STOCHASTIC SIMULATION OF STREAM DISCHARGE DATA OF BRAHMANI RIVER BASIN

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ABSTRACT:

Water is an essential input material and resource for development of a country. India is going to face severe water crisis in near future. Water is required for drinking and sanitation, agriculture and food security and also for Industrial Development. India is a monsoon fed country and primary water source rainfall is very oddly distributed over space and time. Proper planning of water resource structure is dependent on generation of hydrologic data like rainfall and stream discharge time series. In order to apply statistical techniques to the time series first a hydrologic system need to be defined .For the present analysis a watershed of the River Brahmani of Orissa upto the stream discharge station at Jenapur is defined as the hydrologic system. The simulation task is then carried out on Rainfall-Stream Discharge data series. Stochastic hydrology is an essential base of Water resources System Analysis due to the inherent randomness of the input and consequently of the results. These results have to be incorporated in a decision making process regarding the planning and management of water systems. In the present paper the stream discharge of a certain year is hypothesised to be dependent on the discharge of previous year and the rainfall of the same year with a three month lag period. The annual rainfall data for a long period of 1901 to 2010 was analysed the transitional probability matrix and autocorrelation with lag 1 to 30 show that the data are purely random. The stream discharge data at Jenapur for the year 1964 to 2008 was analysed and it was observed that the stream discharge of a certain year is negatively correlated to the previous year. Using cross correlation coefficient with rainfall data and autocorrelation coefficient of discharge data a simple linear model was formulated with addition of a noise component. The characteristics of the noise parameter was established using a random data series.

Key Words: Watershed, Hydrologic System, Stochastic hydrology, transition probability matrix.

INTRODUCTION:

Water is life and the first step for development and improvement of quality of life. With increase in population coupled with increased food demand and fast industrial development the demand for water in India is increasing at a fast rate and soon India is going to face severe water crisis. A comprehensive step to fight this situation needs proper hydrologic data collection, analysis and prediction for future. The supply of water from nature is governed by precipitation i.e. rainfall and snowfall. India being a monsoon fed country the rainfall is oddly distributed over space and time. Since surface water streams are fed from rainfall the stream discharge also varies widely. In the planning stage we need long hydrologic time series data for future to design a water resource project. The first step for this analysis is to define a hydrologic system and then formulation of models keeping in view the various uncertainties in built in the hydrologic parameters .Thus the next step is to formulate a stochastic model which will have a sequential component and a pure random noise component. Present paper is prepared on the basis of rainfall and stream discharge data of Brahmani River flowing through the state of Orissa.

HYDROLOGIC SYSTEM:

A system is an assemblage of group of interacting and interrelated entities that form a unified whole Dooge (1968) defined a system as any structure, device, scheme of procedure real or abstract that interrelates in a given time reference an input, cause or information and an output, effect, or resources of information ,energy or matter. A system is delineated by its spatial and temporal boundaries surrounded or influenced by its environment described by its structure and purpose and expressed in its functioning. System can be of two types: Distributed Parameter System and Lumped Parameter System. Distributed parameter system is a dynamical system that evolves not only in time but also in space. A lumped parameter system is one in which the dependent variables of interest are a function of time alone.

A hydrologic system is defined as a structure or volume in space surrounded by a boundary that accepts water and other inputs, operates on them internally and produces outputs. The boundary is a continuous surface defined in three dimensions enclosing the volume and structure. A working medium enters the system as input interacts with the structure and other media and leaves as output. Physical, chemical, and biological processes operate on the working medium within the system. The most common working media involved in hydrologic analysis are water, air and heat energy. (Dooge, 1968).A parameter is a quantity characterising a hydrological system and which remains constant in time. On the other hand the input and output to the system are termed as variable. (Clarke 1973).A hydrologic system can follow deterministic method of analysis or stochastic methodology.

