Estimation of Runoff using Empirical Equations and Fuzzy Logic method: A case study

Praveen Kumar B J[1], Pradeep H [2], Lokesh. A[3],Akarshraj K.H[4], Surendra H J[5], and Avinash S.D[6]

[1, 2, 3&4] *U.G Students, Dept of. Civil Engineering, REVA ITM , Bangalore-64*
[5&6] *Assistant Professor, School of Civil Engineering, REVA University, Bangalore-64*

careof.indra@gmail.com, akarshrajgowda@gmail.com

ABSTRACT

Water is a basis necessity for sustaining the life and development of society. Water is a precious gift of nature to the mankind. The Important source of water is rainfall and for most of the hydrological models, rainfall is used as one of the main elements to estimate the runoff process. Rainfall-runoff model is a mathematical model describing the rainfall-runoff relations of a catchment area or watershed. Rainfall data is uncertain and Runoff is one of the important hydrologic variables used in the water resources management and planning. Rainstorms generate runoff and its occurrence and quantity are dependent on the characteristics of the rainfall event. Still there are many watersheds or catchments which are un-gauged; hence empirical formulae were useful for estimating runoff volume. This paper describes the estimation of Runoff using various Empirical Equations such as Khuzla's Formula, Inglis and Desouza Formula, Indian Irrigation Department, Khosla's Formula and SCS –CN method. Also These Empirical equations were compared with Fuzzy logic method using Different rules and membership functions. For this purpose Yelahanka is selected as study area. Rainfall data were collected for a period of 15 years from 2000 to 2015 on monthly basis. Various models were developed using empirical equations and Fuzzy logic methods. Performances of the developed models were evaluated using various performance evaluation indices. Best method is selected by comparing empirical method with fuzzy Logic method to estimate the runoff. Results Reveals that Fuzzy method has a promising potential to estimate the runoff for a given catchment area.

KEY WORDS: *Rainfall-Runoff, Empirical Equation's. Fuzzy Logic.*

1. INTRODUCTION

Water is a basis necessity for sustaining the life and development of society. Water is a precious gift of nature to the mankind. The Important source of water is rainfall and for most of the hydrological models, rainfall is used as one of the main elements to estimate the runoff process. As population is increasing day by day so demand of water is increasing and due to industrialization, urban development further load on available water is increased. So it's serious issue or need of estimating available water for optimum use of water for various purposes like domestic, agriculture & industrialization. Hydrological models are important and necessary tools for water and environmental resources management. Hydrologic processes vary both in space and time. For most of the hydrological models, one of the main elements involved are rainfall-runoff process. A rainfall-runoff model is a mathematical model describing the rainfall-runoff relations of a catchment area, drainage basin or watershed. A water resources system may be nonlinear and multivariate and the variables involved having complex interrelationships. The basic requirements in designing water projects, is the estimation of runoff resulted from precipitation. The relationship between precipitation and runoff is a complicated and non-linear relationship which is depended on several factors. To determine accurate quantity of surface run-off that in any river basin, understanding of the complex relationship between rainfall and run-off processes of particular basin is necessary.

Runoff is one of the important hydrologic variables used in the water resources management and planning. However, quickening of the watershed management program for conservation and development of natural resources management has necessitated the runoff information. The process of transformation of rainfall into discharge can be replicated and simplified in the form of models, commonly called rain-flow models. The estimation of discharge from ungauged catchments based on rainfall-runoff analysis is a very frequent task in engineering hydrology.

Many models have been developed in the rain-flow analysis. simulation of rainfall-runoff is a discharge based approach to predict rain that enters the watershed. In order to achieve this purpose, various methods, empirical equations and rainfall-runoff models can be used. In the past, many empirical formulae have been developed, but taken in their applicable only to the region where they were derived. Present research work focus on estimating the runoff using best empirical method and comparing the method with fuzzy logic method.

