FLOOD FREQUENCY ANALYSIS UNDER CLIMATE AND LAND USE CHANGES

by
Dr. N.K. Goel,
Bharat Singh Chair Professor for Water Resources,
Department of Hydrology,
Indian Institute of Technology Roorkee,
Roorkee- 247667
Email: goelhy@gmail.com
Mob. +91-9412393851

Outline of the Presentation

- Genesis of the problem
- Assumption of flood frequency analysis
- Assessment and types of c
- Reasons of non-stationarity
- frequency analysis of non-stationary datasets

Genesis of the Problem

- Right quantity and quality of water is not available at right place at right time.
- The problem is becoming more acute due to rise in population, changes in land use/land cover and natural climatic changes.
- Hence, storages and transfers of water and their sustainable use are required.
- Water availability and design flood estimates are required for variety of hydraulic structures and frequency analysis is one of the approaches for estimation of design flood estimation.
- Flood frequency analysis methods for nonstationary data sets are not commonly available.

Assumptions of flood frequency analysis

- Flood frequency analysis is based on the following assumptions:

1. The sample is representative of population or the population parameters can be derived from sample ---- past is representative of future --- data records are stationary ----- This assumption is no more valid --- reasons – climate change, catchment change, land use change and number of other reasons.

2. The sample used for frequency analysis is random ----- if sample is not random ----what to do?

Further Elaboration: Assumptions Contd…

- The issue became very hot after the publication of paper by Miley et. al. 2008 paper- 'Stationarity is dead'?
- Word over there is discussion and debate on 'Whether stationarity is dead or still alive' see e.g.
  - Matalas, N. C., Comment on the announced death of stationarity, J. Water Resour. Plann. Manage., 138, 311-312, 2012.
- Say it is dead then- How to account for non-stationarity in the designs is the main issue.

How to Proceed?

- Assessment of non- stationarity in hydrometeorological records.
- Investigation of reasons of non- stationarity.
- What to do if data sets are non-stationary.
- Directions in which solutions have been tried.

1. Assessment of Non-stationarity in Hydro-meteorological Records

Types

- Change in mean
- Change in variability
- Presence of short term persistence
- Presence of long term persistence
- Shifts and jumps in data sets
- Presence of periodicity

2. Investigation of Reasons of Non-stationarity

- Climate change
- Change in the exposure conditions
- Change of instrument and instrument type
- Change in observation practices
- Urbanization
- Deforestation
- Changes in land use patterns
- Change in irrigation practice
- Inadequate length of data
- Impacts of the operation of water infrastructure such as dams, weirs and canals

3. What to do if data sets are non-stationary?

- If a series does not pass the prescribed hypothesis tests for stationarity, then how to proceed?
  - For example, if there is trend or persistence in the annual flood series, then how to estimate the design flood quantiles in flood frequency analysis.

Main hurdle- frequency analysis

- $Q_T = \mu + K_T . \sigma$

- Under stationary conditions: parameters are fixed.
- See e.g GEV distribution; Parameters are U, α, and k; U, α and k are time independent
- Under non-stationary conditions: parameters may vary with time. U, α and k are functions of time
- How to estimate the time varying parameters is the challenge.

Theories Developed So Far

- Theory based on mixed noise model Burn and Goel (2001, 2014, 2015)- takes care of long term persistence
- Flood magnification factors – Rich Vogel -2010
- Time dependent parameters – Stedinger and co workers- 2010
- Conditional distributions – Balaji Rajgopalan- 2010

There is need to test and apply these theories on more data sets. More robust methods are required to be developed.

