MULTIYEAR DROUGHTS REGIONAL ANALYSIS AND PREDICTION IN NORTH-WESTERN GREECE

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Project aim

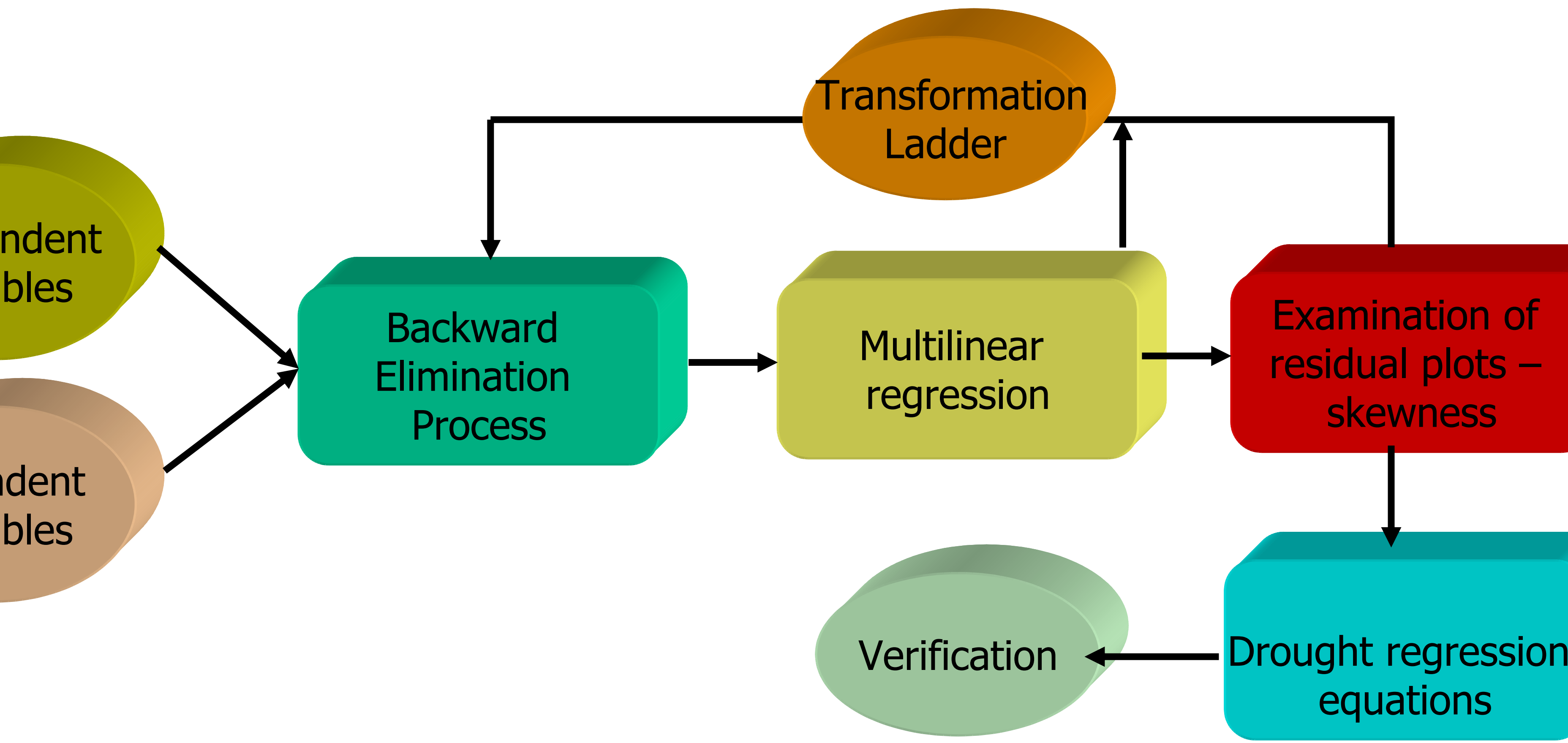
- **grade** previous study in the wider region
  mikou et al., 1993)
- imate geomorphic and climatic characteristic
  m 13 riverbasins of the study area
- rm reliable mathematic **equations** between
  ought characteristics and basin characteristic
  ler to apply in similar **ungauged** catchments
  e study area
- ract conclusions from the equations

Innovations in comparison with the initial study

- **Verification** of regression equations in two riverba
  of the study area
- **Transformation ladder** for optimization of the fin
  equations through the confrontation of skewness in
  histogram of standardized residuals
- **Combined parameters** of independent variables w
  introduced (P_d) – Need for restricted independent
  variables by the small basin sample size:

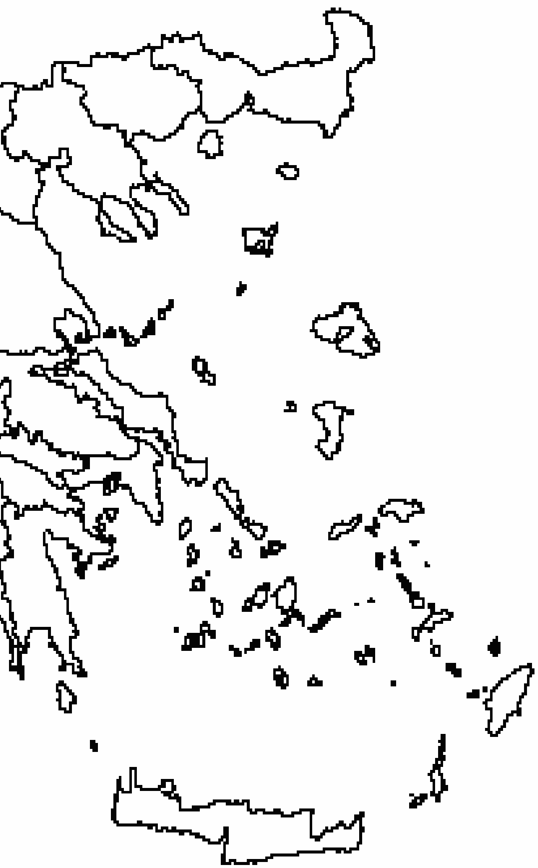
  degrees of freedom=basins-independent variables-1
- **Alternative regression** equations derived for cert
  drought characteristics. Election according to data
  availability

