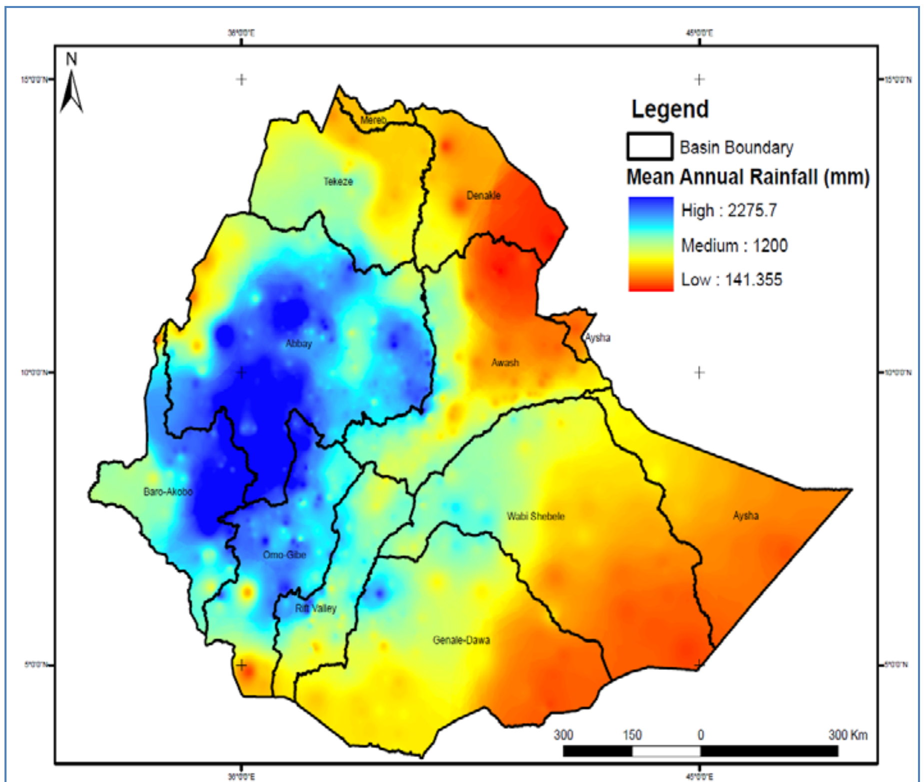
Chapter Two : Precipitation data analysis

- Rainfall Data Processing and Quality Test
- Mean Areal Precipitation:
  - Thiessen polygons - Isohyets - IWD Methods
  - Kriging and Co-Kriging
  - Orographic Influences and their analysis
- Design Storms
  - Design Hyetographs
  - Storm event-based analysis
  - IDF-based analysis
- Estimated Limiting Storms

- **Rainfall in Ethiopia is the results of multi weather systems**
  - Sub Tropical Jet (STJ)
  - Inter Tropical Convergence Zone (ITCZ)
  - Read Sea Convergence Zone (RSCZ)
  - Tropical Easterly Jet (TEJ) and Somalia Jet (NMA, 1996).
- **The rainfall in the country is characterized by**
  - seasonal and inter-annual variability.
  - topography variability of the country
- **It makes the rainfall system of the country more complex.**

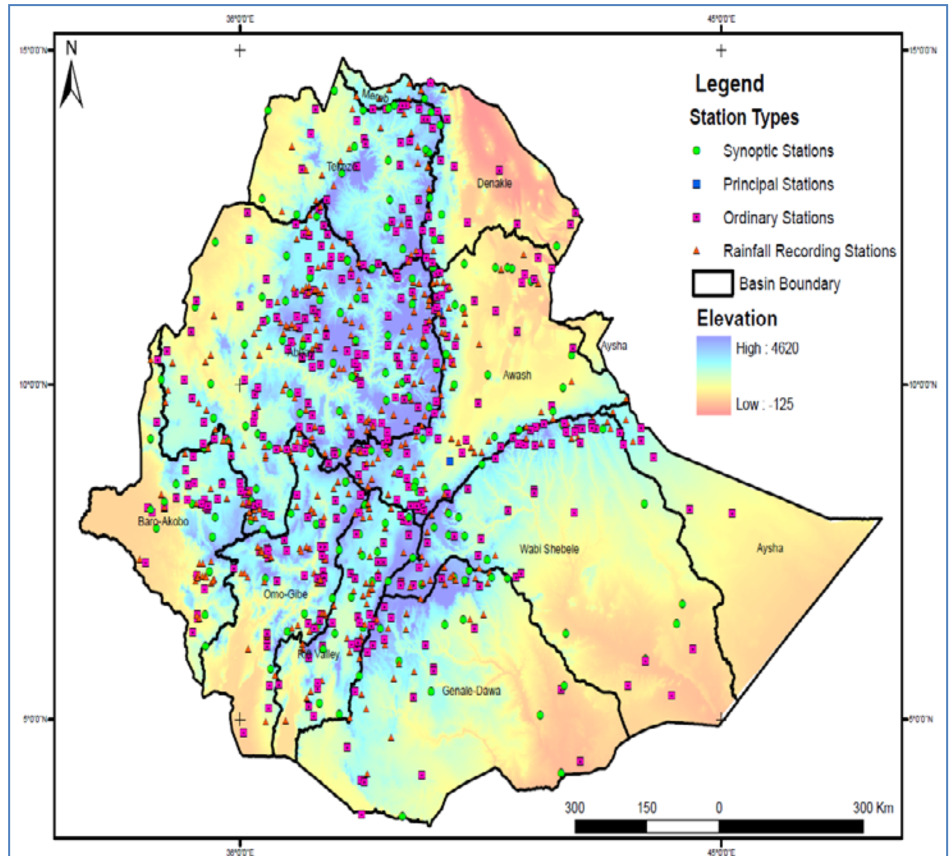
Magnitude

- southeast, east and northeast **lower < 200mm**
- central and north west border **medium 800 – 1200**
- central and west highlands **High up to 2200mm**.



Meteorological Observation data

- There about 1260
- Regional office
  - Adam
  - Jijiga
  - Hawasa
  - Assosa
  - BahirDar
  - Mekele
  - Kombolcha
  - etc ….



