Global Geospatial Potential EvapoTranspiration & Aridity Index

Methodology and Dataset Description

Global Potential Evapo-Transpiration (Global-PET) Geospatial Dataset

Potential Evapo-Transpiration (PET) is a measure of the ability of the atmosphere to remove water through Evapo-Transpiration (ET) processes. The FAO introduced the definition of PET as the ET of a reference crop under optimal conditions, having the characteristics of well watered grass with an assumed height of 12 centimeters, a fixed surface resistance of 70 seconds per meter and an albedo of 0.23 (Allen et al. 1998). Among several equations to estimate PET, a FAO application of the Penman-Monteith equation (Allen et al. 1998), here referred as FAO-PM, is currently widely considered as a standard method (Walter et al. 2000). The FAO-PM is a predominately physically based approach, which can be used globally because it does not require estimations of additional site-specific parameters. However, a major drawback of the FAO-PM method is its relatively high need for specific data for a variety of parameters (i.e. windspeed, relative humidity, solar radiation, etc.) These parameters are reliably observed by a limited number of meteorological stations around the globe, and are especially lacking in developing countries (Droogers & Allen, 2002).

The ***Global-PET*** and ***Global-Aridity*** are both modeled using the data available from the WorldClim Global Climate Data (Hijmans et al. 2005) as input parameters. The WorldClim, based on a high number of climate observations and SRTM topographical data, is a high-resolution global geo-database (30 arc seconds or ~ 1km at equator) of monthly average data (1950-2000) for the following climatic parameters: precipitation, mean, minimum and maximum temperature. This set of parameters is insufficient to fully parameterize physical radiation-based PET equations (i.e. the FAO-PM), though can parameterize simpler temperature-based PET equations.

Monthly average PET was spatially characterized and then tested using 4 different temperature-based methods applied to the WorldClim Global Climate Data to determine their prediction accuracy. The modes that were used and tested are Thornthwaite (1948), Thornthwaite modified by Holland (1978), Hargreaves et al. (1985), Hargreaves modified by Droogers and Allen (2002). The monthly average values using these high resolution temperature PET layers, together with existing medium resolution (10’) FAO-PM monthly average (1950-2000) PET layers (FAO

2004), were compared to Penman-Monteith PET values estimated at climate stations in South America and Africa (n = 2288). The PET measurements used in the validation are calculated using the more complex Penman-Monteith model applied on direct observations of the various climatic parameters, and were obtained from the FAOCLIM 2 climate station dataset (Allen et al., 1998), available online from FAO. Based on the results of the comparative validation (Table 1) for South America and Africa (Figure 1), the Hargreaves model was chosen as the most suitable to model PET globally. This method performed almost as well as the FAO-PM, but required less parameterization, with significantly reduced sensitivity to error in climatic inputs (Hargreaves & Allen 2003).

Monthly average PET (mm/month) according to the Hargreaves method requires monthly average geo-datasets of 1) mean temperature (Tmean, C°); 2) daily temperature range (TD, C°) and 3) extra-terrestrial radiation (RA, radiation on top of atmosphere expressed in mm/month as equivalent of evaporation), as shown below:

$$PET = 0.0023 * RA * (Tmean + 17.8) * TD^{0.5} \qquad (mm / month)$$

TD is an effective proxy to describe the effect of cloud cover on the quantity of extra-terrestrial radiation reaching the land surface and, as such, it describes more complex physical processes with easily available climate data at high resolution.

Monthly spatial distribution of Tmean is acquired from the WorldClim dataset. Monthly spatial distribution of TD is calculated as the difference between average monthly maximum and minimum temperature, both available from WorldClim dataset. Monthly estimate of PET represent average over the 1950-2000 period.