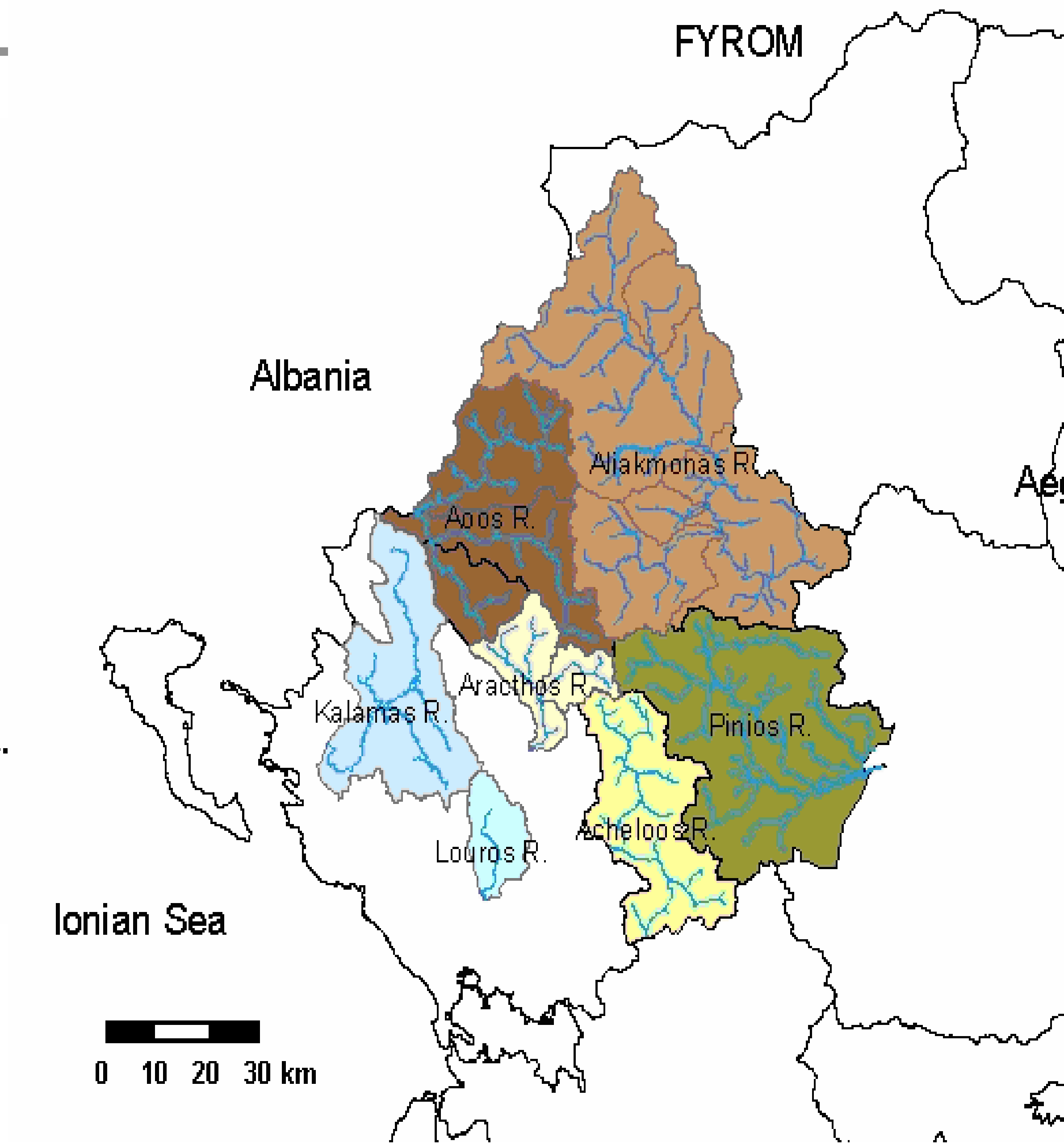
Model


ndent
bles
ndent
bles
Transformation
Ladder
Backward
Elimination
Process
Multilinear
regression
Examination of
residual plots –
skewness
Drought regression
equations
Verification

Study Area: 14200 km^2

120 hydrometeorological gauges with data P,T



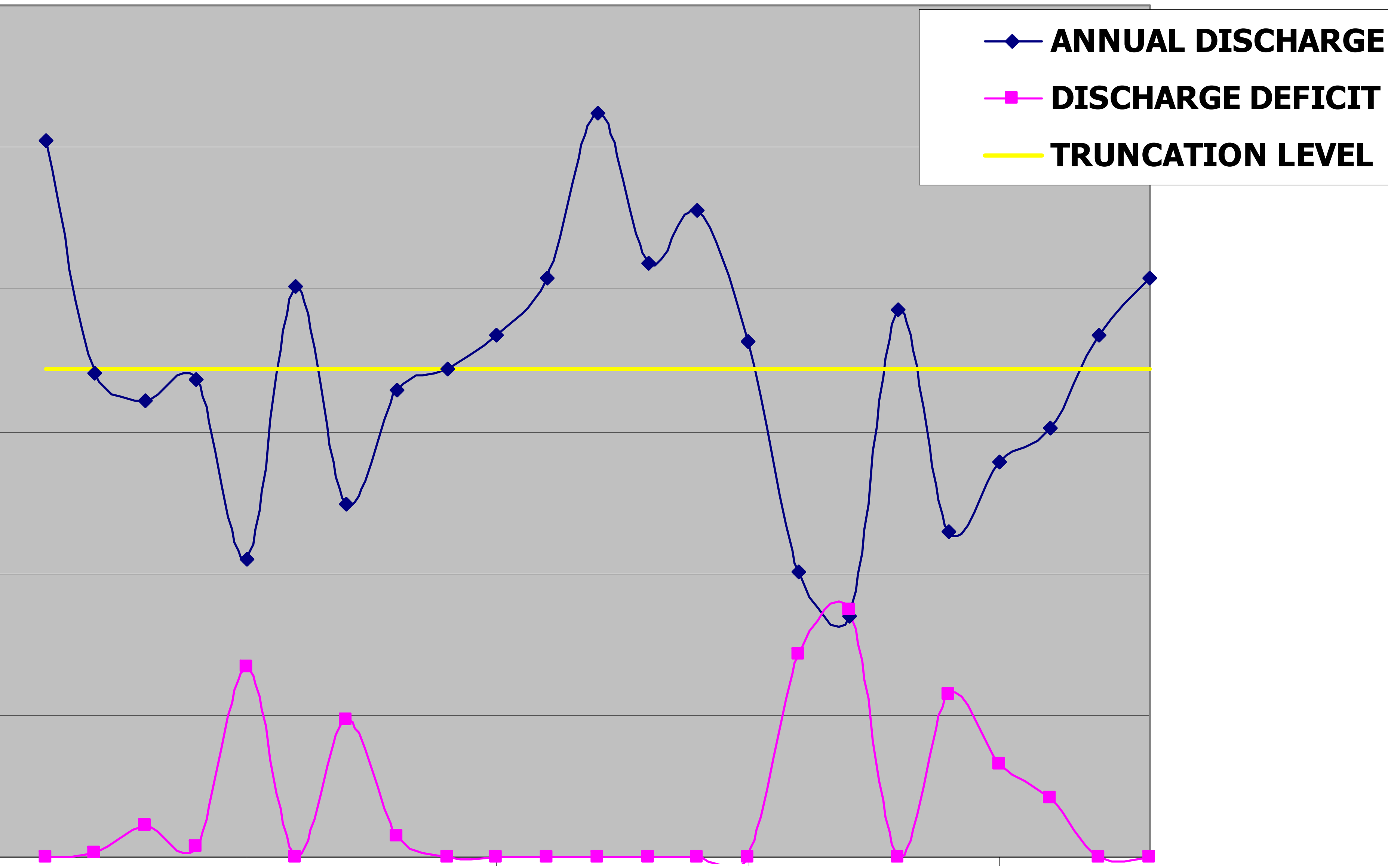


River	Drainage basin	$A(km^2)$
	Calibration	
Aliakmon	Ilarion	5005,89
Aliakmon	Siatista	2724,65
Aracthos	Plaka	970,35
Acheloos	Avlaki	1348,97
Acheloos	Sikia	1173,12
Aoos	Bourazani	2140,48
Aoos	Vovousa	202,09
Kalamas	Kioteki	1485,67
Kalamas	Soulopoulo	661,42
Louros	Louros	345,75
Pinios	Pinios	2873,15
	Verification	
Aracthos	Tsimovo	640,23

n)	Gauging stations precipitation data were acquired from the N Thiessen polygons were constructed using the ARCGIS programme.Finally, elevation reduction was performed.P needed for the calculation of Pd and PV
n)	Dry years were defined as those with streamflow lower thar truncation level for each basin.Then, the difference betwe mean annual areal precipitation and the mean annual a precipitation of the dry years Pd over each basin was calc
C)	Gauging stations temperature data were acquired from the N Thiessen polygons were constructed using the ARCGIS programme.Finally, elevation reduction was performe
	It was calculated using the mean annual areal precipitation I
^{2})	It was calculated using the Arcgis 9 programme
m)	It was calculated using the Arcgis 9 programme
n)	It was calculated using the Arcgis 9 programme
	It was calculated using the Arcgis 9 programme