FREQUENCY ANALYSIS OF NONSTATIONARY SERIES USING MIXED NOISE MODEL APPROACH

Frequency analysis has been carried out for annual daily maximum rainfall and annual flood series as per following steps:

Step1: Q_{50}, Q_{100} and Q_{200} are calculated using GEV (PWM) method for the original series;

Step 2: 1000 samples are generated using mixed noise model as per procedure explained in for the following two cases:

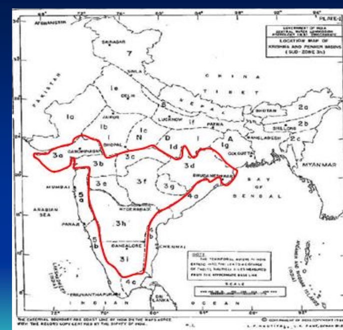
Case I: Assuming series to be stationary i.e. r_1 =0.0 and K=0.5 and

Case II: Nonstationary case i.e. actual values of r_1 and K.

Methodology Contd.

- Step 3: Compute Q_{50}, Q_{100} and $Q_{200}$for each of the generated sample using GEV (PWM) and compute expected values of Q_{50}, Q_{100} and Q_{200} for the above two cases;
- Step 4: Compute under estimation in case of nonstationarity from step (ii) and (iii)
- Step 5: Compute revised values of Q_{50}, Q_{100} and $Q_{200}$by increasing these values by the underestimation introduced due to nonstationarity.

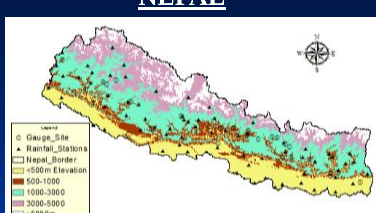
STUDY AREA AND DATA AVAILABILITY



77 Annual flood series
204 annual max. rainfall series

ZONE 3 MAP Bordered by red Line

NEPAL



Annual maximum Daily Rainfall data:
70 stations covering the whole country.

Annual flood series 32 staions

Results of nonstationarity analysis India data:

1. 9.21% of AFS show short-term dependence and 17.10% show long-term dependence.

2. 9.76% of annual maximum daily rainfall series show short-term dependence and 11.22% show long-term dependence.

The probability of long term dependence in data sets is fairly high and there is no reason to disregard them. Hence, if a series shows short-term independence, one should still investigate for long-term dependence.

Similar type of results were obtained for Nepal data also.

Frequency estimates of Original series using GEV (PWM) method (Few stations only)

SN	Stations	r_1	K	Original Series (Stationary case)		
				Q_{50}	Q_{100}	Q_{200}
Extreme annual discharge						
1	Nayalbadi	0.624	0.825	625.81	710.88	800.42
2	Lalighat	0.496	0.915	3048.05	3370.49	3699.27
3	Nagma	0.332	0.863	451.49	520.28	596.64
4	Diware	-0.235	0.693	243.9	287.89	340.97
5	Bangga	0.127	0.701	7815.23	9104.34	10517.41
Annual Maximum daily Rainfall						
1	Baitadi	0.4002	0.727	159.94	174.36	188.34
2	Dadeldhura	0.1702	0.728	227.64	260.62	295.54
3	Mahendranagar	0.1121	0.731	324.85	383.43	449.82
4	Darchula	0.0438	0.619	217.73	248.22	282.07
5	Chainpur(West)	0.0467	0.709	112.01	115.7	118.7

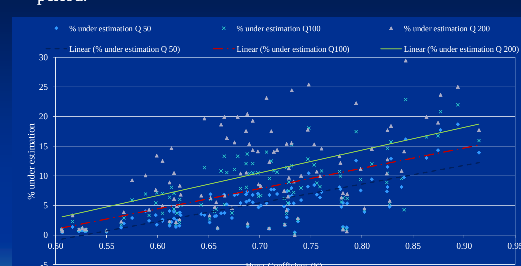
Frequency estimates of generated series using GEV (PWM) method (Few stations only)