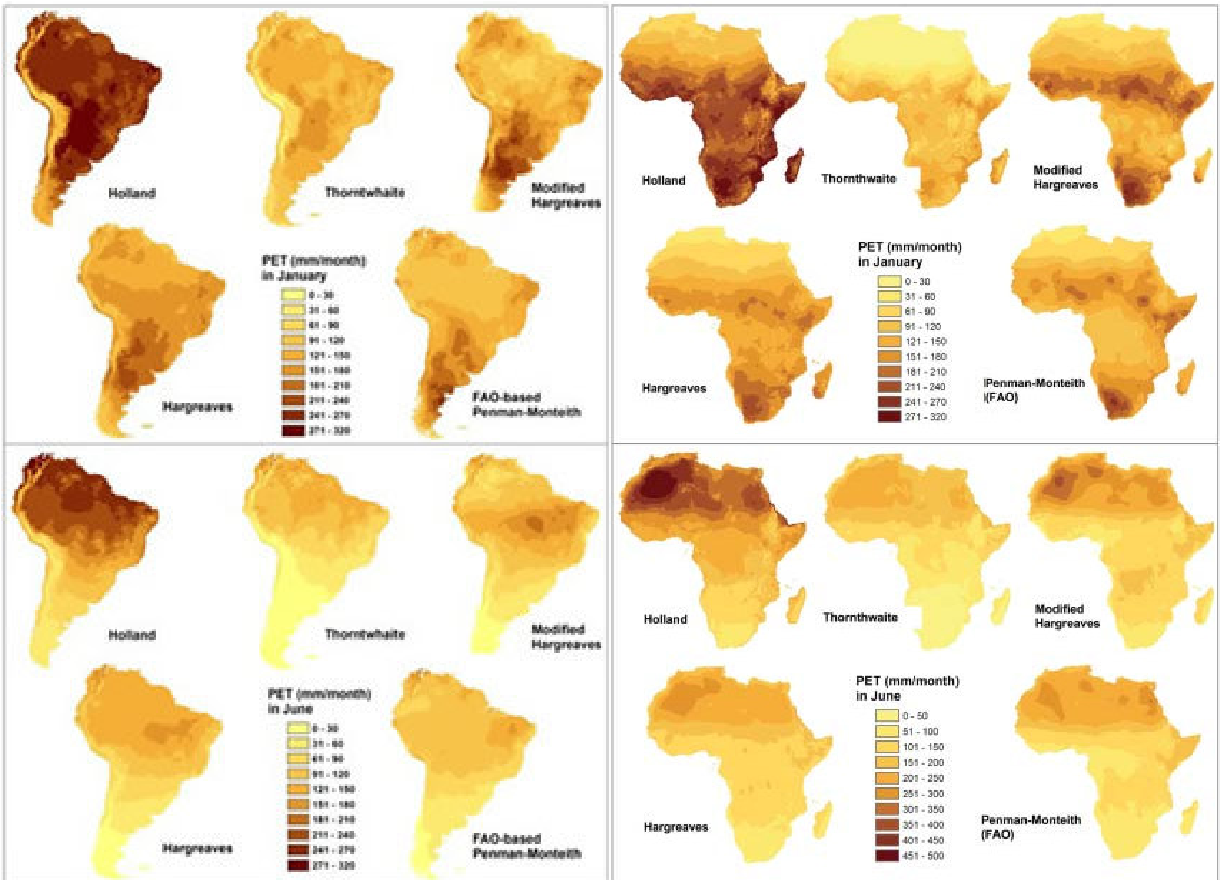
RA per day (mm/day equivalent) is calculated using the methodology presented in Allen et al. (1998), specifically for the 15th day of each month to describe averages per month. Total RA per month (mm/month equivalent) is successively calculated by multiplying the daily value of RA for the 15th day of the month times the number of days in the month.

Table 1. Five different methods of calculating PET were tested to verify which performed the best for the objectives of this analysis: Thornthwaite (Thornthwaite 1948), Thornthwaite modified by Holland (Holland 1978), Hargreaves (Hargreaves et al. 1985), Hargreaves modified by Droogers (Droogers and Allen 2002), and the FAO Global Penman-Monteith Dataset (Allen et al. 1998). Results are given as the mean difference (Diff) between observed and predicted estimates, and their standard deviations (SD).

Comparison of Five Methods Used to Estimate PET:

		Mean Difference (mm) and Standard Deviation (mm) between Observed and Predicted Values									
		Holland (Thornthwaite)		Thornthwaite		Hargreaves		Modified Hargreaves		Penman-Montieth FAO	
Region	Month	Mean Diff	*Std Dev*	Mean Diff	*Std Dev*	Mean Diff	*Std Dev*	Mean Diff	*Std Dev*	Mean Diff	*Std Dev*
Africa											
	Jan	71.8	*40.2*	41.6	*33.3*	22.3	*16.1*	24.8	*20.1*	11.1	*12.6*
	July	84.4	*41.7*	32.1	*23.7*	20.0	*19.3*	21.1	*19.3*	12.7	*16.0*
South America											
	Jan	69.9	*43.6*	50.5	*32.9*	38.2	*19.2*	41.6	*26.0*	34.9	*26.7*
	July	67.3	*35.9*	37.2	*24.7*	27.2	*14*	30.4	*20.1*	24.3	*15.1*
Resolution		1 km		1 km		1 km		1 km		20 km	
Data Requirements											
		Average Temperature		Average Temperature		Average Temperature		Average Temperature		Available online from FAO	
						Average Extraterrestrial Radiation		Average Extraterrestrial Radiation			
						Average Temperature Range		Average Temperature Range			
								Average Precipitation			

Figure 1. Five methods used to calculate PET for South America and Africa during two seasons.