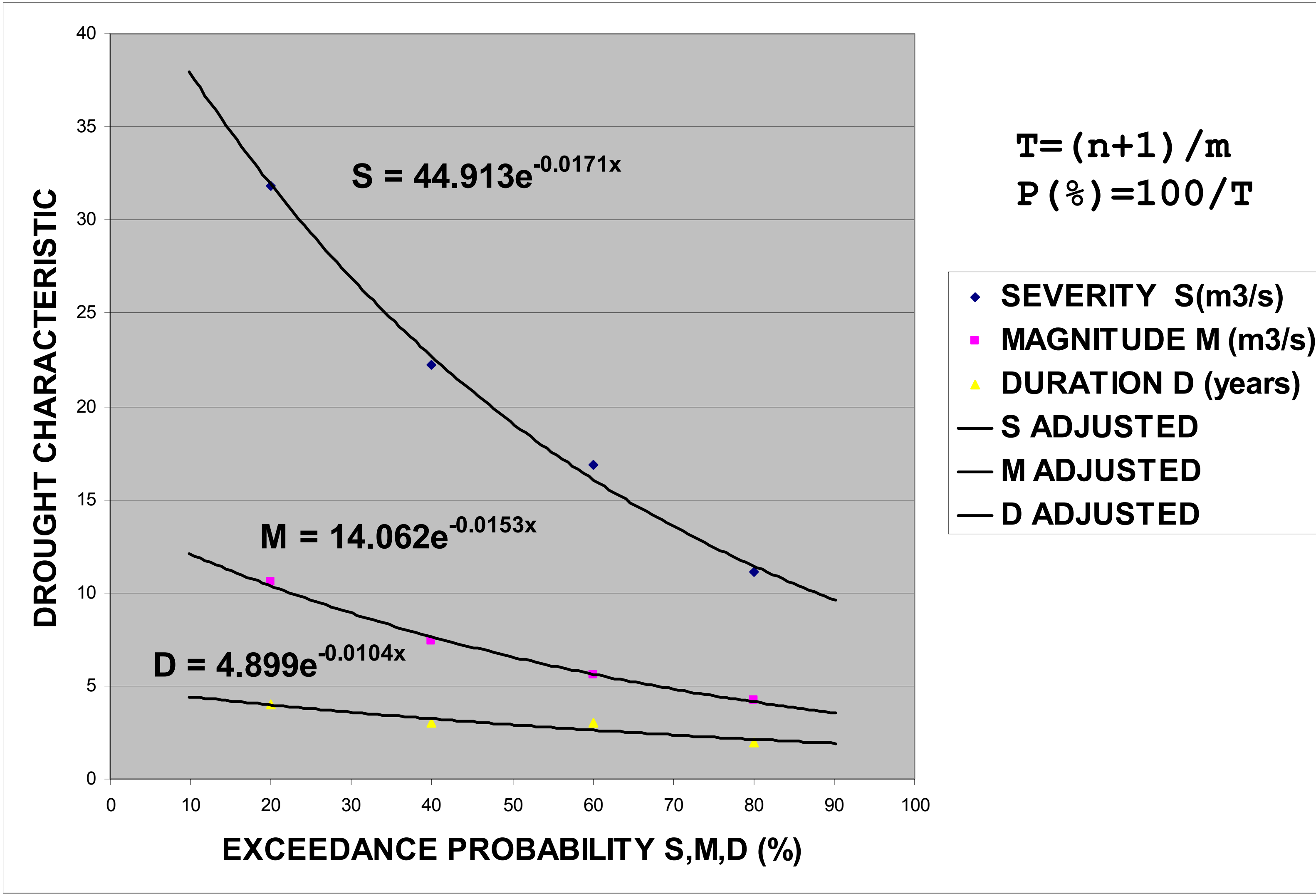
	Drainage basin	P (mm)	P_d (mm)	T (·C)	PV	A(km^2)	PR (km)	E (m)	S
Calibration gauges									
n	Ilarion	770,6	231,2	10,89	0,1983	5005,8	431,0	910,3	0,00234
n	Siatista	502,2	147,7	10,27	0,2979	2724,6	268,0	1005,3	0,00211
s	Plaka	1581,3	184,4	15,10	0,1011	970,3	181,8	1059,2	0,00825
s	Avlaki	1955,5	252,2	10,45	0,1384	1348,9	209,9	1206,2	0,00882
s	Sikia	2023,3	156,4	10,24	0,1312	1173,1	184,3	1172,8	0,00976
	Bourazani	1139,6	193,7	11,73	0,1773	2140,4	361,4	1222,7	0,02720
	Vovousa	1449,0	86,4	9,98	0,1684	202,0	72,0	149,0	0,01608
s	Kioteki	1245,8	227,2	11,84	0,1955	1485,6	218,1	548,3	0,00581
s	Soulopoulo	1421,2	123,4	11,19	0,1857	661,4	116,2	649,8	0,00974
	Louros	1565,8	119,4	12,93	0,1784	345,7	96,0	691,4	0,04214
	Pinios	931,9	191,0	14,42	0,2096	2873,1	336,9	537,2	0,01976
Verification gauges									
s	Tsimovo	1693,3	208,3	10,18	0,1237	640,2	133,9	1069,7	0,00858

ANNUAL DISCHARGE-TRUNCATION LEVEL (SYKIA)



...ological Year	Discharge (m^3/s)	Deficit (m^3/s)	Event's Serial Number			
				Severity S (m^3/s)	Magnitude M (m^3/s)	Durat... (y...
86-87	45.58	0.00				
87-88	36.33	1.93				
88-89	18.12	12.41	3	31.80	10.60	3
89-90	16.94	17.46				
90-91	38.63	0.00				
91-92	22.87	11.53				
92-93	27.90	6.50	4	22.24	7.41	3
93-94	30.19	4.21				
94-95	36.70	0.00				
95-96	40.85	0.00				

ught characteristics - Exceedance probabilities cu



Frequency analysis - Sort in a descending order (Sikia)

[illegible]	Severity S (m^3/s)	Magnitude M (m^3/s)	Duration D (years)	T	P%
	31.80	10.60	4	5	20
	22.24	7.41	3	2.5	40

S10 (m3/s)	S50 (m3/s)	S90 (m3/s)	M10 (m3/s)	M50 (m3/s)	M90 (m3/s)	D10 years	D50 years	D90 years	MDS (m3/s)	MDM (m3/s)	MDD years	TP1
94.38	23.52	2.90	18.31	12.44	2.46	5.15	1.89	1.18	14.17	4.95	2.20	0.40
60.74	9.05	2.35	13.83	4.16	2.04	4.39	2.17	1.16	14.45	6.31	2.00	0.40
57.00	10.01	1.76	13.28	5.75	2.32	4.29	1.74	0.76	15.89	7.02	2.00	0.40
59.10	18.42	5.74	13.59	6.32	2.99	4.35	2.91	1.92	30.29	3.33	3.00	0.01
33.34	10.12	3.07	9.43	3.48	1.60	3.54	2.91	1.92	20.51	6.95	3.00	0.01
120.4	25.30	3.04	21.39	10.66	3.39	5.63	2.37	0.90	35.65	11.27	2.75	0.25
12.46	2.41	0.47	5.03	1.46	0.56	2.48	1.65	0.82	3.55	1.76	1.80	0.40
65.78	11.28	1.93	14.55	6.85	2.34	4.52	1.65	0.82	17.31	8.67	1.80	0.40
21.94	9.07	1.56	4.97	3.80	2.91	4.42	2.91	1.92	11.89	4.03	3.00	0.01
19.00	3.94	0.82	3.57	2.12	1.26	5.33	1.86	0.65	5.60	2.35	2.25	0.50
87.04	22.17	2.52	35.21	10.95	3.41	2.47	1.35	0.74	24.37	14.46	1.50	0.67