SN	Stations	Generated Original Series (nonstationary case i.e. r_1 and K of original series)			Generated Series (stationary case i.e. r_1=0 and K=0.5)		
		Q_{50}	Q_{100}	Q_{200}	Q_{50}	Q_{100}	Q_{200}
Extreme annual discharge							
1	Nayalbadi	525.77	563.15	597.51	594.14	659.81	725.85
2	Lalighat	2416.11	2521.15	2613.53	2805.81	2998.5	3177.53
3	Nagma	368.36	392.91	415.74	423.6	470.7	519.11
4	Diware	234.31	268.71	308.04	248.05	305.56	381.59
5	Bangga	6759.58	7375.17	7960.07	7112.28	7898.8	8679.54
Annual Maximum daily Rainfall							
1	Baitadi	146.42	155.4	163.5	152.97	164.26	174.81
2	Dadeldhura	204.2	223.68	242.44	218.51	245.56	273.21
3	Mahendranagar	288.19	320.6	353.31	313.08	363.07	418.22
4	Darchula	198.95	216.65	234.33	204.11	224.96	246.48
5	Chainpur(West)	110.56	114.28	117.38	111.74	115.57	118.75

Under estimation for nonstationary case and recommended frequency estimates

SN	Stations	% under estimation			Recommended / Adjusted frequency estimates for nonstationarity		
		Q_{50}	Q_{100}	Q_{200}	Q_{50}	Q_{100}	Q_{200}
Extreme annual discharge							
1	Nayalbadi	11.51	14.65	17.68	697.82	815.02	941.94
2	Lalighat	13.89	15.92	17.75	3471.39	3907.06	4355.88
3	Nagma	13.04	16.53	19.91	510.37	606.26	715.45
4	Diware	5.54	12.06	19.27	257.41	322.61	406.69
5	Bangga	4.96	6.63	8.29	8202.79	9707.89	11389.2
Annual Maximum daily Rainfall							
1	Baitadi	4.28	5.39	6.47	166.79	183.76	200.53
2	Dadeldhura	6.55	8.91	11.26	242.55	283.84	328.82
3	Mahendranagar	7.95	11.70	15.52	350.68	428.28	519.63
4	Darchula	2.53	3.69	4.93	223.23	257.39	295.97
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Under estimation increases with the Hurst K value and Return period.



Under estimation in Frequency Estimate with respect Hurst coefficient and return period

CONCLUSIONS

NONSTATIONARITY

•Long term dependence is more dominant than short term dependence in the data sets.
•Almost double station has shown long term dependence as compared to short term.

CLIMATE CHANGE Nepal case

•More than 15% stations have shown negative relationship between annual rainfall and number of rainy days, which is a clear indication of more intense rainfall in future;
•In all the stations except Tamghas there is either long term dependence or short term dependence in annual rainfall or in annual rainy days. In most of the stations there is shift either in annual rainfall or in annual rainy days.
•Analysis of winter rainfall has not shown any significant nonstationarity.
•Similarly annual maximum daily rainfall (5 out of 70) and extreme annual discharge (2 out of 32) have shown rising trend.

CONCLUSIONS

•A framework of frequency analysis of nonstationary series using mixed noise model has been developed. The use of this approach in terms adjustment factors has been demonstrated. Results indicate that frequency estimates are underestimated due to the presence of long term persistence and degree of underestimation increases with increases in return period and also with increase in Hurst Coefficient and also the value of r_1. So the frequency estimates in case of nonstationary series should be increased by the amount of underestimation introduced by nonstationarity.
•The GAMLSS package is a versatile package to handle nonlinearity in location, scale and shape parameters for various distributions. The results of this package are close agreement with the results of a simple case of linear time variant location parameter using Normal, Lognormal and Gumbel distribution for one station in Nepal.

SCOPE FOR FURTHER STUDY

- The effect of nonstationarity on confidence bands of frequency estimates should be studied through the use of mixed noise model.
- The results of mixed noise model need to be improved by carrying out simulation studies for wide range of r_1 and Hurst coefficients.
- The nonlinearity in the data sets should be linked with climate indices.
- The variation of location, scale and shape parameters with respect to time should be studied by taking long terms data of hydrological variables.
- The versatility of GAMLSS package in handling various types of nonstationary in frequency analysis should be explored further.
- The impact of climate change on water availability and hydrological extremes should be studied through scenario generation using GCMs.

Thanks