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The application of transfer functions in creating the climate data layer of the Jamaica Geographical Information System (JAMGIS)

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ABSTRACT: Comprehensive sets of long term climatic data are generally recorded at a limited number of locations. The available information must be extrapolated to a wide range of locations to allow for agro-climatic zoning at the national level. This can be done with mathematical equations called transfer functions. Linear regression has been used to relate: 1) dependable rainfall (minimum amount of rainfall expected in 75 per cent of the years) with long term mean rainfall, 2) potential evapotranspiration with elevation above mean sea level and 3) air temperature with elevation above mean sea level. Information for the climate data layers of the Jamaica Geographical Information System (JAMGIS) can be generated with the discussed transfer functions. Subsequently, agro-climatic zones can be mapped with the GIS.

Key words: transfer functions, agro-climatic zoning, geographic information system, Jamaica

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1. INTRODUCTION

Jamaica, although being a relatively small island, is characterized by a wide range of climatic conditions (Jamaica Meteorological Service (JMS), 1973). This range makes it impractical (or too expensive) for the Meteorological Service to record all variables needed for detailed agro-climatic planning - i.e. daily rainfall, potential evaporation, air temperature, relative humidity, run of wind, radiation and atmospheric pressure- in each micro-climatic zone. Comprehensive sets of climate information are therefore recorded only at a limited number of locations. To allow for the islandwide mapping of agro-climatic zones the information available for climatic variables has to be extrapolated. This can be done with transfer functions.

A transfer function is a mathematical expression which relates different characteristics with one another in case of a limited availability of data. Bouma & van Lanen (1987) discussed their application in quantified land evaluation studies. Many types of mathematical expressions can be used as transfer functions. Linear regression has been applied succesfully in agro-climatic analyses as follows from studies performed in Indonesia (FAO, 1983), Kenya (Wielemaker & Boxem, 1982), Latin America and the Caribbean (IIC, 1986), and Jamaica (IICA, 1983; SSU, 1986b). The rationale of linear regression is discussed in numerous statistical handbooks (e.g. Walpole & Myers, 1978). The transfer functions discussed in this report are based on sets of climatic data that are readily obtainable from the Jamaica Meteorological Service (JMS, 1973 & 1987). The analysis of these data sets is discussed in IICA (1983) and SSU (1986a, 1986b, 1987 & 1988).

Rainfall, potential evapotranspiration and air temperature are the key variables for agro-climatic zoning according to JAMPLES, the computerized land evaluation system for Jamaica (SSU, 1986c). This paper reviews transfer functions which allow for the calculation of:

1) Dependable monthly rainfall -R75, which is defined as the minimum amount of rainfall that will be reached or exceeded in a given time period in 75% of the years- from long term mean monthly rainfall records (Section 2).
2) Daily air temperature (minimum, maximum and mean) from elevation above mean sea level (Section 3).
3) Mean monthly potential evapotranspiration from elevation above mean sea level (Section 4).

The applicability of the presented transfer functions to GIS mapping has been tested during the Cocoa Pilot Study (RPPD, 1988). Presently, the functions are being used to generate information required for the "Climate Layer", which was originally termed "Meteorology Layer" by ESRI (1987) , of the Jamaica Geographical Information System (JAMGIS). Maps which show suitable agro-climatic zones for specific crops on an islandwide or parish basis can be prepared upon the elaboration of the above data layer.

2. DEPENDABLE RAINFALL

A thorough understanding of the variability and reliability of seasonal rainfall (e.g. 10-day or monthly) is needed in agro-economic studies since it allows for the assessment of the probability of occurrence of specified events. Staff members of the Rural Physical Planning Division use "dependable rainfall" (R75) as the measure for the risk deemed bearable by small farmers (SSU, 1986a & 1988). Dependable rainfall is a useful criterion in agricultural planning because it strikes the balance between yield maximization and economic security to farmers.

R75 stands for the minimum amount of rainfall that will be reached or exceeded in 75% of the years in a given time period at the specified location. In 25% of the years rainfall will be less than this amount.

Information about dependable rainfall over short time intervals (10-day periods) is needed for detailed agro-climatic planning. This information can be readily calculated provided an extensive, computer data base of daily rainfall records is available. Such a data base, however, is not available at present for Jamaica (IICA, 1982). Therefore, records of monthly rainfall totals issued by the Jamaica Meteorological Service (JMS 1987) had to be used by RPPD staff for their agro-climatic studies.