Verification Basins

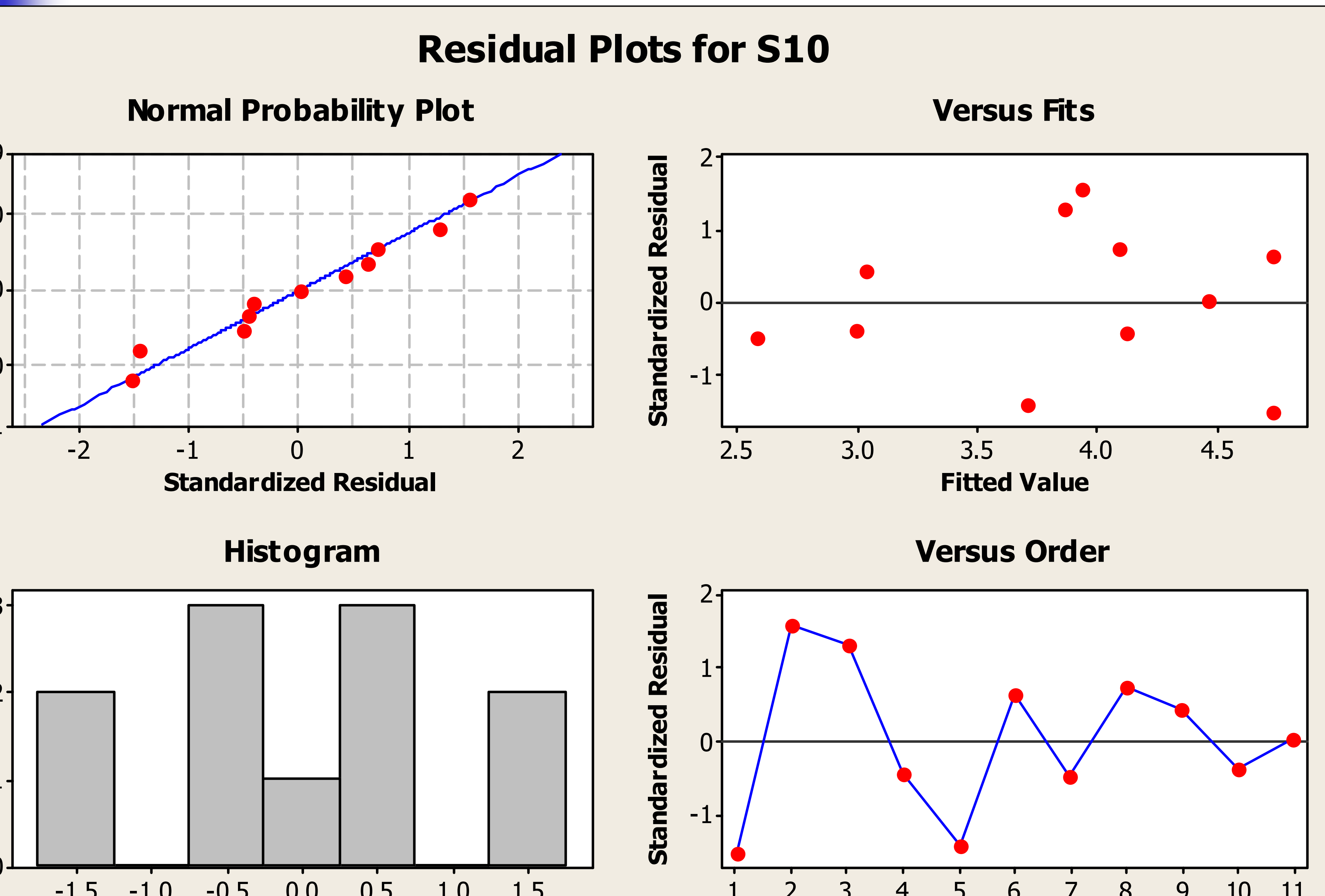
33.50	9.34	3.09	9.38	3.27	1.43	3.50	2.53	1.46	14.78	3.73	2.75	0.01

	1	2	3	4	5	6
t	-7,713	-7,619	-7,200	-6,711	-5,559	-4,862
	0,89	0,95	0,71	0,50	0,48	0,52
	2,10	2,88	2,73	2,24	2,00	2,14
	0,171	0,064	0,053	0,075	0,093	**0,069**
	0,79	0,77	0,76	0,63	0,42	
	1,96	2,27	2,17	1,75	1,19	
	0,189	0,108	0,096	0,141	**0,208**	
	0,34	0,29	0,28			
	1,25	1,43	1,34			
	0,339	0,249	**0,253**			
	-0,91	-0,82	-0,93	-0,73	-0,41	-0,49
	-1,96	-2,42	-2,77	-2,26	-1,70	-2,09
	0,189	0,094	0,050	0,074	0,139	**0,075**
	2,16	2,04	2,28	2,11	1,67	1,80
	3,12	3,93	4,70	4,19	3,99	4,33
	0,089	0,029	0,009	0,009	0,007	**0,003**
	0,05					
	0,39					
	0,734					
	0,27	0,36				
	0,61	1,13				
	0,601	**0,341**				
	-0,387	-0,457	-0,136	-0,110		
	-0,99	-1,55	-1,76	-1,37		
	0,427	0,218	0,153	**0,228**		

```
 4,86 - 0,492 A + 1,80 PR + 0,522 Pd

tor            Coef   SE Coef       T       P
nt          -4,8624    0,8482   -5,73   0,001
            -0,4923    0,2356   -2,09   0,075
             1,8049    0,4164    4,33   0,003
             0,5220    0,2434    2,14   0,069

149218   R-Sq = 97,1%   R-Sq(adj) = 95,8%

is of Variance
             DF       SS       MS       F       P
sion          3   5,1439   1,7146   77,01   0,001
al Error      7   0,1559   0,0223
             10   5,2997

           DF   Seq SS
            1   4,4166
            1   0,6249
            1   0,1024
```

s case of the regional regression analysis, the primary
tion to applicability is that the basin, geomorphic and cli
s should be within the range of those used to develop the
sion equations. It is not wise to extrapolate the use of th

Residual Plots

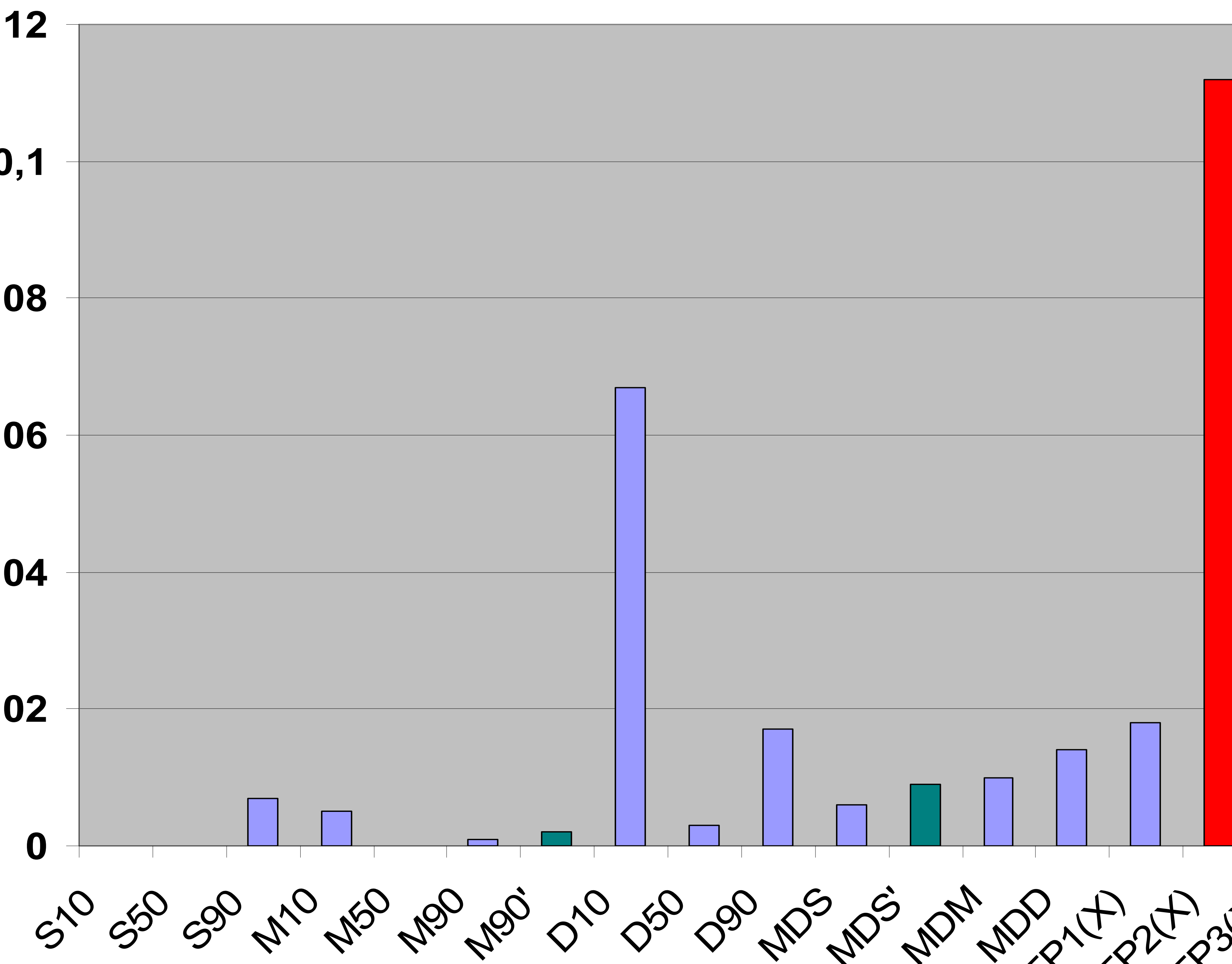


	θ	Transformation	Name	Comment
		• • •		higher powers can b
s	3	x^3	cube	
	2	x^2	square	
	1	x	original units	no transformatio
	1/2	$\sqrt{x}$	square root	commonly use
	1/3	$\sqrt[3]{x}$	cube root	commonly use
	0	log(x)	logarithm	commonly used. Ho place of x^0
s	–1/2	$-1/\sqrt{x}$	reciprocal root	the minus sign pres order of observati
	–1	–1/x	reciprocal	
	–2	$-1/x^2$		