Global Aridity Index (Global -Aridity)

Aridity is usually expressed as a generalized function of precipitation, temperature, and/or potential evapo-transpiration (PET). An Aridity Index (UNEP, 1997) can be used to quantify precipitation availability over atmospheric water demand.

Global mapping of mean Aridity Index from the 1950-2000 period at 30 arc second spatial resolution is calculated as:

Aridity Index (AI) = MAP / MAE

Where: MAP = Mean Annual Precipitation and MAE = Mean Annual Potential Evapo-Transpiration

Note: In the ***Global-Aridity*** dataset, following this formulation, Aridity Index values increase for more humid conditions, and decrease with more arid conditions.

Mean annual precipitation (MAP) values were obtained from the WorldClim Global Climate Data (Hijmans et al. 2005), for years 1950-2000, while PET layers estimated on a monthly average basis by the Global-PET (i.e. modeled using the Hargreaves method, as described above) were aggregated to mean annual values (MAE).

The ***Global-Aridity*** surface (Figure 2) shows moisture availability for potential growth of reference vegetation excluding the specific impact of soil condition to adsorb and hold water. UNEP (UNEP 1997) breaks up Aridity Index, in the traditional classification scheme presented in Table 2.

Figure 2. Global Aridity Index (***Global-Aridity)*** was calculated for the entire globe. Aridity maps for South America, South and East Asia, and Africa are shown below. Note that higher AI and darker color represents more humid conditions, with low AI and lighter colors representing higher aridity.

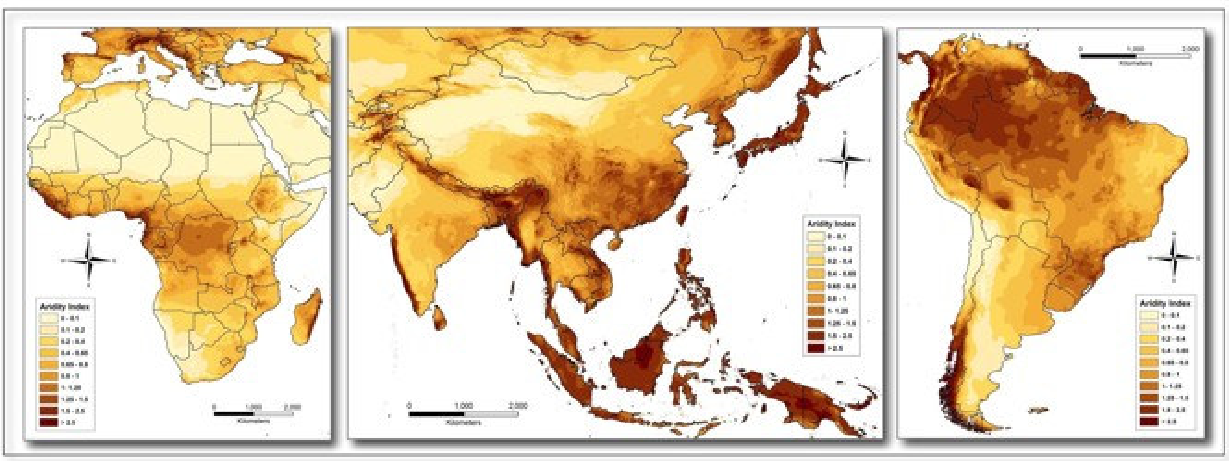


Table 2. Generalized climate classification scheme for Global-Aridity values (UNEP 1997).

Value	**Climate Class**
< 0.03	Hyper Arid
0.03 – 0.2	Arid
0.2 – 0.5	Semi-Arid
0.5 – 0.65	Dry sub-humid
> 0.65	Humid

DATA FORMAT

Global-PET grid layers are available as monthly averages (12 data layers, i.e. one layer for each month, averaged over the 1950-2000 period) or as an annual average (1 data layer) for the 1950-2000 period.

Global-Aridity is available as one grid layer representing the annual average over the 1950-2000 period.