Deterministic methods in system hydrology presents the basic theory underlying the multitude of parameter-rich models which dominate the hydrological literature. Its objectives are to introduce the elements of systems science as applied to hydrological problems; to present flood prediction and flood routing as problems in linear systems theory, clarifying the basic assumptions and evaluating their accuracy; and to review and to evaluate some deterministic models of components of the hydrological cycle, with a view to assembling the most appropriate model of catchment response, for a particular problem in applied hydrology. (Dooge & Kane,2003). Hydrologic simulation models, such as precipitation-runoff watershed models, are sometime used in a deterministic manner for environmental and water resources design, planning, and management. In operational hydrology, simulated responses are now routinely used to plan, design, and manage a very wide class of water resource systems.(Farmer & Vogel, 2016). However, all such models are calibrated to existing data sets and retain some residual error. This residual error is neglected in Deterministic system analysis.

While deterministic methodology neglects the residual error the stochastic methods try to extract maximum possible information from the available record of a hydrologic variable .Hydrologic phenomena are in reality stochastic in nature and their behaviour changes with the time in accordance with the law of probability as well as with the sequential relationship between the occurrences of the phenomenon.(Chow & Kareliotis,1970).

CONSTRAINTS IMPOSED BY WATER RESOURCES PROBLEMS:

The nature of water resources process leads to a complex interconnection of subsystems and isolation of a portion of the system may destroy its natural function and lead to identification of a purely hypothetical process.

Many complete systems are however, too complicated for any reasonable model to include all factors that might be important. An important bottleneck in water resources studies is formed by low quality of experimental data. Thus a truly representative system analysis can be framed through three items namely Excitation (Input), System Proper and Response (Output).

MODEL CATEGORIZATION:

Modelling approach may be grouped into three categories; Black box models, white box models and grey box models.

Black box models are purely data based model. They approach the system in terms of input and output with the internals hidden in a black box.

White box models are the opposite of the black box ones. The internal of the system is fully known. In order the develop a white box the modeller must know the physical laws governing the movement of the fluid or throughput inside the system.

Grey box models are placed in between black- and white- box modelling approaches. A model is viewed as grey box if physical knowledge about the system is used along with the data. Thus the model is not completely described by physical equations but the equations and the parameters are physically interpretable.

The white box approach is governed by deductive reasoning and the process can be modelled by taking care of all the processes active within the boundary. The structure and parameters of the model are analytic functions of physical process parameters. The black box approach is governed by Inductive Approach where only input and output are measured.

STOCHASTIC MODELLING:

The term Stochastics originates from the Greek word Stochazesthai which means to aim at the target. In the modern sense the term Stochastics refer to the random elements incorporated in the model.

In an ideal world, where all phenomena have been developed through the application of physical laws, all occurrence can be described completely by physical equations. However, this is not the reality in our world, and particularly not in the field of hydrology. Consequently, use of stochastic models can be a useful option.(Brunner et al 2019)

Models described by deterministic physical equation are often referred to as white box models. The stochastic models can be grouped into grey box models and black box models. The grey box models are described by physical equations and a noise factor. The noise factor is an extra term which is due to factors that are not described by the physical factors. The black box models are built up in such a way that statistical methods are used to find relation between input and output not necessarily based on physical processes.

The basic physical equation in hydrology is the equation of conservation of mass. The change of mass within a volume equals net outflow of the volume, i.e., the difference of the mass of inflow into the volume minus the mass of outflow out of the volume. In hydrology the control volume unit is a watershed. The total volume is found by integrating over the entire watershed, and the change of mass is found by the time derivative of the water inside the volume (watershed). The net outflow is found by inflow and outflow through the watershed's boundary. To carry out these calculations detailed information about precipitation, evaporation, transpiration, infiltration, surface runoff and groundwater runoff must be known. Information must be available in the whole watershed. In general such information does not exist and it is, therefore necessary to introduce stochastic terms in the models.(Olivero Et Al, 2018, Ivezic Et Al,2017). The use of Monte Carlo methods fostered the development of a new time series using random and stochastic applications.