Linear regression equations of "dependable monthly rainfall" (R75) against "mean monthly rainfall" (Rm) were developed using the information generated during the agro-climatic studies of the parish of St. Catherine and Clarendon (SSU, 1987 & 1988). The above studies include only data from rainfall stations with over 20 years of observations. The relevant equations are:

a) Dependable monthly rainfall (mm/month):

$$R75 = -14.63 + 0.6453 * Rm \quad (N=253;\ r\text{-square}=0.911)$$

b) Dependable annual rainfall (mm/year):

$$R75 = -139.2 + 0.90 * Rm \quad (N=33;\ r\text{-square}=0.976)$$

"Rm" stands for mean rainfall and is expressed in mm/month (a) and mm/year (b) respectively.

Both regression equation are highly significant ($P<<0.01$). About 91 and 97 percent of the differences in dependable monthly and annual rainfall can be explained by differences in the Rm variable respectively. Similar strong linear relations between dependable monthly rainfall and mean monthly rainfall for long term rainfall series have been reported in the review by Oldeman (1987).

Lists of mean monthly rainfall totals for over 288 stations in

Jamaica can be obtained from the Jamaica Meteorological Service, thereby allowing for the widespread use of equations (a) and (b) provided similar rainfall conditions occur as in the original data set (St. Catherine and Clarendon). The data covered in this study include rainfall totals that range from 0 to 410 mm/month (equation a) and from 700 to 2400 mm/year (equation b). Other types of transfer functions -different parameters in the regression equations- may be needed for the high rainfall areas of St. Thomas and Portland where mean rainfall exceeds 3000 mm/year.

3. POTENTIAL EVAPO-TRANSPIRATION

Knowledge of potential evapotranspiration totals is required in agricultural studies mainly to determine the water balance, irrigation requirements and the length of the growing period. Potential evapo-transpiration (PET) can be calculated according to many methods as shown by the review by ILACO (1981), each of these methods having their specific data requirements. In many cases the data requirements of accurate methods are high thereby restricting their widespread use. For example, the Penman method in its fullest form requires some 15 variables. Such detailed sets of data are seldom available for sufficient locations. IICA (1983) therefore used the Priestley & Taylor method, which uses radiation and temperature as input variables, for calculating PET in Jamaica. Radiation and temperature observations for a time period of about 10 years were available at 11 locations at the time of IICA's study.

IICA (1983) showed that mean daily PET (Priestley & Taylor method, mm/day) is linearly related with elevation above mean sea level (H in meters) in Jamaica. The relevant equations are:

January:	PET = 3.41 - 0.00068*H	(n=11; r-square=0.68)
February:	PET = 3.96 - 0.00099*H	(n=11; r-square=0.58)
March:	PET = 4.61 - 0.00131*H	(n=11; r-square=0.84)
April:	PET = 4.90 - 0.00144*H	(n=11; r-square=0.79)
May:	PET = 4.99 - 0.00134*H	(n=11; r-square=0.70)
June:	PET = 4.96 - 0.00108*H	(n=11; r-square=0.56)
July:	PET = 5.11 - 0.00112*H	(n=11; r-square=0.61)
August:	PET = 4.75 - 0.00093*H	(n=11; r-square=0.55)
September:	PET = 4.24 - 0.00082*H	(n=11; r-square=0.48)
October:	PET = 4.04 - 0.00084*H	(n=11; r-square=0.43)
November:	PET = 3.58 - 0.00089*H	(n=11; r-square=0.80)
December:	PET = 3.41 - 0.00073*H	(n=11; r-square=0.61)

For 9 degrees of freedom (n-2=9) the 2% value of r is 0.685 (r-square= 0.47). The observed linear relationships are at least significant at the 2% level of statistical confidence except in the case of "October". The regression for the month of October is only significant at the 5% level of statistical confidence and hence will have a poorer predictive value than the equations for the other months. The coefficients of linear determination (r-square) indicate that from 43 to 84 percent of the differences in monthly PET values can be explained by differences in elevation above mean sea level; the predictive value of the equations is fair to good.

The 11 climate stations considered in the study of IICA (1983) occur between 0 to 800 meter above mean sea level. The transfer functions can only be used satisfactorily within this range of elevation (Appendix I).

3. AIR TEMPERATURE

Altitude in Jamaica, which lies at about 18 degrees of latitude, ranges from 0 to about 2250 meter. As a result air temperature may be limiting -either too cold or too hot- for growth of specific crops at some time of the year. Fluctuations in air temperature in time and space may thus shorten the length of the growing period of some crops (SSU, 1986b).