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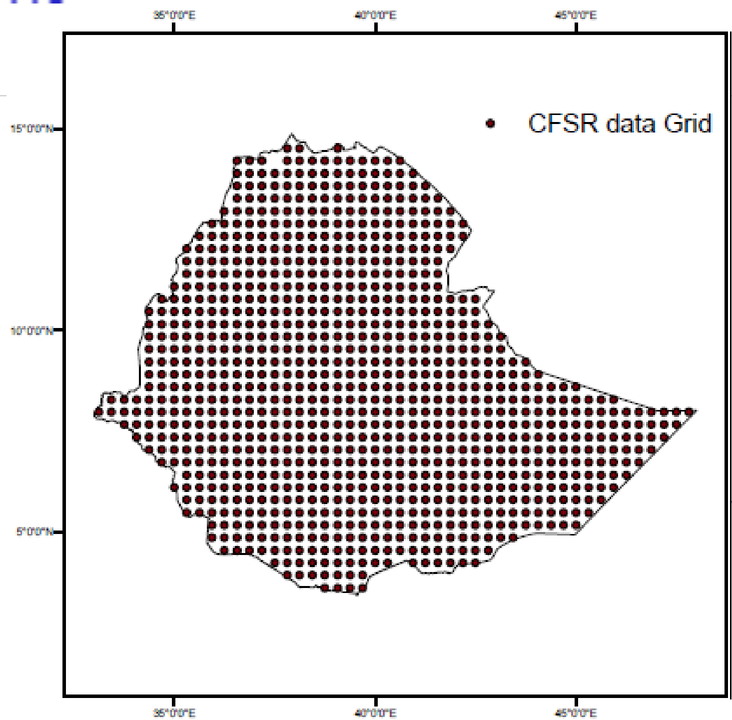
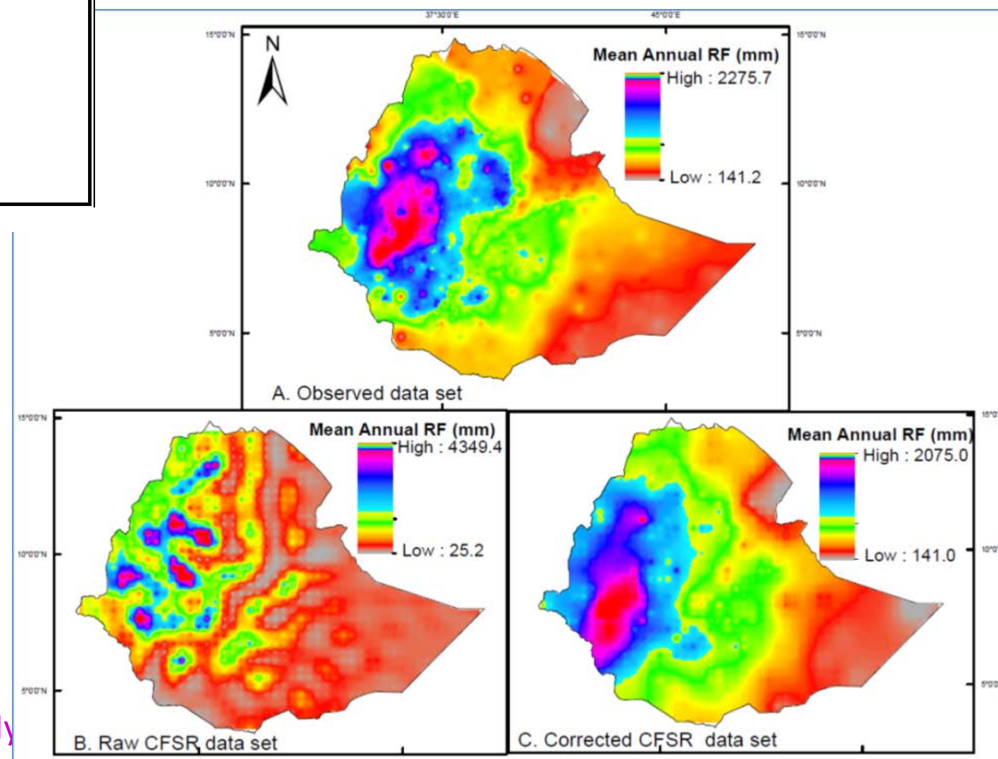
CFSR reanalysis data set





Satellite Data set (RFE and TERMM)

Rainfall estimates (*RFE*) - FEWS NET *Data* Portals – USGS

- http://www.cpc.ncep.noaa.gov/products/fews/rfe.shtml
- Starts from 2001
- Spatial Resolution 8km
- Temporal data set (Daily, Decadal, monthly and Annually)

Tropical Rainfall Measuring Mission (*TRMM*)

- http://disc.sci.gsfc.nasa.gov/airquality/services/opendap/TRMM/trmm.shtml
- Starts from 1998
- Spatial Resolution 8km
- Temporal data set (Daily, Decadal, monthly and Annually)

Global Data Sources

GPCC Global Precipitation Climatology Centre

- http://www.esrl.noaa.gov/psd/data/gridded/data.gpcc.html

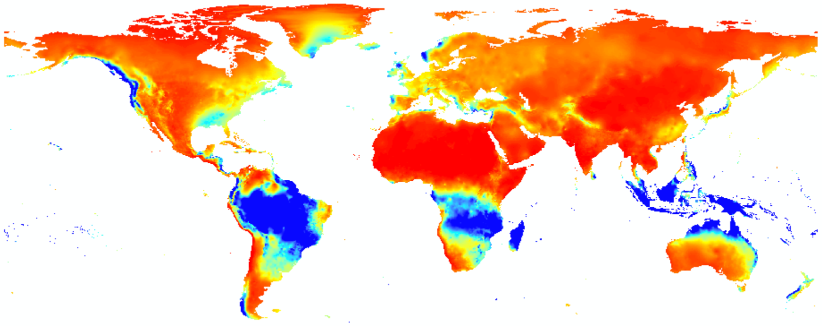
Temporal Coverage:

- Monthly values 1901/01 through 2010 (full V6).

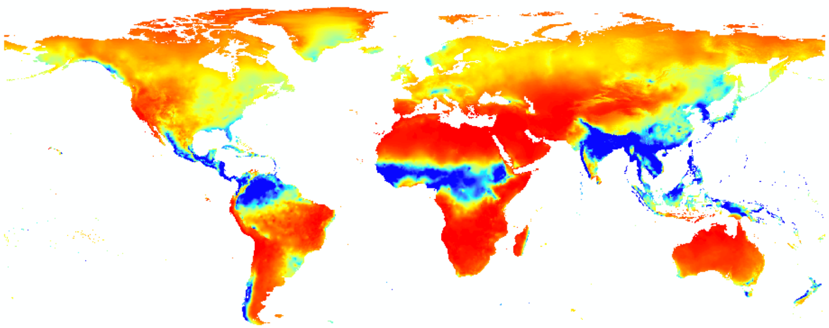
Spatial Coverage:

- 0.5 degree latitude x 0.5 degree longitude
- 1.0 degree latitude x 1.0 degree longitude
- 2.5 degree latitude x 2.5 degree longitude

January Rainfall



August Rainfall



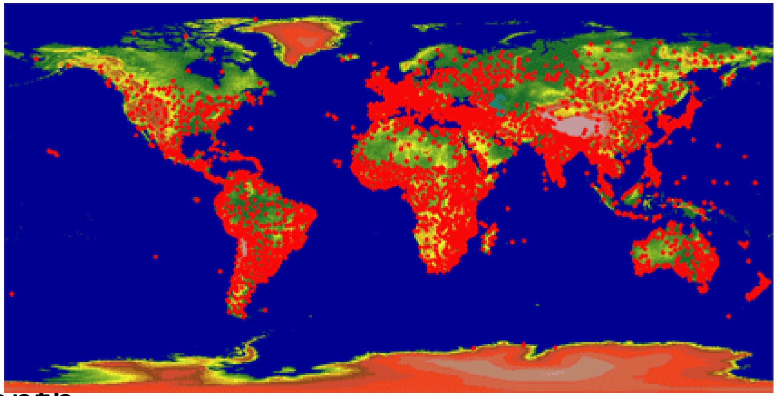
Global Data Sources

CLIMWAT 2.0 for CROPWAT

http://www.fao.org/nr/water/infores_databases_climwat.html

CLIMWAT provides long-term monthly mean values of seven climatic parameters, namely:

- Mean daily maximum temperature in °C
- Mean daily minimum temperature in °C
- Mean relative humidity in %
- Mean wind speed in km/day
- Mean sunshine hours per day
- Mean solar radiation in MJ/m2/day
- Monthly rainfall in mm/month
- Monthly effective rainfall in mm/month
- Reference evapotranspiration calculated with the Penman-Monteith method in mm/day.



