of advective contribution

Adv = (γ * 900 * U * Ds) / (Ta+273)

γ = .066 (kPa/°C)

U= wind speed in m/s

Ds = saturation shortage (kPa)

Step 6. Calculation of the radioactive contribution

Rad = 0.408 * Δ * Rn

Step 7. Calculation of denominator (resistance to vapor diffusion in the limit layer)

Dn = Δ + .066 * (1 + .34 * U)

Step 8. Calculation of the radioactive component of ETo

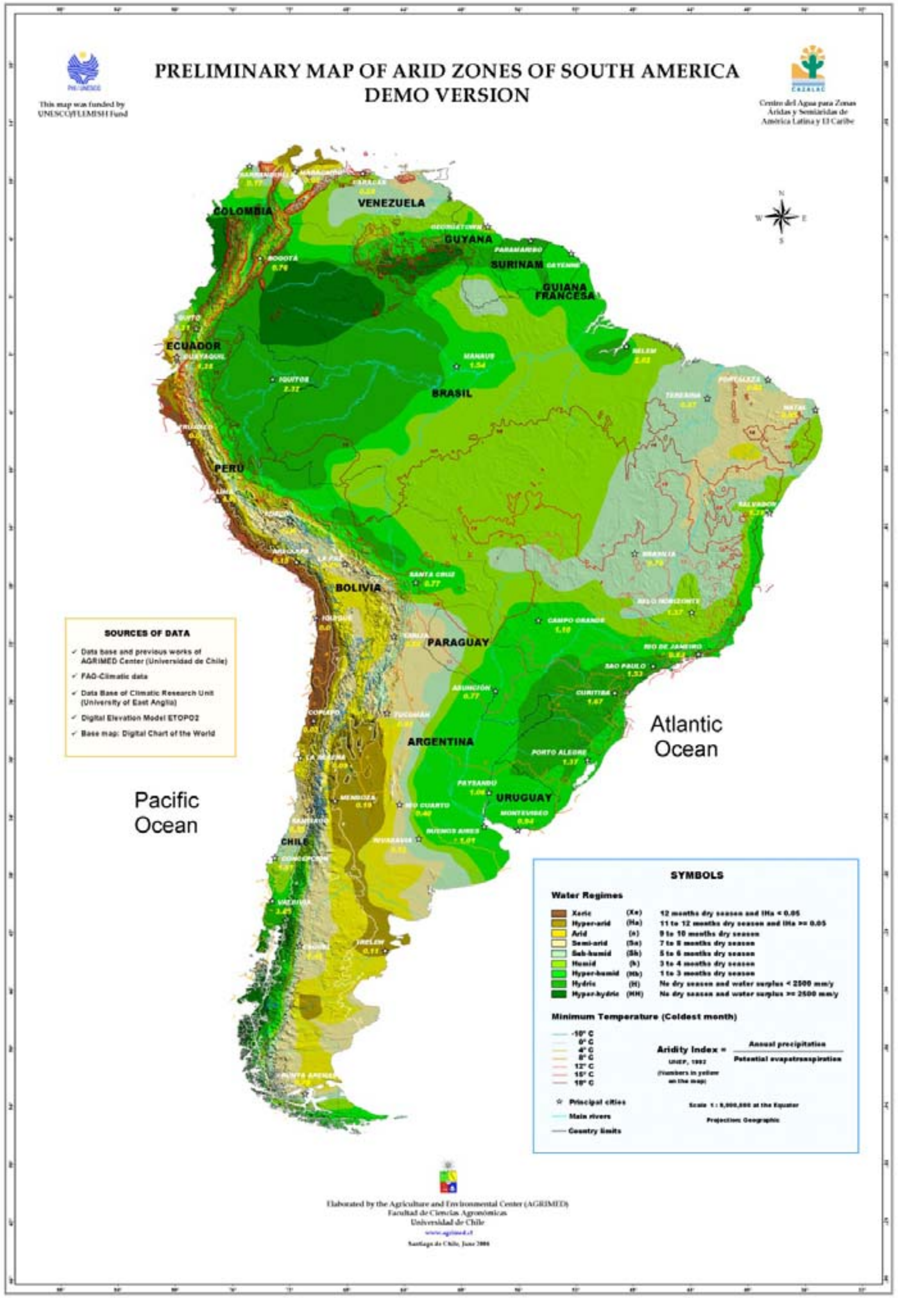
$$ETRAD = Rad / Dn$$

Step 9. Calculation of the advective component of ETo

$$ETADV = Adv / Dn$$

Step 10. Calculation of ETo

$$ETo = ETRAD + ETADV$$


PRELIMINARY MAP OF ARID ZONES OF SOUTH AMERICA
DEMO VERSION
This map was funded by UNESCO/FLEMISH Fund
Centro del Agua para Zonas Áridas y Semiáridas de América Latina y El Caribe
VENEZUELA
COLOMBIA
GUYANA
SURINAM
GUIANA FRANCESA
ECUADOR
BRASIL
PERU
BOLIVIA
PARAGUAY
ARGENTINA
URUGUAY
CHILE
Atlantic Ocean
Pacific Ocean
SOURCES OF DATA
Data base and previous works of AGRIMED Center (Universidad de Chile)
FAO-Climatic data
Data Base of Climatic Research Unit (University of East Anglia)
Digital Elevation Model ETOPO2
Base map: Digital Chart of the World
SYMBOLS
Water Regimes
Xeric (Xe) 12 months dry season and IHa < 0.05
Hyper-arid (Ha) 11 to 12 months dry season and IHa >= 0.05
Arid (a) 9 to 10 months dry season
Semi-arid (Sa) 7 to 8 months dry season
Sub-humid (Sh) 5 to 6 months dry season
Humid (h) 3 to 4 months dry season
Hyper-humid (Hh) 1 to 3 months dry season
Hydric (H) No dry season and water surplus < 2500 mm/y
Hyper-hydric (HH) No dry season and water surplus >= 2500 mm/y
Minimum Temperature (Coldest month)
-10° C
0° C
4° C
8° C
12° C
15° C
18° C
Aridity Index = Annual precipitation / Potential evapotranspiration
(Numbers in yellow on the map)
Principal cities
Main rivers
Country limits
Projection: Geographic
Elaborated by the Agriculture and Environmental Center (AGRIMED)
Facultad de Ciencias Agronómicas
Universidad de Chile