Here one thing must be clarified that both deterministic and stochastic models can use physical laws (such mass and momentum conservation) or both can be empirical. Deterministic models can be either physically-based (e.g. a model based on Saint-Venant equations for flood routing) and empirical (e.g. a rating curve used as a deterministic model for predicting sediment loads from water levels).(Jonsdottier,2006) Conversely, any physically-based model becomes a stochastic model once its inputs, parameters or outputs are treated as random.(Bierkens Et Al, Srikanthan Et Al 2001)

The random noise part of a stochastic model takes care of the following aspects of a hydrologic variable:

1) Observational Error
2) Errors in Boundary Conditions & Input.
3) Unknown heterogeneity and parameters.
4) Scale Discrepancy
5) Model or System errors.

THE BRAHMANI BASIN:

The Brahmani is a major seasonal river in the Odisha state of Eastern India. Brahmani river basin is an inter-state river basin covering Chattisgarh Jharkhand and Orissa. It lies between Latitudes 200 28’ North to 230 35’ North and longitudes 830 52’ East to 870 30’ East latitudes.In Orissa the river Brahmani flows through the districts of Sundargarh, Deogarh, Angul, Dhenkanal, Cuttack, Jajapur and Kendrapara· The major industrial town Rourkela gets its water supply from the river Brahmani through a captive dam Mandira. The Sankh has its origins near the Jharkhand Chhattisgarh Border and the South Koel originates in Jharkhand, near Lohardaga. Both of these sources are in the Chota Nagpur Plateau. The site of the Brahmani's origin is mythologically reputed to be the place where Sage Parashara fell in love with the fisherman's daughter, Satyavati who later gave birth to Ved Vyasa, the compiler of the Mahabharata. The place is thus called Ved Vyasa. The deltaic region starts at Jenapur. Here the river branches into numerous spill channels, criss-crossing with the spill channels of the adjacent Baitarani River and finally discharges into the Bay of Bengal. The total length of the river is 446 km. The map of Brahmani river basin. The basin has a total drainage area of 39,268 sq.km.(Visakh)

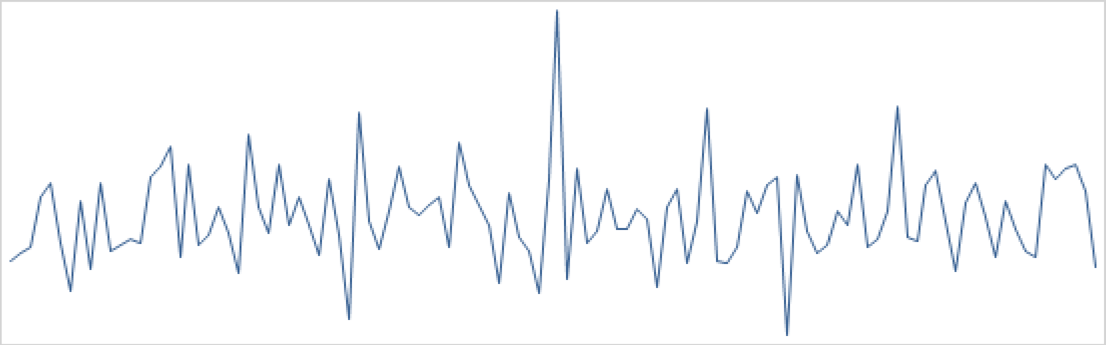
COLLECTION OF DATA :

For the present paper the annual rainfall data for the period 1901 to 2010 was collected from INDIA WATER PORTAL .The Annual rainfall for districts Sundargarh, Deogarh, Angul, Dhenkanal,Cuttack,Jajpur and Kendrapara were collected and the average was used for the annual rainfall for the Brahmani Basin from source to the discharge measuring station at Jenapur. The annual data series is presented in line curve Figure 1.

In 1949 using Khosla’s empirical formula the water resources of the Brahmani Basin was estimated as 39,225 million cu m. (MCM).In 1960 the Central Water & Power Commission assessed the total annual runoff of the basin as 28,691 MCM.In 1968 the central water & power commission reported 36,227 MCM as average water resources of the Brahmani Baitarani Basin using Khosla formula. In 1993 CWC undertook reassessment of water resources potential of India. The Brahmani Baitarani basin was assessed to have a catchment area of 51,822 square Km. The map of Brahmani river basin is presented in Figure 2.