Optimum number of rain gauges

Region Type	Range of norms for min network [km²/gauge]	Range of provisional norms in difficult conditions [km²/gauge]
I	600 – 900	900 – 3000
IIa	100 – 250	250 – 1,000
IIb	25	
III	1500 – 10,000	

- The optimum number of rain gauges (N) can be obtained using statistical methods :

$$N = \left[\frac{C_v}{E} \right]^2$$

Where: Cv = Coefficient of variation of rainfall based on the existing rain gauge stations;

E = Allowable percentage error in the estimate of basic mean rainfall

Optimum number of rain gauges

Example 3.1:

There are four rain gauge stations existing in the catchment of a river. The average annual rainfall values at these stations are 800, 620, 400 and 540 mm respectively.

(a) Determine the optimum number of rain gauges in the catchment, if it is desired to limit error in the mean value of rainfall in the catchment to 10%.

(b) How many more gauges will then be required to be installed?

Optimum number of rain gauges

Solution

Stations	RF(mm)				
1	800		CV	0.28	
2	620		E	0.1	
3	400		N	7.84	~8
4	540				
sum	2360		Additional	8-4 =	4
Average	590				
SD	166.93				
CV	0.28				

Estimation of Missing data

Arithmetic Mean Method

$$P_x = \frac{1}{M}\left[P_1 + P_2 + P_3 \ldots. + P_m\right]$$

Normal-Ratio Method

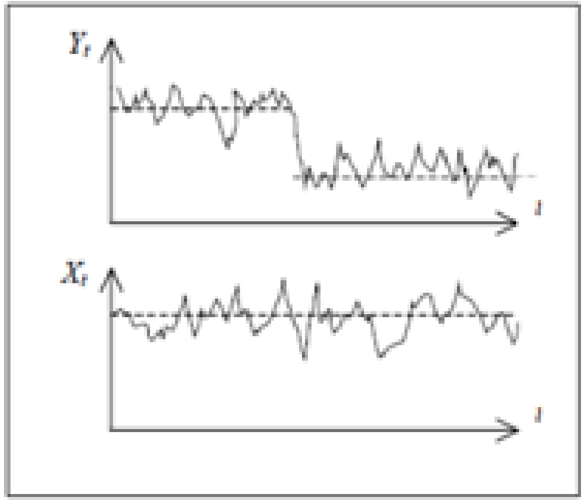
$$P_x = \frac{N_x}{M}\left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} \ldots\ldots. + \frac{P_m}{N_m}\right]$$

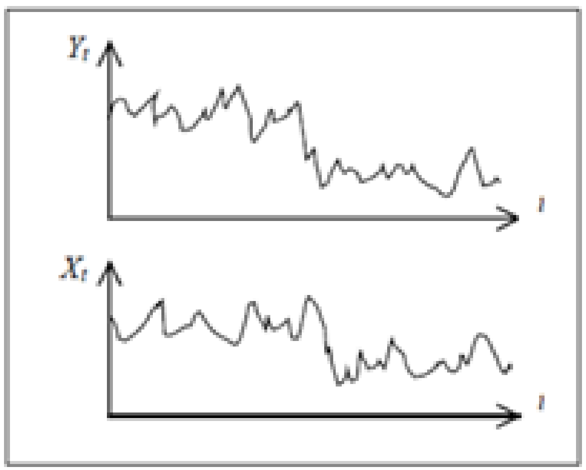
Inverse Distance Method

$$Px = \sum_{1}^{n} w_i p_i$$ **where** $$w_i = \frac{1/d_i^2}{\sum_{1}^{4} 1/d_i^2}$$

Multiple Regression : **Develop fitting equation with different stations in the same rainfall regimes Equating**

Data Inconsistency Test





Double Mass Curve

Procedure

- The mean annual (monthly) data of the station X and the average rainfall of the base stations covering a long period is arranged in the reverse chronological order
- The accumulated rainfall of the station X (i.e., ΣPx) and the accumulated values of the average of the base stations (i.e., ΣPav) are calculated starting from the latest record.
- Plot the accumulated values of Station X against the accumulated value of base stations
- A break in the slope of the resulting plot indicates a change in the precipitation regime of station X.
- The precipitation values at station X beyond the period of change of regime is corrected by using the relation

$$P_{cx} = P_x \frac{M_c}{M_a}$$

Data Inconsistent Test

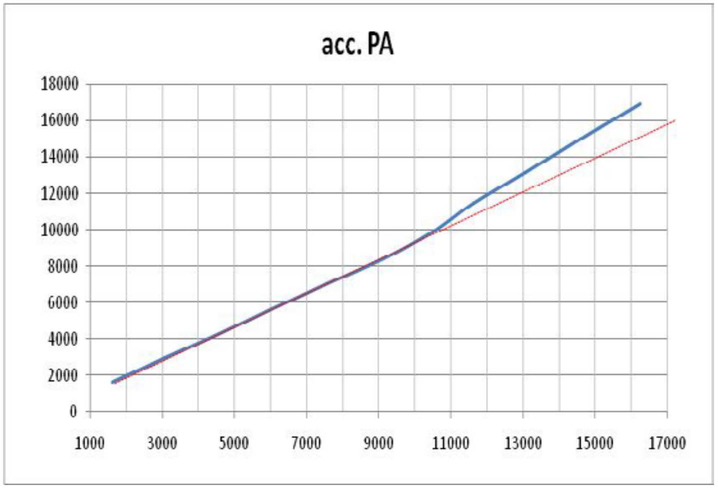
Example

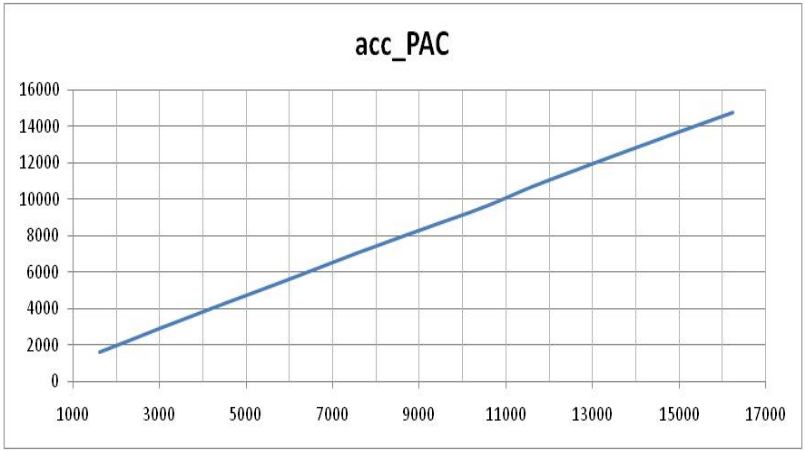
Test the consistency of the 10 year data of annual rainfall measured at station A. Rainfall data for the station A and the average annual rainfall measured at group of Eight stations located in the meteorologically homogonous region are given below in the table.