SSU (1986b) calculated the following linear regression equations between minimum daily (Tmin), mean daily (Tmean=[Tmax+Tmin]/2) and maximum daily (Tmax) air temperature (T in degrees Celsius) respectively and elevation above mean sea level (H in meters) (SSU, 1986b):

January:

Tmean = 23.90 - 0.005294*H (n=22; r-square=0.885)
Tmin = 19.06 - 0.004957*H (n=22; r-square=0.631)
Tmax = 28.93 - 0.005887*H (n=22; r-square=0.876)

February:

Tmean = 23.86 - 0.005453*H (n=22; r-square=0.868)
Tmin = 18.69 - 0.005066*H (n=22; r-square=0.590)
Tmax = 29.04 - 0.005882*H (n=22; r-square=0.900)

March:

Tmean = 24.14 - 0.005081*H (n=22; r-square=0.878)
Tmin = 19.14 - 0.005139*H (n=22; r-square=0.627)
Tmax = 29.49 - 0.005406*H (n=22; r-square=0.906)

April:

Tmean = 25.06 - 0.005126*H (n=22; r-square=0.900)
Tmin = 20.11 - 0.005157*H (n=22; r-square=0.665)
Tmax = 30.06 - 0.005164*H (n=22; r-square=0.888)

May:

Tmean = 25.91 - 0.005251*H (n=22; r-square=0.903)
Tmin = 21.44 - 0.005226*H (n=22; r-square=0.706)
Tmax = 30.41 - 0.005340*H (n=22; r-square=0.943)

June:

Tmean	= 26.53 - 0.005412*H	(n=22; r-square=0.902)
Tmin	= 22.10 - 0.005237*H	(n=22; r-square=0.689)
Tmax	= 30.94 - 0.005554*H	(n=22; r-square=0.955)

July:

Tmean	= 26.82 - 0.005348*H	(n=22; r-square=0.878)
Tmin	= 22.07 - 0.005291*H	(n=22; r-square=0.719)
Tmax	= 31.45 - 0.005324*H	(n=22; r-square=0.931)

August:

Tmean	= 27.15 - 0.005385*H	(n=22; r-square=0.878)
Tmin	= 22.09 - 0.005191*H	(n=22; r-square=0.746)
Tmax	= 31.61 - 0.004982*H	(n=22; r-square=0.909)

October:

Tmean	= 26.53 - 0.005629*H	(n=22; r-square=0.869)
Tmin	= 21.81 - 0.005207*H	(n=22; r-square=0.747)
Tmax	= 30.95 - 0.005773*H	(n=22; r-square=0.869)

November:

Tmean	= 25.87 - 0.005670*H	(n=22; r-square=0.865)
Tmin	= 21.16 - 0.005179*H	(n=22; r-square=0.745)
Tmax	= 30.23 - 0.005812*H	(n=22; r-square=0.927)

December:

Tmean	= 24.87 - 0.005642*H	(n=22; r-square=0.912)
Tmin	= 20.19 - 0.005197*H	(n=22; r-square=0.707)
Tmax	= 29.46 - 0.005927*H	(n=22; r-square=0.904)

Year:

Tmean	= 25.61 - 0.005423*H	(n=22; r-square=0.917)
Tmin	= 20.86 - 0.005234*H	(n=22; r-square=0.713)
Tmax	= 30.34 - 0.005446*H	(n=22; r-square=0.949)

At 20 degrees of freedom the 1% value of r is 0.537 (r-square=0.28). All linear regressions equations for air temperature against elevation are highly significant (P<<0.01).

The range in elevation accounted for by the data set is from 0 to 1520 meters. Tmin, Tmean and Tmax values calculated for this range in elevation are shown in Appendix II.

5. DISCUSSION

The transfer functions that are discussed in this paper allow for the rapid calculation of monthly and annual dependable rainfall, potential evapotranspiration and air temperature from information that is readily available for many locations in Jamaica. They may show shortcomings when used for extrapolation outside the original range of the dependent variables. This should be understood when the transfer functions are used for GIS mapping of broad agro-climatic zones at the national level. An inherent characteristic of transfer functions is that they cannot account for micro-climatic variations. To account for such variations a wider network of climate stations, where daily rainfall, evaporation (e.g. pan Class A), temperature, run of wind, relative humidity, atmospheric pressure and radiation are measured over a long period of time (at least 20 years), will be needed. The crucial aspect of data gathering, storage and retrieval is often overlooked in long term planning, eventhough meaningful analyses are rarely feasible without such information.