The discharge data for the Brahmani Basin at Jenapur streamflow discharge measuring station for the period 1964 to 2008 is collected from ISRO, BELANAGAR REPORT dated December 2011.The annual discharge data are presented in line curve Figure 3

Rainfall mm along Y Axis



Year 1901 to 2010 along X Axis

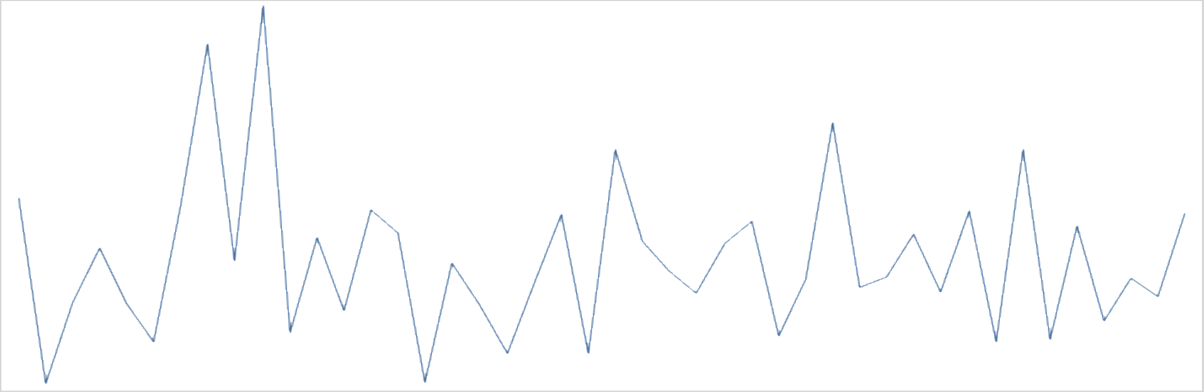
FIGURE 1 : ANNUAL RAINFALLmm, BRAHMANI BASIN 1901 to 2010

Maxm Rainfall : 1956 : 2191mm

Min. Rainfall : 1979: 876.379

FIGURE 2 : THE RIVER BRAHMANI BASIN

Discharge in mm along Y axis



Year 1964 to 2007 along X Axis

FIGURE 3: DISCHARGE DATA BRAHMANI BASIN AT JENAPUR

Maxm.Discharge : 1973 : 45052MCM = 1241 mm

Min.Discharge : 1965: 8097MCM = 223 mm

ANALYSIS OF RAINFALL AND STREAM DISCHARGE DATA:

RAINFALL DATA : 1901 to 2010:

Average : 1358mm

Max. : 2191mm

Min. : 876mm

Median : 1338.663

Standard Deviation : 188.0864

Pearson Skewness : 0.311521

Transition Probability Matrix :

$$\begin{array}{c|cc} & + & - \\ \hline + & 14 & 30 \\ - & 30 & 35 \end{array}$$

AUTO CORRELATION COEFFICIENT:

LAG	AUTO CORRELATION COEFFICIENT
Lag 1	-0.15183
Lag 2	-0.17791
Lag 3	+0.057896
Lag 4	+0.002831
Lag 5	-0.07006
Lag 6	-0.04676
Lag 7	-0.02211
Lag8	-0.03493
Lag9	+0.064556
Lag10	-0.00561
Lag11	-0.06827
Lag12	-0.062735
Lag13	-0.11679
Lag14	+0.239047
Lag15	-0.04538
Lag16	-0.03831
Lag17	-0.13295
Lag18	+0.141346
Lag19	+0.059754
Lag20	-0.1139
Lag21	+0.149291
Lag22	-0.08846
Lag23	-0.10419
Lag24	+0.041854
Lag25	-0.07709
Lag26	+0.088951
Lag27	-0.05393
Lag28	+0.121634
Lag29	+0.216481
Lag30	-0.00536

SIGNIFICANCE TEST:

APPROXIMATE TEST :(Clarke, 1973)