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Rainfall Station A (mm)	1880	1850	1720	1550	1480	1420	1400	1300	1370	1300	1630
Avg. Rainfall of 8 Stations (mm)	1640	1550	1430	1150	1350	1580	1550	1430	1500	1450	1610

Data Inconsistent Test : **Solution**

Year	PA(mm)	PAvg. (mm)	acc. Pavg	acc. PA			Cor.PA	acc_P_{AC}
2010	1630	1610	1610	1630			1630	1630
2009	1300	1450	3060	2930			1300	2930
2008	1370	1500	4560	4300	Mc =	0.9	1370	4300
2007	1300	1430	5990	5600			1300	5600
2006	1400	1550	7540	7000			1400	7000
2005	1420	1580	9120	8420	k	0.75	1420	8420
2004	1480	1350	10470	9900			1103	9523
2003	1550	1150	11620	11450	Ma	1.21	1155.2	10678
2002	1720	1430	13050	13170			1281.8	11960
2001	1850	1550	14600	15020			1378.7	13339
2000	1880	1640	16240	16900			1401.1	14740





Area rainfall

- Thiessen polygons - Isohyets - IWD Methods
- Kriging and Co-Kriging
- Orographic Influences and their analysis

KRIGIG

- Kriging is developed the method empirically for estimating amounts of gold in bodies of rock from fragmentary information in the mines of South Africa (D. G. Krige, 1951, 1966).
- Kriging is a general term that embraces several estimation procedures (Krige et al., 1989)
- What makes kriging unique and highly commendable compared with other methods of estimation is that its estimates are unbiased and have minimum variance
  - punctual kriging
  - Simple kriging
  - cokriging
  - universal kriging

THEORY

- The general statistical approach to prediction embodied in regionalized variable theory combines a deterministic component, such as that of trend surface analysis, with a stochastic one, so that the spatial variation in an attribute is expressed by

$$z(\mathbf{x}) = \sum a_k f_k(\mathbf{x}) + \varepsilon(\mathbf{x}),$$

Stochastic Element

Deterministic Element

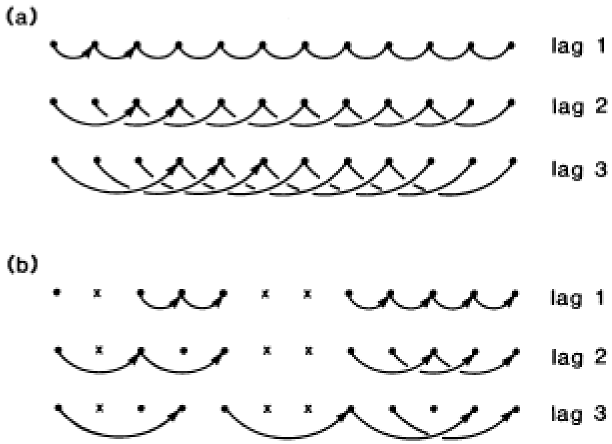
$$z(\mathbf{x}) = \mu_v + \varepsilon(\mathbf{x}),$$

$$\mathrm{var}[\varepsilon(\mathbf{x}) - \varepsilon(\mathbf{x}+\mathbf{h})] = \mathrm{E}[\{\varepsilon(\mathbf{x}) - \varepsilon(\mathbf{x}+\mathbf{h})\}^2] = 2\gamma(\mathbf{h})$$

Where h is a vector, the lag that separates the two places X and X+h

ESTIMATING THE VARIOGRAM

- The variogram is central to geostatistics.
- it is essential for optimal estimation and interpolation by kriging
- The variogram describes the magnitude, spatial scale and general form of the variation. It can indicate whether the data are second-order stationary or just intrinsi
- The semi-variance for any given lag h in one, two or three dimensions is readily estimated from sample data.
- The variogram describes the magnitude, spatial scale and general form of the variation. It can indicate whether the data are second-order stationary or just intrinsi
- Several points must be considered when estimating and interpreting the variogram. The sample variogram of any property in a given region is not unique



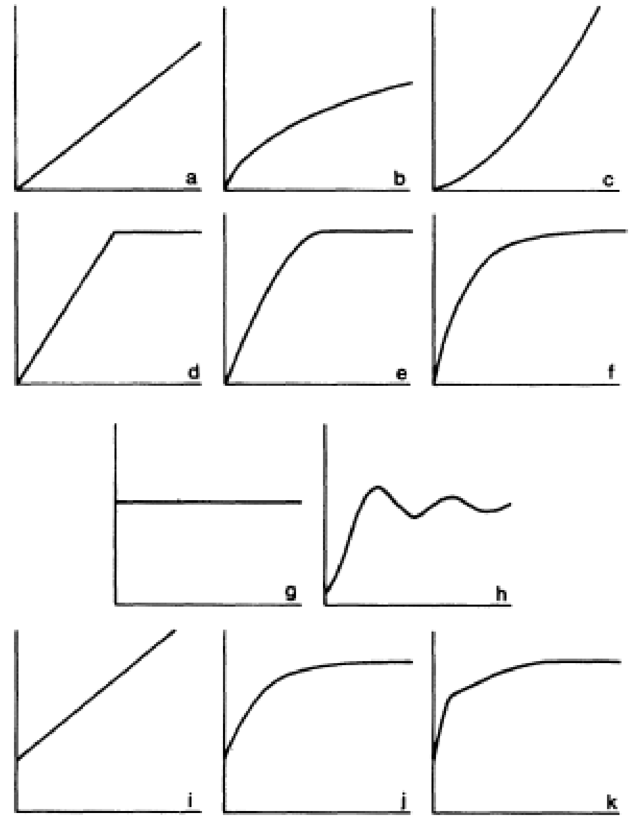
FORMS AND MODELS OF VARIOGRAMS

- An ordered set of values, y(h), a sample variogram, when plotted displays the average change of a property with changing lag

- They fall into two broad groups
  - unbounded (Fig. 2a, b and c)
  - bounded

- Unbounded models have no finite a priori variance and the intrinsic hypothesis only holds.

- Bounded or transitive models reach an upper bound, known as the sill



Project Assignment : Section one

- Select one basin of the country and develop Annual surface rainfall for the basin using Co-kriging
- Hint
  - Access location and point rainfall data from NMA
  - Select station that can address your basin
  - Use 90m dem for elevation input

Design Storm

- Design storm:– precipitation pattern defined for use in the design of hydrologic system serves as an input to the hydrologic system

- It Can by described by:
  1. Hyetograph (time distribution of rainfall)
  2. Isohyetal map (spatial distribution of rainfall)

Design Point Storms

- Historic data of precipitation is available
- Precipitation data are converted to different durations
- Annual maximum precipitation for a given duration is selected for each year
- Frequency analysis is performed to derive design precipitation depths for different return periods
- The depths are converted to intensities by dividing by precipitation durations