Transformation-the ladder of powe

- **Transformation ladder** for optimization of the fin equations through the confrontation of skewness in histogram of standardized residuals concerning. In specific study several transformations were examine from square and cube to reciprocal square $(-1/x^2)$
- $\ln Y = a_1 \ln X_1 + a_2 \ln X_2 + \ldots + a_n \ln X_n$
- $TP = a_1 X_1 + a_2 X_2 + \ldots + a_n X_n$

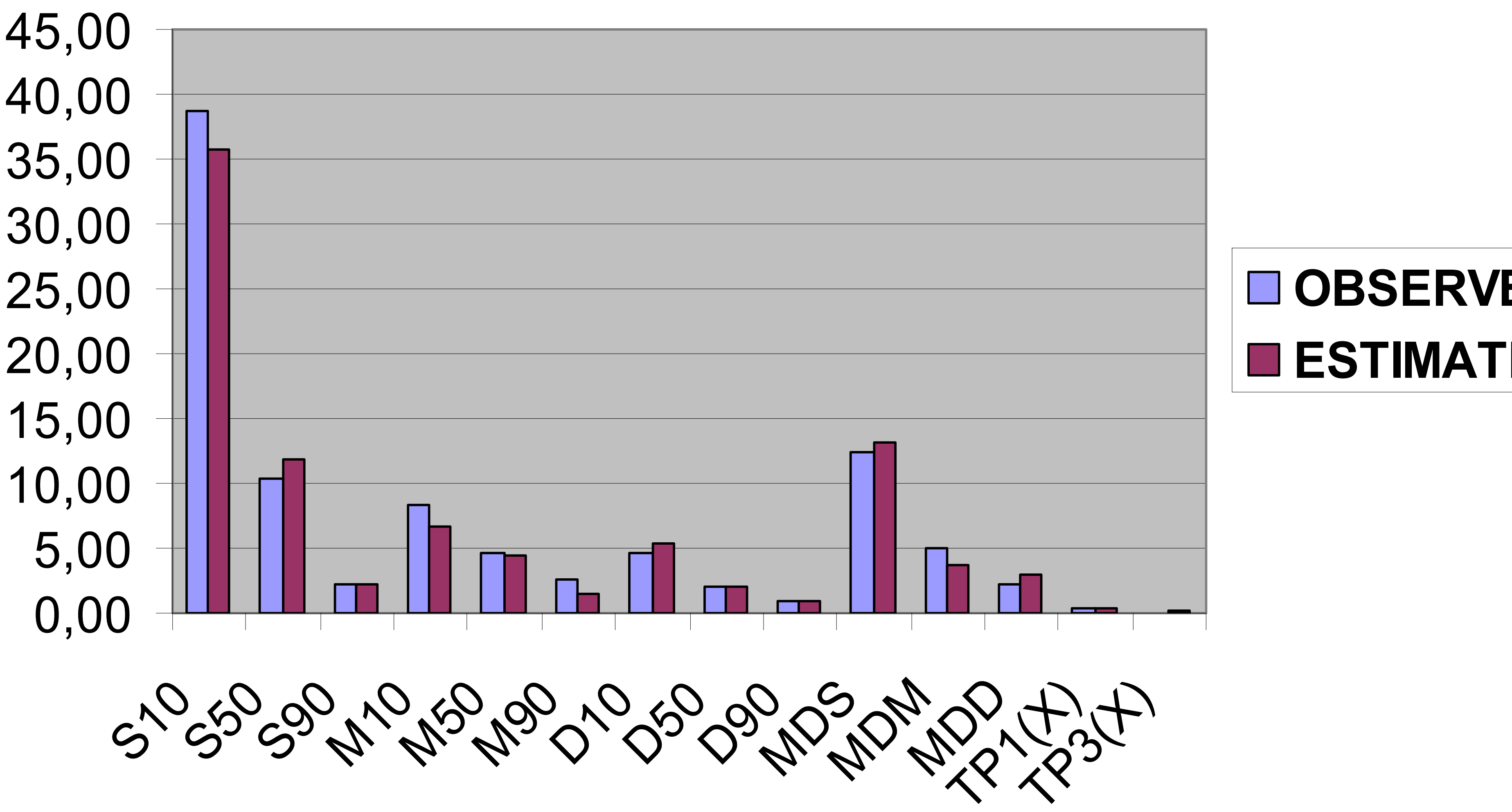
										(adj)	
	P_d	T	P_V	A	PR	E	S	R			
-4.86	0.52			-0.49	1.80				97.1	95.8	0.0
-5.14	0.87			0.58			-0.23		92.1	88.8	0.0
-3.81	2.00	1.78	-0.80	2.03	-2.77		-1.78	-1.31	98.8	95.9	0.0
-5.03	1.72			0.54		-0.55	-1.62	-1.38	93.7	87.5	0.0
-7.75	0.61	0.80			0.81				93.1	90.2	0.0
-3.00			-0.53	0.50			-0.16		88.8	84.0	0.0
-3.29			-0.59	0.42					80.2	75.2	0.0
-1.59			0.89	-1.43	1.74	0.63	-1.02	0.77	88.6	71.4	0.0
2.17		1.13			-0.24	0.39			84.3	77.6	0.0
6.79		2.58	-1.05	2.11	-2.97		-0.32		89.6	79.2	0.0
-8.15	2.40						-1.70	-1.50	81.1	73.0	0.0
-6.11	1.83						-0.11		69.4	61.7	0.0
-6.00		1.75		0.48					68.1	60.2	0.0
2.56		1.27				0.29		0.13	76.3	66.2	0.0
-0.95		1.16	0.39			-0.13			74.2	63.1	0.0



12
0,1
08
06
04
02
0
S10
S50
S90
M10
M50
M90
M90'
D10
D50
D90
MDS
MDS'
MDM
MDD
EP1(X)
EP2(X)

VERIFICATION RESULTS
MEAN PREDICTION ERROR
$\varepsilon\ (\%) = [\ (Y_i - \tilde{Y}_i)/Y_i] = 16{,}54\ \%$