Large Sample Standard Error : +/-{2/(N)^0.5}

With N = 110, the range is +/- 0.190693

EXACT TEST☹Clarke, 1973)

-{1/(N-1)} +/-{ 1.96{(N-2)/(N-1)^1.5}

With N=110 the range is +0.176837 to – 0.19519

The statistical calculations on transitional probability matrix and correlation analysis show that the rainfall data have autocorrelation above 0.2 only at 14 years lag and 29 years lag. Otherwise the autocorrelation factor varies between +0.15 to -0.15. These serial correlation figures are insignificant as per the tests presented above since the skewness is within the range of +0.5 to -0.5 the data can be classified as Symmetric.

Thus, the rainfall series can be simulated by generating random series with mean (0) zero and standard deviation one (1) and then generating a rainfall series with mean 1358 and standard deviation 188.0864 by using the following formula:

$Y = (y - \mu)/\delta$ where μ = mean and δ = standard deviation .

STREAM DISCHARGE DATA : 1964 to 2008

Average: 19846 MCM = 558 mm

Max : 45052 MCM = 1241mm

Min: 8097MCM = 223 mm

Median: 518.6412

Standard Deviation 214.204

Pearson Skewness 0.560187

Transition Probability Matrix :

$$\begin{array}{c|cc} & + & - \\ \hline + & 4 & 14 \\ - & 14 & 11 \end{array}$$

AUTOCORRELATION COEFFICIENT:

LAG	AUTOCORRELATION COEFFICIENT
Lag1	-0.23235
Lag2	+0.191114
Lag3	-0.02578
Lag4	+0.023185
Lag5	-0.18576
Lag6	-0.16008

The statistical calculations of Transition Probability Matrix and Autocorrelation Coefficient shows that the data are negatively correlated at Lag 1 and positively correlated at Lag 2.The skewness factor shows that data set is moderately asymmetric.

CROSSCORELATION OF DISCHARGE DATA AGAINST RAINFALL DATA:

The Cross Correlation Coefficient of Stream Discharge Data and Rainfall Data is 0.428439. This shows that there is a positive correlation between Stream Discharge and Rainfall.

FORMULATION OF MODEL:

Based on the statistical observations presented in previous sections a simple linear multivariate model is formulated considering Stream Discharge in third year (SD3) as a function of SD1, SD2 and Rainfall in the third year(RF3).A lag period of three months from rainfall to stream discharge is considered. This function is presented in Equation 1 below :

SD3 = 0.437* RF3 – 0.232* SD2 +0.191*SD1 + € ----------- (1)

Where € represent the noise component.

The relationship in equation 1 is presented in a general form in equation 2:

D(tn) = 0.437*{R(tn)} – 0.232*{Dt(n-1)} + 0.191*{Dt(n-2)} + € ----------(2)

Where, D (tn) is the discharge in mm in nth year.

R (n) is the rainfall in nth year.

DT (n-1) is the discharge in (n-1) th Year

Dt (n-2) is the discharge in (n-2) th year.

€ = Noise Component.

The next task is to evaluate the characteristics of the noise component.

The series of noise component was generated by subtracting the sequential portion (0.437* RF3 – 0.232* SD2 +0.191*SD1) from the natural stream discharge data. The statistical characteristics of the Noise Component are presented below:

Average: -12.6974

Standard Deviation: 206.4684

Median : -45.8748

Pearson Skewness : 0.48207

Correl with Lag 1: 0.065194

Thus, the Noise series can be simulated by generating random series with mean (0) zero and standard deviation one (1) and then generating a noise series with mean -12.6974 and standard deviation 206.4684 by using the following formula:

$Y = (y - \mu)/\delta$ where μ = mean and δ = standard deviation.

CONCLUDING REMARKS :

The stochastic simulation of stream discharge data for future years can be carried out by following steps:

1. Generation of series of rainfall data for future years.
2. Generation of series of Noise Component of Discharge Data.
3. Generation of Sequential part of the stream discharge data step by step.
4. Final generation of Stream Generation Data by adding Noise Component to Sequential part.

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