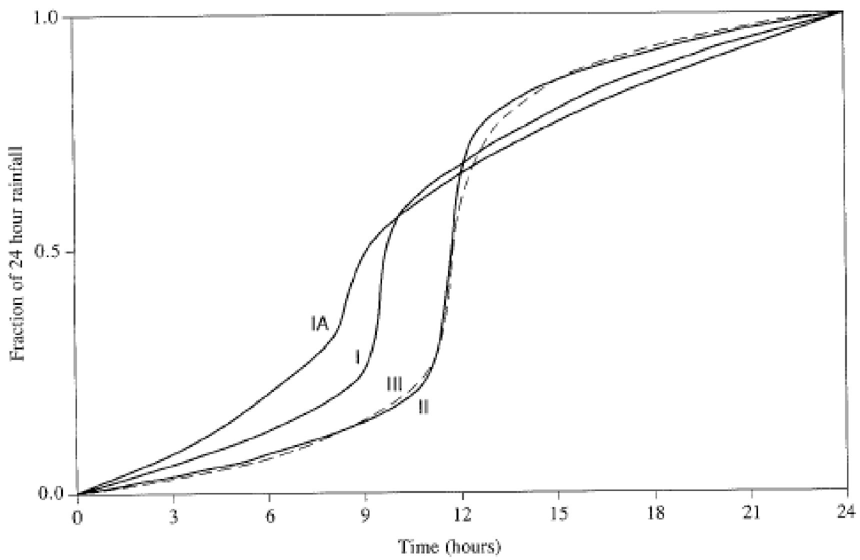
Design Precipitation Hyetographs

- Most often hydrologists are interested in precipitation hyetographs and not just the peak estimates.

- Techniques for developing design precipitation hyetographs
  1. SCS method
  2. Triangular hyetograph method
  3. Using IDF relationships (Alternating block method)

SCS Method

- SCS (1973) adopted method similar to DDF to develop dimensionless rainfall temporal patterns called type curves for four different regions in the US.
- SCS type curves are in the form of percentage mass (cumulative) curves based on 24-hr rainfall of the desired frequency.
- If a single precipitation depth of desired frequency is known, the SCS type curve is rescaled (multiplied by the known number) to get the time distribution.
- For durations less than 24 hr, the steepest part of the type curve for required duration is used



SCS Method Steps

- Given T_d and frequency/T, find the design hyetograph

1. Compute P/i (from DDF/IDF curves or equations)

2. Pick a SCS type curve based on the location

3. If T_d = 24 hour, multiply (rescale) the type curve with P to get the design mass curve

   - If T_d is less than 24 hr, pick the steepest part of the type curve for rescaling

4. Get the incremental precipitation from the rescaled mass curve to develop the design hyetograph

SCS type curves for Texas (II&III)

SCS 24-Hour Rainfall Distributions

T (hrs)	Fraction of 24-hr rainfall	
	Type II	Type III
0.0	0.000	0.000
1.0	0.011	0.010
2.0	0.022	0.020
3.0	0.034	0.031
4.0	0.048	0.043
5.0	0.063	0.057
6.0	0.080	0.072
7.0	0.098	0.089
8.0	0.120	0.115
8.5	0.133	0.130
9.0	0.147	0.148
9.5	0.163	0.167
9.8	0.172	0.178
10.0	0.181	0.189
10.5	0.204	0.216
11.0	0.235	0.250

SCS 24-Hour Rainfall Distributions

T (hrs)	Fraction of 24-hr rainfall	
	Type II	Type III
11.5	0.283	0.298
11.8	0.357	0.339
12.0	0.663	0.500
12.5	0.735	0.702
13.0	0.772	0.751
13.5	0.799	0.785
14.0	0.820	0.811
15.0	0.854	0.854
16.0	0.880	0.886
17.0	0.903	0.910
18.0	0.922	0.928
19.0	0.938	0.943
20.0	0.952	0.957
21.0	0.964	0.969
22.0	0.976	0.981
23.0	0.988	0.991
24.0	1.000	1.000

Example – SCS Method

- Find - rainfall hyetograph for a 25-year, 24-hour duration SCS Type-III storm in Harris County using a one-hour time increment a = 81, b = 7.7, c = 0.724 (from Tx-DOT hydraulic manual)

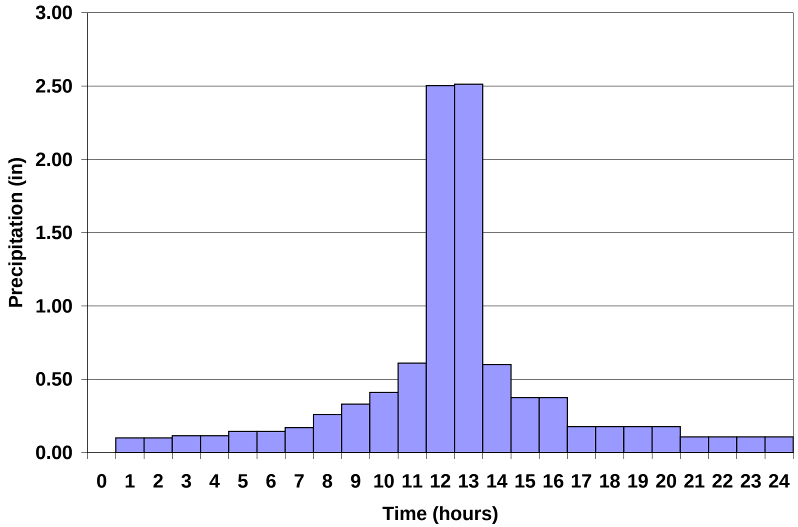
$$i = \frac{a}{(t+b)^c} = \frac{81}{(24*60+7.7)^{0.724}} = 0.417\, in/hr$$

$$P = i * T_d = 0.417\, in/hr * 24\, hr = 10.01 in$$

- Find
  - Cumulative fraction - interpolate SCS table
  - Cumulative rainfall = product of cumulative fraction * total 24-hour rainfall (10.01 *in*)
  - Incremental rainfall = difference between current and preceding cumulative rainfall

TxDOT hydraulic manual is available at:
http://manuals.dot.state.tx.us/docs/colbridg/forms/hyd.pdf

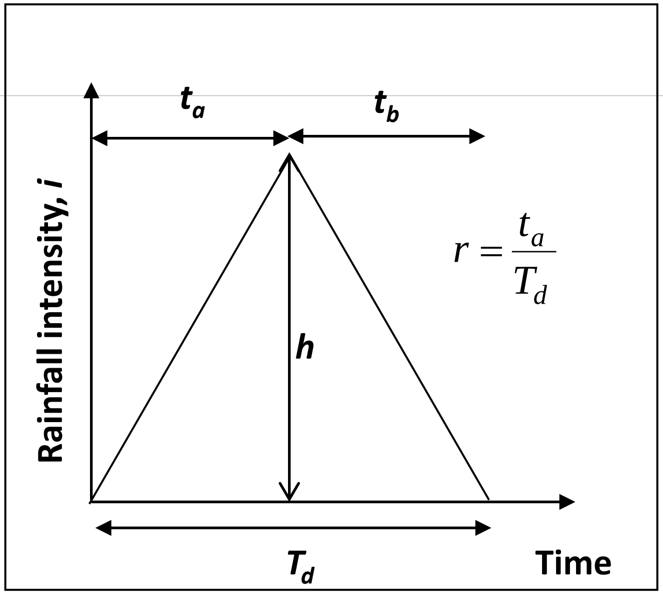
SCS – Example (Cont.)



If a hyetograph for less than 24 needs to be prepared, pick time intervals that include the steepest part of the type curve (to capture peak rainfall). For 3-hr pick 11 to 13, 6-hr pick 9 to 14 and so on.