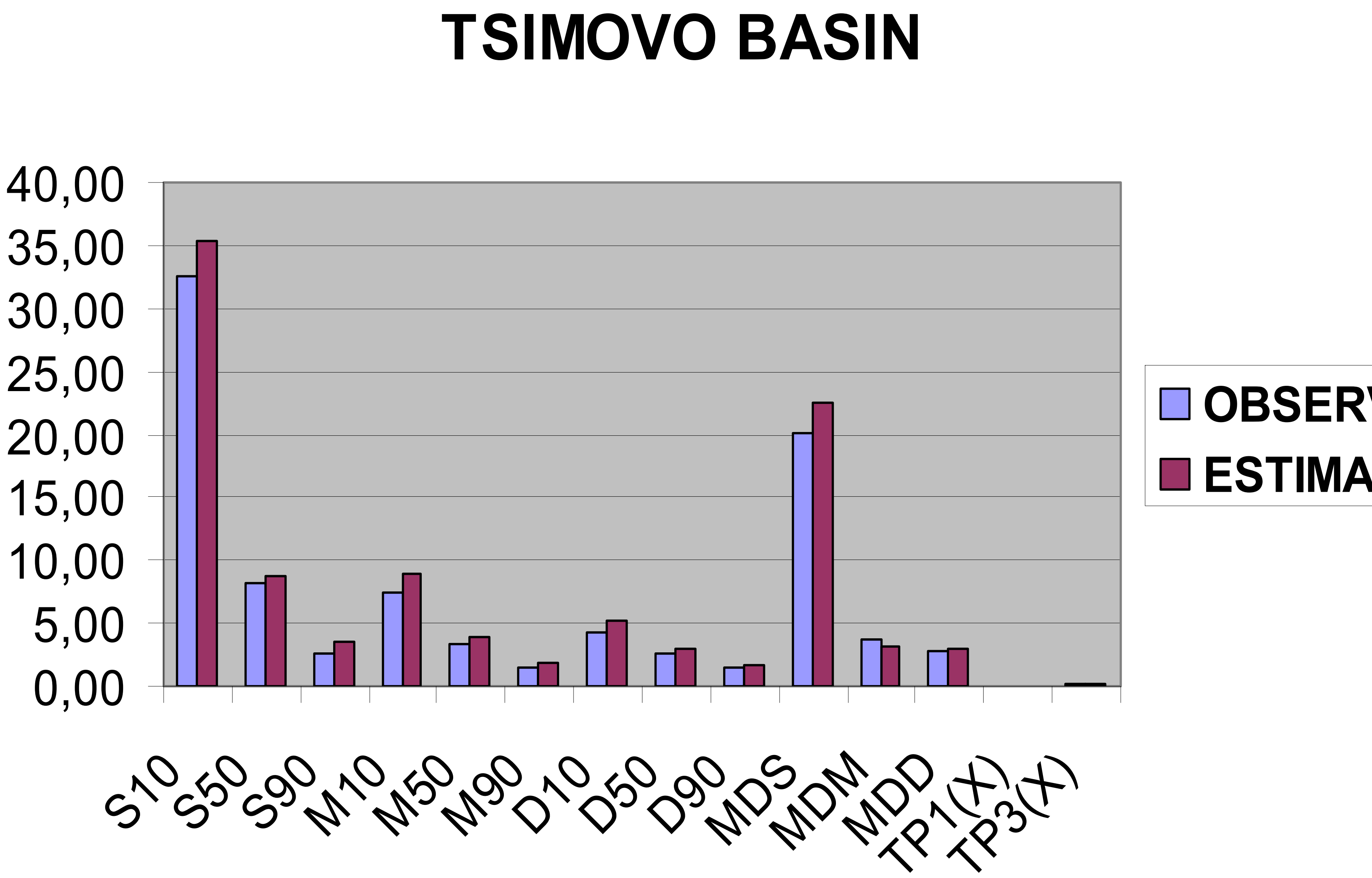
MESOCHORA BASIN



VERIFICATION RESULTS

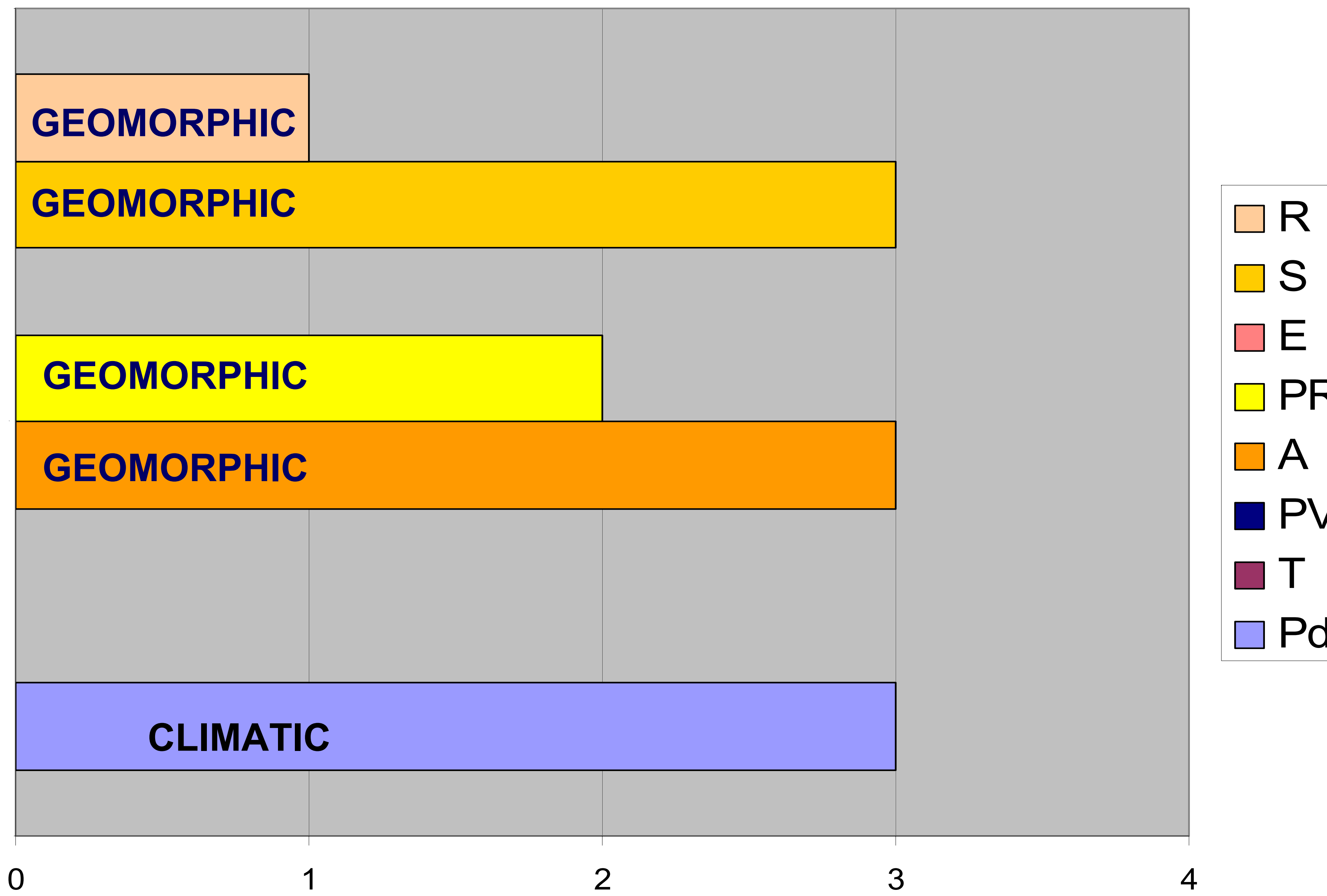
MEAN PREDICTION ERROR

ε (%)= [(Yi-Ỹi)/Yi] =21,55 %

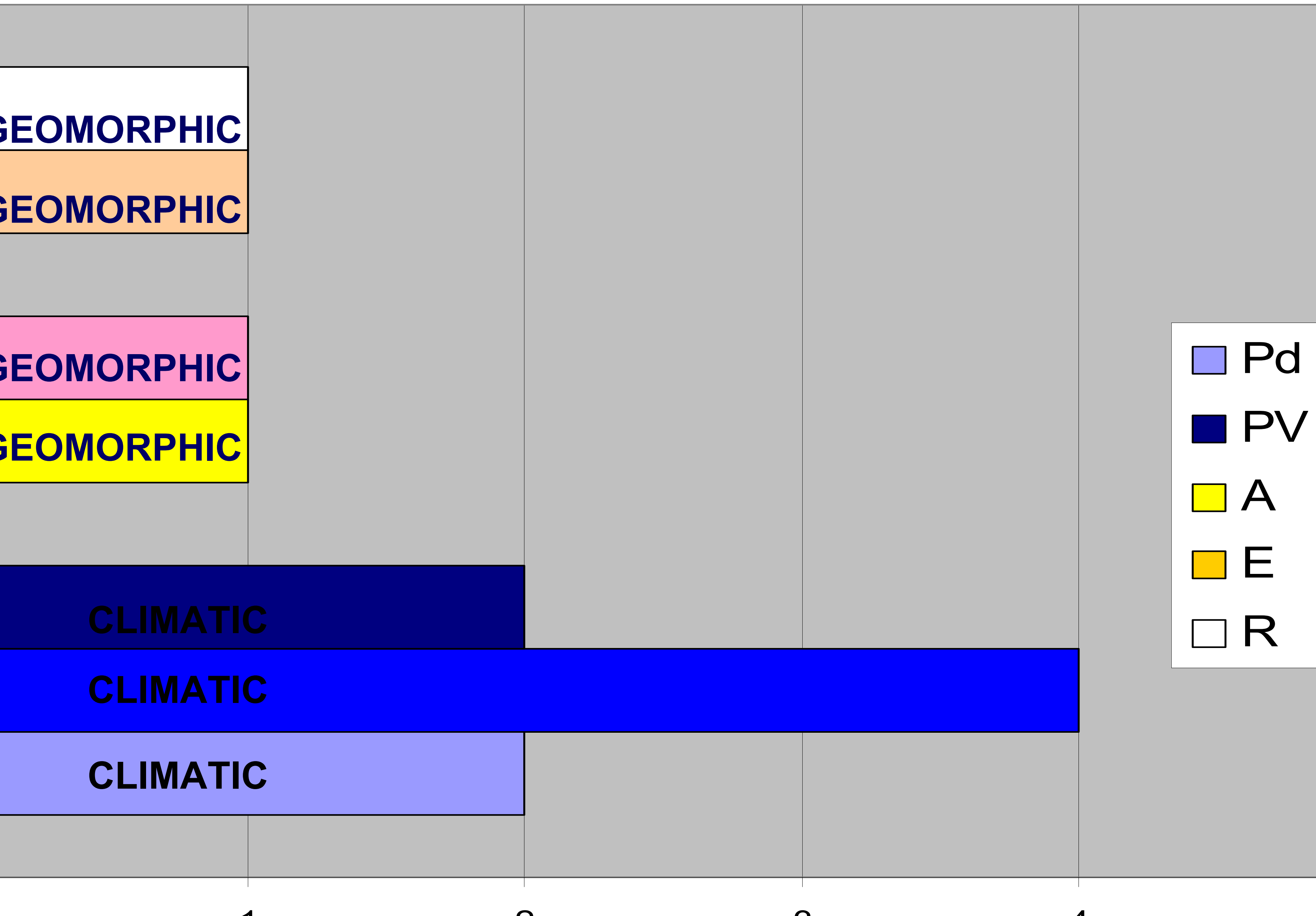


ought acteristics	Significant Variable	P_d	T	P_V	A	PR	E	S
erity S	1η	2			1	2		
	2η	1			1			2
	3η				1			1
	Sum	3	0	0	3	2	0	3
itude M	1η				3	1		
	2η	1		1		1	1	
	3η	1	1					1
	Sum	2	1	1	3	2	1	1
tion D	1η	2	2	1			0	
	2η		2	2				
	3η				1	1		1
	Sum	2	4	2	1	1	0	1
ination ability TP	1η		1		1			
	2η			1		1		

Most significant variables – Drought severity S equations



Most significant variables – Drought duration D equations



Conclusions 1

- The verification results in two waterbasins of the study regio proved that the constructed models function satisfactorily w
- Moreover, variables that are strongly related to precipitation or $\mathbf{P_V}$, they are steadily significant in all the drought express - agreement with similar studies conducted in California (Pa et al., 1985) and Greece (Mimikou et al, 1993).
- Of the drought indices examined, **S** and **M** are determined mainly by **geomorphic** indices. On the other hand, **D** and **T** appear most closely related to **climatic factors**, although **T** seems wider than **D** in its expressions, in terms of independ variables -agreement with Mimikou, Paulson.
- The explanatory variables the most frequently occurring in t regression equations as being first, second or third most significant in order of importance are **A**, $\mathbf{P_d}$ and **T.**

Conclusions 2

- **M_{90}** & **MDS**: **Alternative** regression equations derived. Electio according to data availability
- In comparison to similar studies conducted in California (Paulso al., 1985) and Greece (Mimikou et al, 1993), more precise estimating accuracy was achieved regarding **S**, **M** and especial **MDS** while a relation for **D** proved here acceptable. Compariso made using the SE of estimate.
- In addition, **S**, **M** seem to remain quite unaffected by a temperature increase, while duration characteristics (**D**, **TP**) se to be more sensitive. That is, the droughts would tend to have more adverse characteristics in terms of duration, due to the greenhouse effect.
- A climate change in the precipitation pattern towards more ext phenomena (**P_d** increase) is estimated to result in more advers effects in terms of increasing sensitivity regarding **S**.

Study prospects

- Water consumption as an input to regional model:
  - Domestic demand
  - Agricultural demand
- Advanced regression tools:
  - Partial least squares
  - Best subsets
- Application to further sets of riverbasins for equatio extraction
- Addition independent variables
  - Runoff coefficient
  - Catchment's land cover (urbanization, forests)