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APPENDIX I: Potential evapotranspiration (PET) caluclated through linear regression against elevation [PET Priestley & Taylor, after IICA (1983)]

Alt (m)	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT	OCT.	NOV.	DEC.	YEAR
0	106	112	143	147	155	149	158	147	127	125	107	102	1579
50	105	110	141	145	153	147	157	146	126	124	106	101	1560
100	104	109	139	143	151	146	155	144	125	123	105	100	1542
150	103	108	137	141	148	144	153	143	124	121	103	99	1523
200	101	106	135	138	146	142	151	141	122	120	102	98	1505
250	100	105	133	136	144	141	150	140	121	119	101	97	1486
300	99	103	131	134	142	139	148	139	120	117	99	96	1468
350	98	102	129	132	140	137	146	137	119	116	98	95	1449
400	97	101	127	130	138	136	145	136	117	115	97	94	1431
450	96	99	125	128	136	134	143	134	116	114	95	92	1412
500	95	98	123	125	134	133	141	133	115	112	94	91	1394
550	94	96	121	123	132	131	139	131	114	111	93	90	1376
600	93	95	119	121	130	129	138	130	112	110	91	89	1357
650	92	94	117	119	128	128	136	129	111	108	90	88	1339
700	91	92	114	117	126	126	134	127	110	107	89	87	1320
750	90	91	112	115	124	125	132	126	109	106	87	86	1302
800	89	89	110	112	121	123	131	124	108	104	86	85	1283

* PET is expressed in mm/month and mm/year respectively
SSU, 04-19-1988

APPENDIX II: Mean daily temperature in degrees Celsius calculated through linear regression against elevation in meters (SSU, 1986b).