Time	Cumulative Fraction	Cumulative Precipitation	Incremental Precipitation
(hours)	Pt/P24	Pt (in)	(in)
0	0.000	0.00	0.00
1	0.010	0.10	0.10
2	0.020	0.20	0.10
3	0.032	0.32	0.12
4	0.043	0.43	0.12
5	0.058	0.58	0.15
6	0.072	0.72	0.15
7	0.089	0.89	0.17
8	0.115	1.15	0.26
9	0.148	1.48	0.33
10	0.189	1.89	0.41
11	0.250	2.50	0.61
12	0.500	5.01	2.50
13	0.751	7.52	2.51
14	0.811	8.12	0.60
15	0.849	8.49	0.38
16	0.886	8.87	0.38
17	0.904	9.05	0.18
18	0.922	9.22	0.18
19	0.939	9.40	0.18
20	0.957	9.58	0.18
21	0.968	9.69	0.11
22	0.979	9.79	0.11
23	0.989	9.90	0.11
24	1.000	10.01	0.11

Triangular Hyetograph Method



$$P = \frac{1}{2} T_d h$$

$$h = \frac{2P}{T_d}$$

T_d: hyetograph base length = precipitation duration

t_a: time before the peak

r: storm advancement coefficient = t_a/T_d

t_b: recession time = $T_d - t_a = (1-r)T_d$

- **Given T_d and frequency/T, find the design hyetograph**
  1. Compute P/i (from DDF/IDF curves or equations)
  2. Use above equations to get t_a, t_b, T_d and h (*r* is available for various locations)

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Triangular hyetograph - example

Find - rainfall hyetograph for a 25-year, 6-hour duration in Harris County. Use storm advancement coefficient of 0.5.
a = 81, b = 7.7, c = 0.724 (from Tx-DOT hydraulic manual)

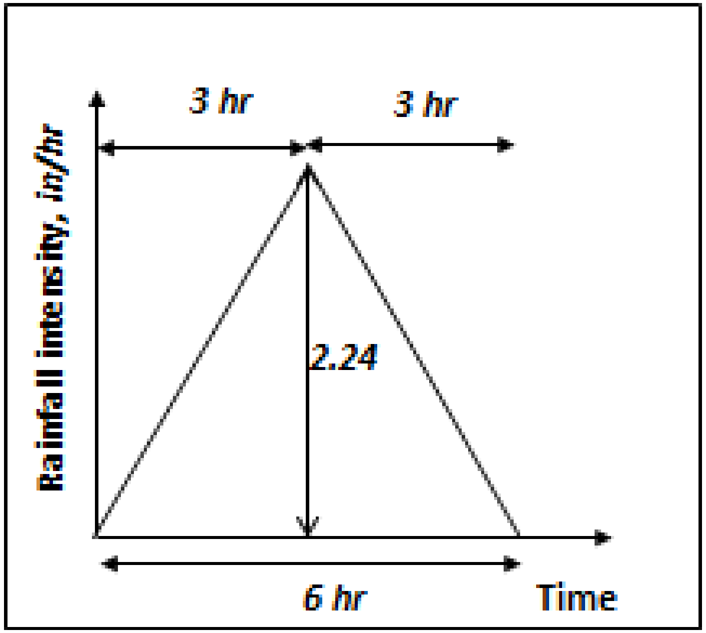
$$i = \frac{a}{(t+b)^c} = \frac{81}{(6*60+7.7)^{0.724}} = 1.12\, in/hr$$

$$P = i*6 = 1.12\, in/hr * 6\, hr = 6.72\ \ in$$

$$h = \frac{2P}{T_d} = \frac{2\times 6.72}{6} = \frac{13.44}{6} = 2.24\ \ in/hr$$

$$t_a = rT_d = 0.5\times 6 = 3\ \ hr$$

$$t_b = T_d - t_a = 6-3 = 3\ \ hr$$



Alternating block method

Given T_d and T/frequency, develop a hyetograph in Δt increments

1. Using T, find i for Δt, $2\Delta t$, $3\Delta t$,…$n\Delta t$ using the IDF curve for the specified location

2. Using i compute P for Δt, $2\Delta t$, $3\Delta t$,…$n\Delta t$. This gives cumulative P.

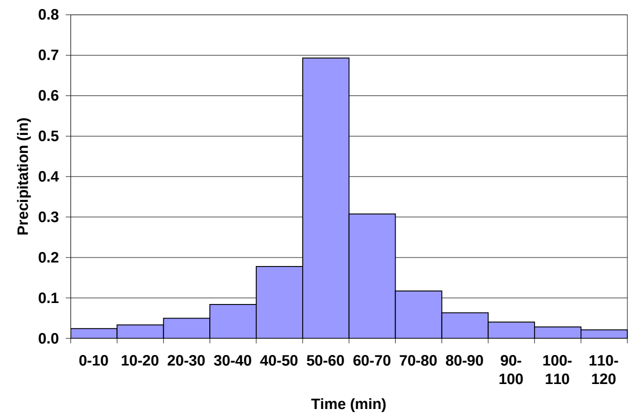
3. Compute incremental precipitation from cumulative P.

4. Pick the highest incremental precipitation (maximum block) and place it in the middle of the hyetograph. Pick the second highest block and place it to the right of the maximum block, pick the third highest block and place it to the left of the maximum block, pick the fourth highest block and place it to the right of the maximum block (after second block), and so on until the last block.

Example: Alternating Block Method

Find: Design precipitation hyetograph for a 2-hour storm (in 10 minute increments) in Denver with a 10-year return period 10-minute

$$i = \frac{c}{(T_d)^e + f} = \frac{96.6}{(T_d)^{0.97} + 13.90}$$



i = design rainfall intensity
T_d = Duration of storm
c, e, f = coefficients

Duration (min)	Intensity (in/hr)	Cumulative Depth (in)	Incremental Depth (in)	Time (min)	Precip (in)
10	4.158	0.693	0.693	0-10	0.024
20	3.002	1.001	0.308	10-20	0.033
30	2.357	1.178	0.178	20-30	0.050
40	1.943	1.296	0.117	30-40	0.084
50	1.655	1.379	0.084	40-50	0.178
60	1.443	1.443	0.063	50-60	0.693
70	1.279	1.492	0.050	60-70	0.308
80	1.149	1.533	0.040	70-80	0.117
90	1.044	1.566	0.033	80-90	0.063
100	0.956	1.594	0.028	90-100	0.040
110	0.883	1.618	0.024	100-110	0.028
120	0.820	1.639	0.021	110-120	0.021

IDF curves

- An IDF is a three parameter curve, in which intensity of a certain return period is related to duration of rainfall even
- An IDF curve enables the hydrologists to develop hydrologic systems that consider worst-case scenarios of rainfall intensity and duration during a given interval of time
- For instance, in urban watersheds, flooding may occur such that large volumes of water may not be handled by the storm water
- system appropriate values of precipitation intensities and frequencies should be considered in the design of the hydrologic systems
- Different relationships of IDF

$$i = \frac{C}{T^{e}_{d} + f} \quad i = \frac{CT^{m}}{T_d + f} \quad or \quad i = \frac{CT^{m}}{T_d^{\,e} + f} \quad I = \frac{A}{(D+B)^{C}} \quad or \quad I = \frac{A}{D^{C} + B}$$