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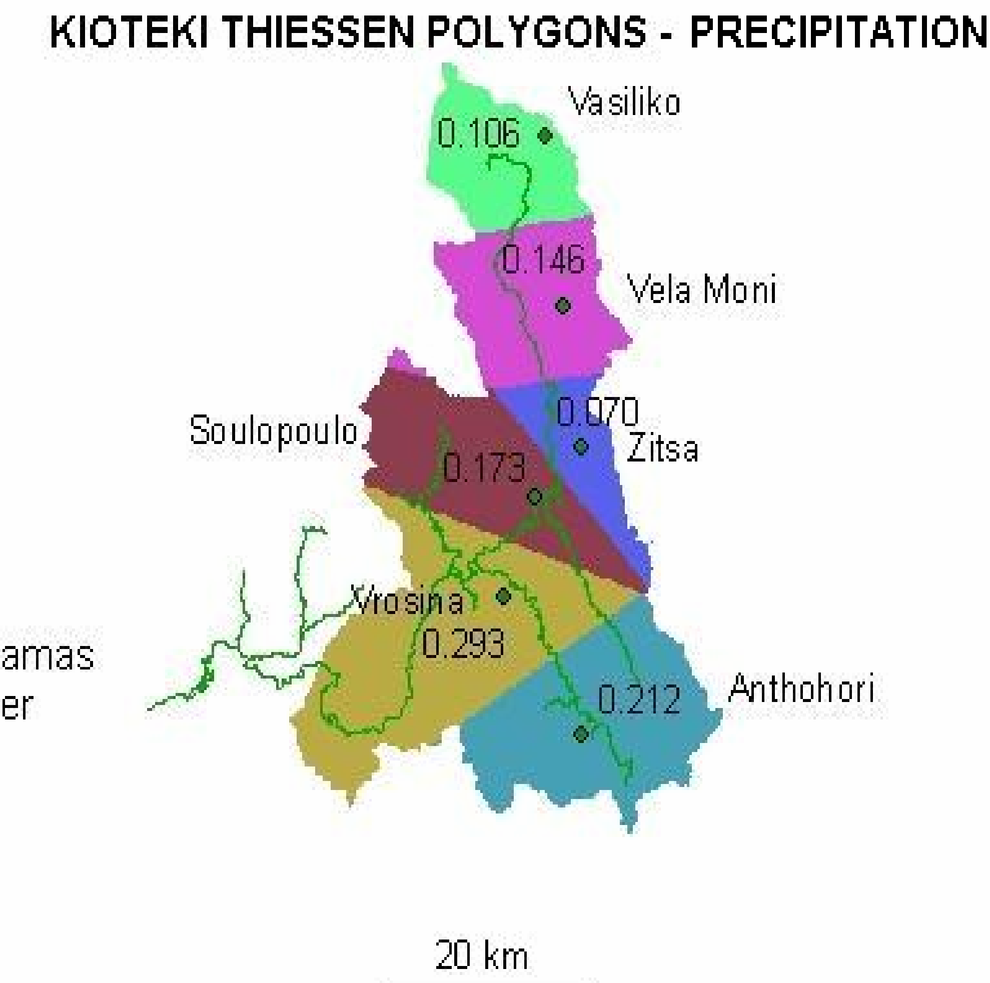
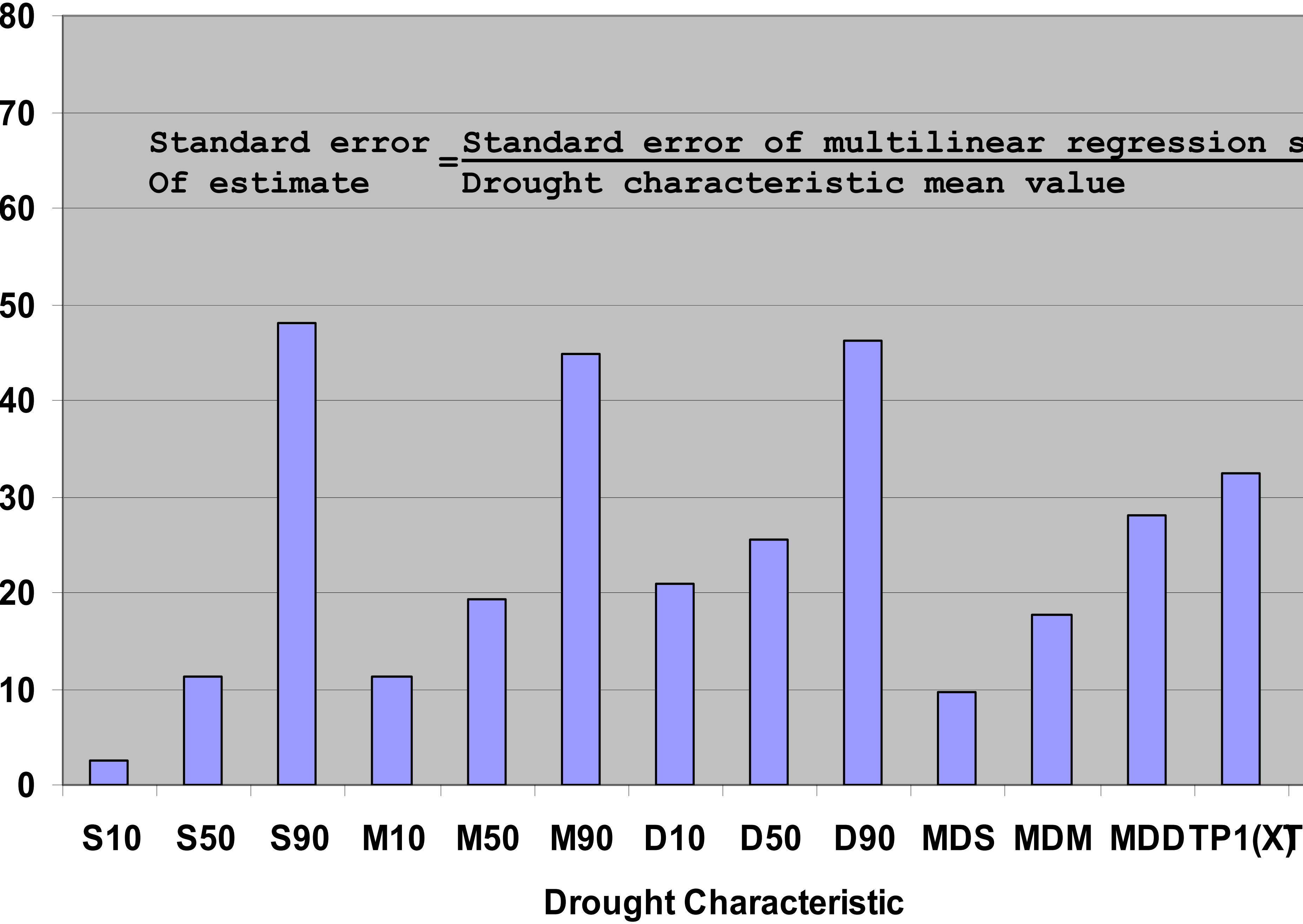
Thank you

Questions

Thiessen Polygons- Precipitation



Regression's Standard Error of Estimate



DEPENDENT VARIABLES

	Pd	T	PV	A	PR	E	S
	0.130						
	-0.120	**-0.261**					
	0.562	**-0.033**	**0.453**				
	0.668	**0.086**	**0.328**	**0.930**			
	0.501	**-0.740**	**-0.202**	**0.259**	**0.404**		
	-0.371	**0.325**	**-0.135**	**-0.385**	**-0.247**	**-0.157**	

egression Analysis: TP1(X) versus T, PV, E

he regression equation is

P1(X) = - 0.953 + 1.16 T + 0.394 PV - 0.134 E (m)

redictor	Coef	SE Coef	T	P
onstant	-0.9534	0.8188	-1.16	0.282
	1.1575	0.3110	3.72	0.007
V	0.3943	0.1571	2.51	0.040
	-0.13382	0.06969	-1.92	0.096

= 0.132639   R-Sq = 74.2%   R-Sq(adj) = 63.1%

nalysis of Variance

ource	DF	SS	MS	F	P
egression	3	0.35367	0.11789	6.70	0.018
esidual Error	7	0.12315	0.01759		
otal	10	0.47682			

ource	DF	Seq SS
	1	0.15008
V	1	0.13872
(m)	1	0.06486

e regression equation is

.(LN) = - 14.6 + 7.49 T + 3.24 PV

edictor	Coef	SE Coef	T	P
nstant	-14.602	7.997	-1.83	0.105
	7.486	3.375	2.22	0.057
	3.236	1.693	1.91	0.092

= 1.44406   R-Sq = 45.7%   R-Sq(adj) = 32.

alysis of Variance

urce	DF	SS	MS	F	
gression	2	14.061	7.030	3.37	0.0
sidual Error	8	16.682	2.085		
tal	10	30.743			

urce	DF	Seq SS
	1	6.444
	1	7.617

	1	2	3	4	5	6	7
t	-2,896	-2,899	-3,660	-2,972	-2,384	-2,996	-3,291
	0,64	0,63	0,66	0,32			
	0,95	1,26	1,43	0,92			
	0,442	0,297	0,227	0,398			
	-0,31	-0,30					
	-0,48	-0,59					
	0,680	0,596					
	-0,49	-0,49	-0,44	-0,46	-0,61	-0,53	-0,60
	-1,13	-1,57	-1,60	-1,65	-2,73	-2,58	-2,37
	0,376	0,214	0,184	0,159	0,034	**0,036**	**0,046**
	1,000	0,997	0,931	0,866	0,931	0,506	0,425
	1,35	1,93	2,02	1,86	2,05	7,26	5,67
	0,309	0,149	0,113	0,122	0,086	**0,000**	**0,000**
	-1,00	-1,00	-0,94	-0,72	-0,65		
	-0,91	-1,26	-1,31	-1,02	-0,95		
	0,458	0,296	0,262	0,354	0,380		
	-0,00						
	-0,01						
	0,995						
	0,699	0,696	0,702	0,231	0,231	0,162	
	1,00	1,43	1,58	2,26	2,29	2,32	
	0,421	0,247	0,189	0,073	0,062	**0,054**	
	-0,41	-0,41	-0,44				
	-0,66	-0,90	-1,09				
	0,578	0,433	0,337				
	0,227	0,186	0,170	0,173	0,171	0,170	0,211

Altitude (m) Temperature (°C) Mean annual rainfall(mm)Area (ha) Perimeter (Periarea (km)

Estimated as the ratio of the watershed area to the perimeter

Aspect (degrees) It was computed using the azimuth

eam slope (%) Computed as the ratio between the elevation at the point where main stream i

first order and its length

Watershed slope (%) Computed as the fraction of slope and the length of watershed

Watershed length (km) Measured considering a plane parallel to the main stream

Form factor The ratio between measured area and watershed length

Lenwid This new variable was defined as the ratio between

watershed length and watershed width described above

Length of stream (km) Relief ratio Land use (ordinal)

Soil texture (ordinal) Soil textures were classified according to U.S. Department

of Agricultural textural classification triangle

Soil permeability(ordinal) The soil permeability of all watersheds was

classified in eleven categories

UNESCO Index of aridity

It is computed as the ratio of annual precipitation and potential evapotranspiration

Horton form factor (dimensionless)

It is the dimensionless ratio of watershed area A to the

square of watershed length

Thiessen Polygons- Temperature