Global-ExtraTerrestrial Solar Radiation grid layers are available as monthly averages (12 data layers, i.e. one layer for each month)

The following nomenclature is used to describe the dataset:

Prefix is either:

- PET_HE_	for PET layers calculated based on Hargreaves Method
- AI	for Aridity Index
- ET_SOLRAD	for ExtraTerrestrial Solar Radiation

Suffix is either:

- 1, 2, ... 12	Month of the year
- YR	Yearly average

Examples:

- PET_HE_2	is the PET average for the month of February
- PET_HE_YR	is the PET annual average
- AI_YR	is the AI annual average
- ET_SOLRAD_12	is the ExtraTerrestrial Solar Radiation for the month of December

The ***Global-PET*** geodatasets values are defined as total mm of PET per month or per year.

The Aridity Index values reported within the ***Global-Aridity*** geodataset have been multiplied by a factor of 10,000 to derive and distribute the data as integers (with 4 decimal accuracy). This multiplier has been used to increase the precision of the variable values without using decimals (real or floating values are less efficient in terms of computing time and space compared to integer values). Global-Aridity values need to be multiplied for 0.0001 to retrieve the values in the correct units.

The **Global-ET Solar Radiation** reports the radiation on top of atmosphere expressed in mm/day as equivalent of evaporation. Values have floating precision. No multiplier is applied. To derive monthly equivalent, these daily values should be multiplied by the number of days in the month.

The geospatial dataset is in geographic coordinates; datum and spheroid are WGS84; spatial units are decimal degrees. The spatial resolution is 30 arc-seconds or 0.008333 degrees. Arc degrees and seconds are angular distances, and conversion to linear units (like km) varies with latitude, as below:

Latitude	**Linear distance equivalent to 30 arc sec**
0	0.9266 km
20	0.8707 km
40	0.7098 km
60	0.4633 km

The ***Global-PET*** and ***Global-Aridity*** data layers are processed and finalized for use in ARC/INFO grid data format. These layers have been zipped (.zip) into monthly series or individual annual layers available for online access.

References:

- Allen RG, Pereira LS, Raes D & Smith M, 1998. Crop evapotranspiration: Guidelines for computing crop requirements. Irrigation and Drainage Paper No. 56, FAO, Rome, Italy.
- Droogers P & Allen RG, 2002. Estimating reference evapotranspiration under inaccurate data conditions. Irrigation and Drainage Systems 16 (1): 33-45.
- FAO, 2001. FAOCLIM - world-wide agroclimatic data. Version 2. FAO - SDRN (Environment and Natural Resources Service). Rome.
- Fao, 2004. Global map of monthly reference evapotranspiration - 10 arc minutes. Available at: http://www.fao.org/geonetwork/srv/en/main.home.
- Hargreaves GH & Allen RG 2003. History and evaluation of Hargreaves evapotranspiration equation. J. Irrig. Drain. Eng. 129 (1): 53-63.
- Hargreaves GL, Hargreaves GH & Riley JP, 1985. Irrigation water requirements for Senegal River Basin. J. Irrig. Drain. Eng. 111 (3): 265-275.
- Hijmans RJ, Cameron SE, Parra JL, Jones PG & Jarvis A, 2004. The WorldClim interpolated global terrestrial climate surfaces, version 1.3. Available at http://biogeo.berkeley.edu/.
- Holland HD, 1978. The Chemistry of the Atmosphere and Oceans.Wiley, New York.
- Thornthwaite C, 1948. An approach toward a rational classification of climate. Geogr. Rev. 38 (1): 55-94.
- Trabucco A, Zomer RJ, Bossio DA, van Straaten O & Verchot LV, 2008. Climate Change Mitigation through Afforestation / Reforestation: A global analysis of hydrologic impacts with four case studies. Agric. Ecosystems and Environment 126: 81-97.
- UNEP (United Nations Environment Programme), 1997. World atlas of desertification 2ED. UNEP, London.

- Walter IA, Allen RG, Elliott R et al., 2000. ASCE Standardized Reference Evapotranspiration Equation, p. 209 - 215. In: Evans RG, Benham BL, Trooien TP (eds.) Proc. National Irrigation Symposium, ASAE, Nov. 14-16, 2000, Phoenix, AZ.
- Zomer RJ, Trabucco A, Bossio DA, van Straaten O, Verchot LV, 2008. Climate Change Mitigation: A Spatial Analysis of Global Land Suitability for Clean Development Mechanism Afforestation and Reforestation. Agric. Ecosystems and Envir. 126: 67-80.
- Zomer RJ, Bossio DA, Trabucco A, Yuanjie L, Gupta DC & Singh VP, 2007. Trees and Water: Smallholder Agroforestry on Irrigated Lands in Northern India. Colombo, Sri Lanka: International Water Management Institute. pp 45. (IWMI Research Report 122).