IDF development in Ethiopia

$$I = \frac{A}{(D+B)^{C}}$$

Where; I= rainfall intensity (mm/hr)

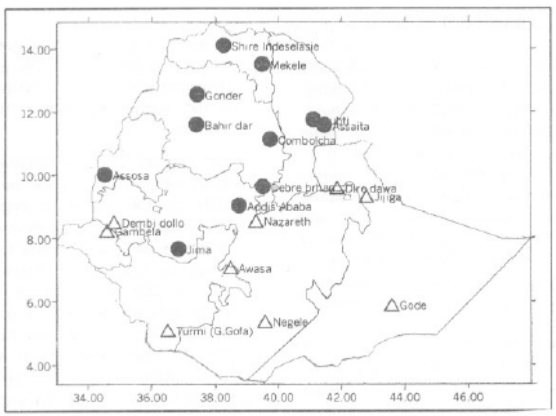
D= duration of rainfall (minutes)

A= coefficient with units of mm/hr

B= time constant in minutes

C= an exponent usually less than one

Cherkos TeJera, Muluneh Yitaye and Ylema Seleshi 2006



No	Name of station	Longitude (degree)	Latitude (degree)	Parameters for T=2 Yrs			Parameters for T=5 Yrs		
				a	b	c	a	b	c
1	Addis Ababa OB	38.75	9.03	1292	11.7	0.89	1870	11.1	0.906
2	Debre Brehan	39.50	9.63	1422	44.9	0.932	731	5.0	0.816
3	Combolcha	39.73	11.12	1442	11.1	0.886	1709	8.1	0.917
4	Assaita	41.45	11.57	190	13.4	0.849	155	13.4	0.74
5	Dubti	41.10	11.75	1334	39.5	0.995	1319	24.8	0.924
6	Mekele	39.48	13.50	804	4.1	0.895	863	0.0	0.851
7	Shire Indeselasie	38.27	14.10	1237	20.2	0.906	1778	25.4	0.915
8	Bahir dar	37.40	11.60	1619	26.2	0.844	2367	20.2	0.899
9	Gonder	37.42	12.55	505	0.0	0.802	615	0.0	0.789
10	Assosa	34.52	10.02	1412	13.3	0.946	1454	6.1	0.907
11	Lima	36.83	7.67	666	2.2	0.815	910	0.0	0.829

IDF development in Ethiopia

$$I = \frac{A}{(D+B)^{C}}$$

Works of Felek & moges (2007)

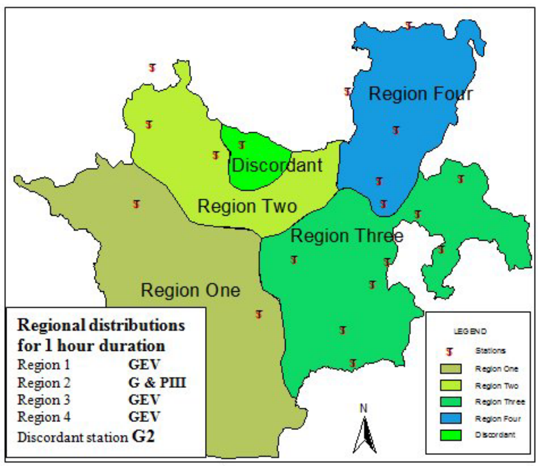
Where; I= rainfall intensity (mm/hr)

D= duration of rainfall (minutes)

A= coefficient with units of mm/hr

B= time constant in minutes

C= an exponent usually less than one



Region	Parameters	Estimated parameters for the indicated frequency					
		T=2	T=5	T=10	T=25	T=50	T=100
Region one	A	1885.08	2029.85	1877.43	1628.18	1394.11	1781.66
	B	14.25	12.81	10.10	6.62	3.20	7.47
	C	0.92	0.89	0.86	0.82	0.78	0.81
	SEE	0.61	0.75	0.85	1.06	1.25	1.07
Region two	A	1483.25	1777.78	2211.10	2811.00	3464.46	4262.60
	B	0.01	0.99	5.35	11.15	16.94	23.27
	C	0.91	0.90	0.91	0.93	0.95	0.96
	SEE	2.24	1.61	1.10	0.59	0.52	0.72
Region three	A	1551.18	2182.20	2537.83	2992.38	3315.94	3576.87
	B	7.47	10.10	11.15	12.67	13.76	14.45
	C	0.92	0.93	0.93	0.94	0.94	0.94
	SEE	0.22	0.37	0.51	0.75	0.97	1.20
Region four	A	1403.61	1852.58	2098.90	2471.82	2741.05	2791.64
	B	10.80	10.09	9.24	9.21	9.23	7.47
	C	0.90	0.91	0.92	0.93	0.93	0.93
	SEE	0.55	0.71	0.91	1.25	1.58	1.95
Station Gojeb	A	840.72	1768.13	2967.40	4978.40	7986.20	11664.43
	B	34.03	55.42	71.99	88.05	104.67	117.38
	C	0.82	0.92	0.99	1.06	1.12	1.17
	SE	5.35	5.02	4.65	4.23	4.01	3.91

IDF development Ethiopia

Arnold and Williams (1989) proposed a statistical disaggregating method, proposed by is applied to disaggregate

$$R_{tc} = \alpha_{tc} \cdot R_{day}$$

$$\alpha_{tc,\min} = \frac{R_{tc}}{R_{day}} = \frac{i \cdot t_{conc}}{i_{24} \cdot 24} = \frac{t_{conc}}{24}$$

Thus, α_{tc} falls in the range $t_{conc}/24 \le \alpha_{tc} \le 1.0$.