Alt (m)	T	jan.	feb.	mar.	apr.	may	jun.	jul.	aug.	sept	oct.	nov.	dec.	year
0	Tmin	19.1	18.7	19.1	20.1	21.4	22.1	22.1	22.1	22.2	21.8	21.2	20.2	20.9
	Tmean	23.9	23.9	24.1	25.1	25.9	26.5	26.8	27.2	26.7	26.5	25.9	24.9	25.6
	Tmax	28.9	29.0	29.5	30.1	30.4	30.9	31.5	31.6	31.3	31.0	30.2	29.5	30.3
100	Tmin	18.6	18.2	18.6	19.6	20.9	21.6	21.5	21.6	21.6	21.3	20.6	19.7	20.3
	Tmean	23.4	23.3	23.6	24.5	25.4	26.0	26.3	26.6	26.2	26.0	25.3	24.3	25.1
	Tmax	28.3	28.5	28.9	29.5	29.9	30.4	30.9	31.1	30.8	30.4	29.6	28.9	29.8
200	Tmin	18.1	17.7	18.1	19.1	20.4	21.1	21.0	21.1	21.1	20.8	20.1	19.2	19.8
	Tmean	22.8	22.8	23.1	24.0	24.9	25.4	25.8	26.1	25.7	25.4	24.7	23.7	24.5
	Tmax	27.8	27.9	28.4	29.0	29.3	29.8	30.4	30.6	30.2	29.8	29.1	28.3	29.3
300	Tmin	17.6	17.2	17.6	18.6	19.9	20.5	20.5	20.5	20.5	20.2	19.6	18.6	19.3
	Tmean	22.3	22.2	22.6	23.5	24.3	24.9	25.2	25.5	25.1	24.8	24.2	23.2	24.0
	Tmax	27.2	27.3	27.9	28.5	28.8	29.3	29.9	30.1	29.7	29.2	28.5	27.7	28.7
400	Tmin	17.1	16.7	17.1	18.0	19.3	20.0	20.0	20.0	20.0	19.7	19.1	18.1	18.8
	Tmean	21.8	21.7	22.1	23.0	23.8	24.4	24.7	25.0	24.6	24.3	23.6	22.6	23.5
	Tmax	26.6	26.7	27.3	28.0	28.3	28.7	29.3	29.6	29.2	28.6	27.9	27.1	28.2
500	Tmin	16.6	16.2	16.6	17.5	18.8	19.5	19.4	19.5	19.5	19.2	18.6	17.6	18.3
	Tmean	21.3	21.1	21.6	22.5	23.3	23.8	24.1	24.5	24.1	23.7	23.0	22.0	22.9
	Tmax	26.0	26.1	26.8	27.5	27.7	28.2	28.8	29.1	28.6	28.1	27.3	26.5	27.6
600	Tmin	16.1	15.7	16.1	17.0	18.3	19.0	18.9	19.0	18.9	18.7	18.1	17.1	17.7
	Tmean	20.7	20.6	21.1	22.0	22.8	23.3	23.6	23.9	23.5	23.2	22.5	21.5	22.4
	Tmax	25.4	25.5	26.2	27.0	27.2	27.6	28.3	28.6	28.1	27.5	26.7	25.9	27.1
700	Tmin	15.6	15.1	15.5	16.5	17.8	18.4	18.4	18.5	18.4	18.2	17.5	16.6	17.2
	Tmean	20.2	20.0	20.6	21.5	22.2	22.7	23.1	23.4	23.0	22.6	21.9	20.9	21.8
	Tmax	24.8	24.9	25.7	26.4	26.7	27.1	27.7	28.1	27.6	26.9	26.2	25.3	26.6
800	Tmin	15.1	14.6	15.0	16.0	17.3	17.9	17.8	17.9	17.9	17.6	17.0	16.0	16.7
	Tmean	19.7	19.5	20.1	21.0	21.7	22.2	22.5	22.8	22.5	22.0	21.3	20.4	21.3
	Tmax	24.2	24.3	25.2	25.9	26.1	26.5	27.2	27.6	27.0	26.3	25.6	24.7	26.0
900	Tmin	14.6	14.1	14.5	15.5	16.7	17.4	17.3	17.4	17.3	17.1	16.5	15.5	16.2
	Tmean	19.1	19.0	19.6	20.4	21.2	21.7	22.0	22.3	22.0	21.5	20.8	19.8	20.8
	Tmax	23.6	23.7	24.6	25.4	25.6	25.9	26.7	27.1	26.5	25.8	25.0	24.1	25.5
1000	Tmin	14.1	13.6	14.0	15.0	16.2	16.9	16.8	16.9	16.8	16.6	16.0	15.0	15.7
	Tmean	18.6	18.4	19.1	19.9	20.7	21.1	21.5	21.8	21.4	20.9	20.2	19.2	20.2
	Tmax	23.0	23.2	24.1	24.9	25.1	25.4	26.1	26.6	25.9	25.2	24.4	23.5	24.9
1100	Tmin	13.6	13.1	13.5	14.4	15.7	16.3	16.2	16.4	16.3	16.1	15.5	14.5	15.1
	Tmean	18.1	17.9	18.6	19.4	20.1	20.6	20.9	21.2	20.9	20.3	19.6	18.7	19.7
	Tmax	22.5	22.6	23.5	24.4	24.5	24.8	25.6	26.1	25.4	24.6	23.8	22.9	24.4
1200	Tmin	13.1	12.6	13.0	13.9	15.2	15.8	15.7	15.9	15.7	15.6	14.9	14.0	14.6
	Tmean	17.5	17.3	18.0	18.9	19.6	20.0	20.4	20.7	20.4	19.8	19.1	18.1	19.1
	Tmax	21.9	22.0	23.0	23.9	24.0	24.3	25.1	25.6	24.9	24.0	23.3	22.3	23.9
1300	Tmin	12.6	12.1	12.5	13.4	14.6	15.3	15.2	15.3	15.2	15.0	14.4	13.4	14.1
	Tmean	17.0	16.8	17.5	18.4	19.1	19.5	19.9	20.1	19.8	19.2	18.5	17.5	18.6
	Tmax	21.3	21.4	22.5	23.3	23.5	23.7	24.5	25.1	24.3	23.4	22.7	21.8	23.3
1400	Tmin	12.1	11.6	11.9	12.9	14.1	14.8	14.7	14.8	14.7	14.5	13.9	12.9	13.6
	Tmean	16.5	16.2	17.0	17.9	18.6	19.0	19.3	19.6	19.3	18.6	17.9	17.0	18.0
	Tmax	20.7	20.8	21.9	22.8	22.9	23.2	24.0	24.6	23.8	22.9	22.1	21.2	22.8
1500	Tmin	11.6	11.1	11.4	12.4	13.6	14.2	14.1	14.3	14.1	14.0	13.4	12.4	13.1
	Tmean	16.0	15.7	16.5	17.4	18.0	18.4	18.8	19.1	18.8	18.1	17.4	16.4	17.5
	Tmax	20.1	20.2	21.4	22.3	22.4	22.6	23.5	24.1	23.2	22.3	21.5	20.6	22.2

* Tmin = mean daily minimum air temperature
Tmean= mean daily air temperature
Tmax = mean maximum daily air temperature

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