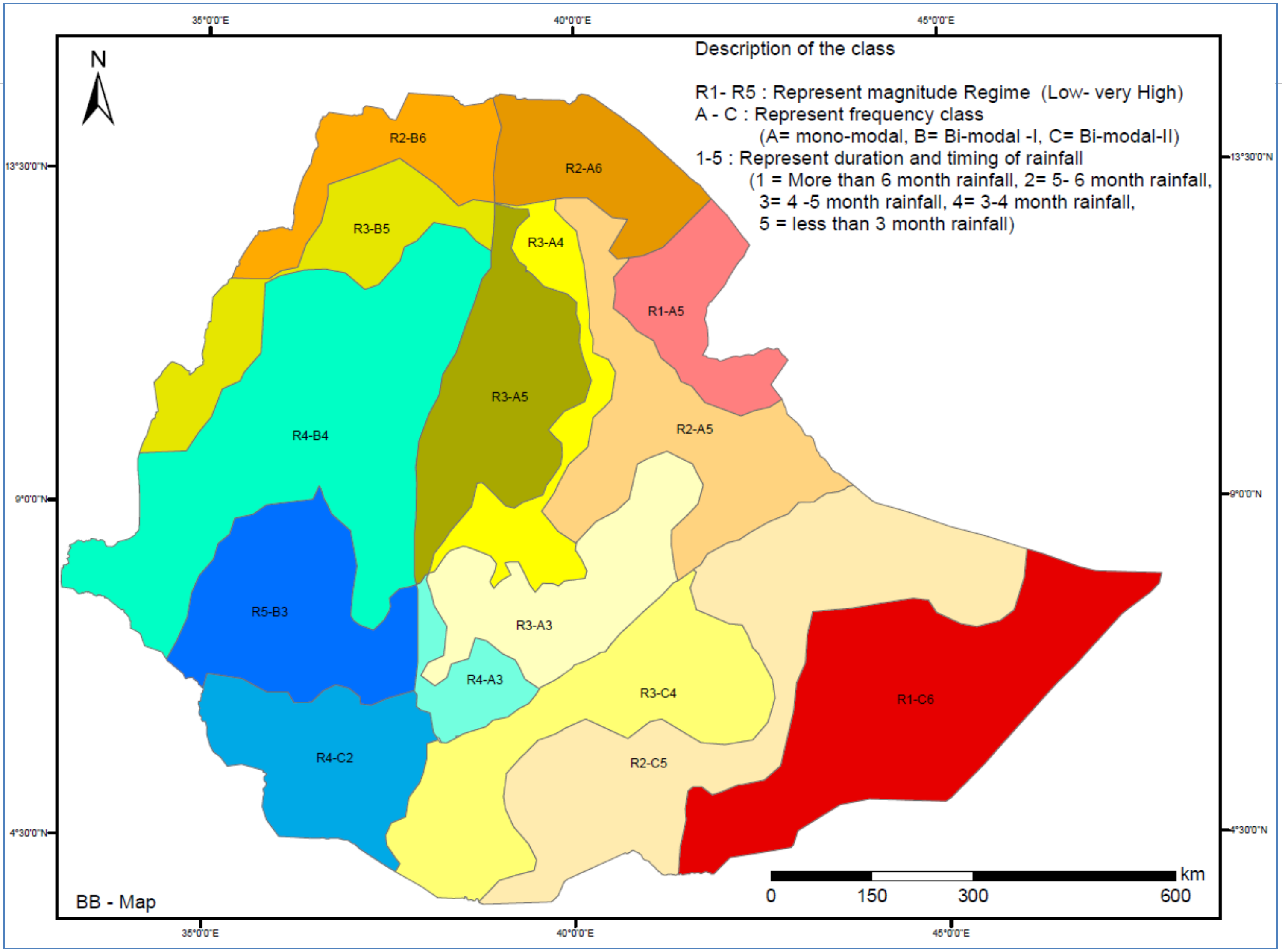
$$i = \frac{R_{tc}}{t_{conc}}$$

$$\alpha_{tc} = 1 - \exp[2 \cdot t_{conc} \cdot \ln(1 - \alpha_{0.5})]$$

$$\boldsymbol{\alpha_{0.5} = 1 - \exp(-125/(R_{day} + 5)}.$$

$$I = \frac{(1 - \exp(2Tc * \ln(1 - \alpha 0.5))) * Rday}{Tc}$$

IDF development Ethiopia



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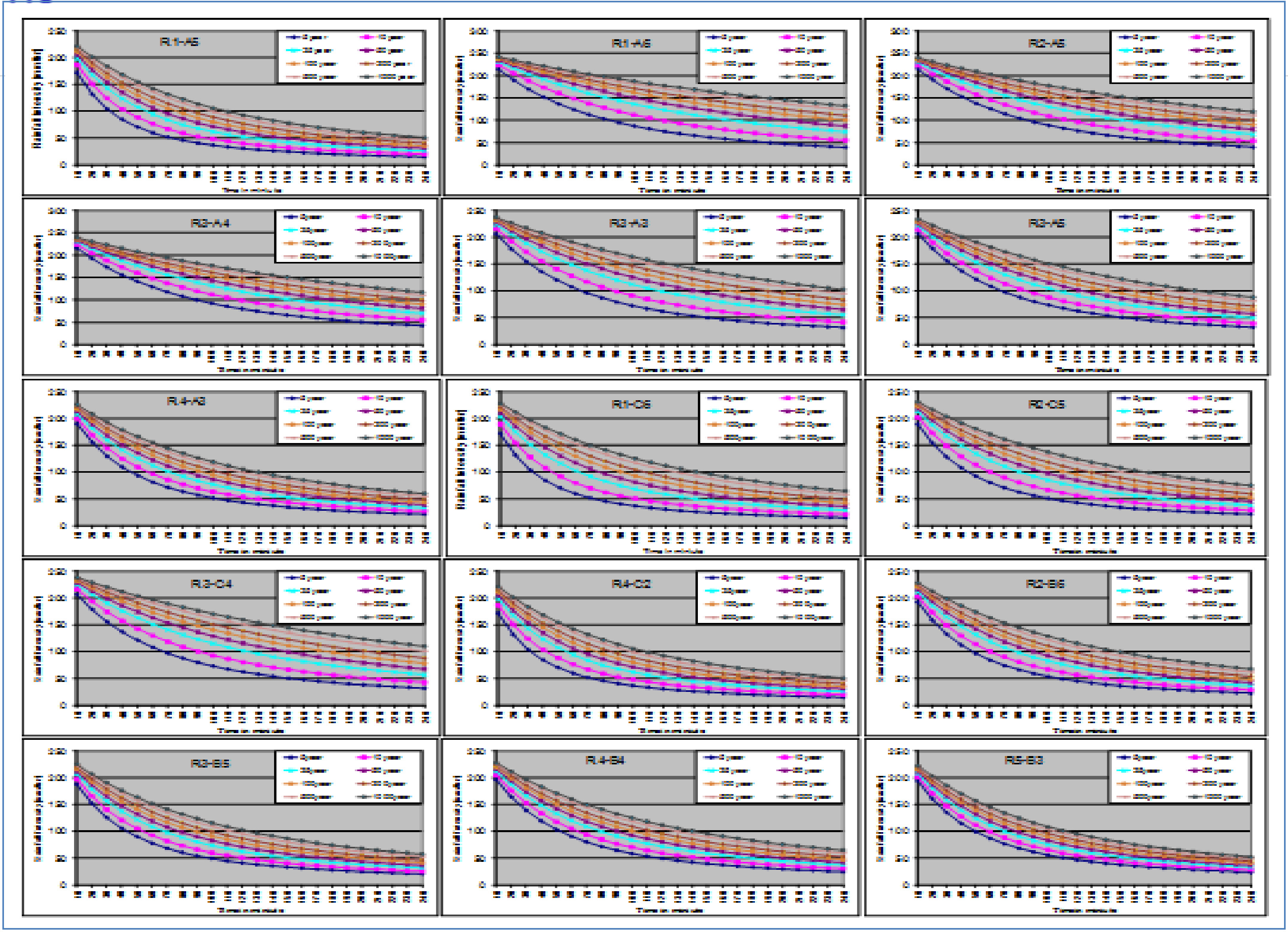
IDF development Ethiopia



Probable Maximum Precipitation

- Probable maximum precipitation
  - Greatest depth of precipitation for a given duration that is physically possible and reasonably characteristic over a particular geographic region at a certain time of year
  - Not completely reliable; probability of occurrence is unknown
- Variety of methods to estimate PMP
  1. Application of storm models
  2. Maximization of actual storms
  3. Generalized PMP charts

Probable Maximum Storm

- Probable maximum storm
  - Temporal distribution of rainfall
  - Given as maximum accumulated depths for a specified duration
  - Information on spatial and temporal distribution of PMP is required to develop probable maximum storm hyetograph