2. STUDY AREA

Yelahanka is a suburb of Bangalore North is more or less a level plateau, in the state of Karnataka originally envisaged as a satellite town of Bangalore city, India and geographically lies between 13˚06'50"N and 13˚11'38"N Latitude and 77˚35'54"E and 77˚59'33"E Longitude and covers an area of about 38.88 sq.kms. The study area attains a maximum elevation of 962.000m and a minimum of 839.000m. It has a typical subtropical climate with hot dry summers and cool dry winters. The main features of the climate of Yelahanka are agreeable range of temperature, from the highest maximum of 35˚C in April to the lowest minimum of 14˚C in January. The two main rainy seasons, June to September and October to November, come one after the other but with opposite with regimes, corresponding to the South-West and North-East monsoons. June to September being rainy seasons receives 54% of the total annual rainfall in S-W monsoons period and remaining 46% during the N-E monsoons. The rainfall in the study area is highly erratic varying between 80mm to 200mm. The mean annual rainfall is 83.60mm with three different rainy periods covering eight months of the year. Selected study area is shown in the figure 1.

Figure 1: Study Area

3. METHODOLOGY

In the past, many empirical formulae have been developed, but these are applicable only to the region where they were derived. Furthermore, caution must be taken in their application if the characteristics of the region have been subjected to manmade disturbance (settlement, land use pattern change). These are essentially rainfall-runoff relationships with additional third or fourth parameters to account for climatic or catchment characteristics. Some of the important empirical runoff estimation formulae used in various parts of India are given below:

1) Khuzla Formula

The Khuzla proposed the equation to calculate runoff using Temperature and Rainfall parameters:

$R = P - (T/3.74)$

2) Inglis and Desouza Formula

As a result of careful stream gauging in 53 sites in Western India, Inglis and DeSouza (1929) evolved two regional formulae, between Runoff R in mm and Rainfall P in mm as follows:

For Ghat regions of western India usually Highlands

$R = (0.85*P) - 30.5$

For Deccan plateau usually Plain areas

$R = ((1/254)*P)*(P - 17.8)$

3) Indian Irrigation Department

Indian Irrigation Department uses the equation between Rainfall and Runoff

$R = P - (1.17*P^{0.86})$

4) Khosla's Formula

Khosla (1960) analyzed the rainfall, runoff and temperature data for various catchments in India and USA to arrive at an empirical relationship between runoff and rainfall. The time period is taken as a month. His relationship for monthly runoff is

For $T > 4.5$ °C

$R = P – L$ where $L = (0.48*T)$

For, $T \leq$ the loss may provisionally be assumed as

Annual runoff = $\sum R$

Khosla's formula is indirectly based on the water-balance concept and the mean monthly catchment temperature is used to reflect the losses due to evapotranspiration. The formula has been tested on a number of catchments in India and is found to give fairly good results for the annual yield for use in preliminary studies.

Where,

R = monthly runoff in mm and $R \geq 0$;

P =monthly rainfall in mm;

L = monthly losses in mm;

T = mean monthly temperature of the catchment in °C

5) SCS Curve Number Method

The most commonly used empirical method is the Soil Conservation Service Curve Number (SCS-CN) method to estimate the direct runoff from a watershed. The estimation of run-off using GIS based SCS method can be used for the watershed management efficiently. The SCS-CN method explaining the water balance equation can be expressed as below

$P= Q +F + Ia$……………………… (1)

$Q/ P- Ia = F/S$…………………….. (2)

$Q = (P – Ia)*2/ (P – Ia) + S$………... (3)

where,

P = Total precipitation (mm),

Q = Actual Runoff (mm),

F= Cumulative Infiltration (mm),

Ia= Initial abstraction (mm) which represents all losses before the runoff begins

Ia = 0.2 S…………………………..… (4)

Substituting in equation (3)

Q = (P – 0.2S)*2 / (P + 0.8S)……... (5)

Where S= potential maximum retention (mm) after the runoff begins in the watershed and is given by empirical equation

S = (25400/CN) - 254 …………...….. (6)

f) Fuzzy logic method

Fuzzy logic Fuzzy logic is capable of modelling vagueness, handling uncertainty, and supporting human type reasoning. They estimate a function without any mathematical model and learn from experience with sample data. Fuzzy logic starts with the concept of a fuzzy set. A fuzzy set is a set without a crisp; clearly defined boundary. Fuzzy set theory provides a systematic calculus to deal with such information linguistically and it performs numerical computations by using linguistic labels stipulated by membership functions. Moreover, a selection of fuzzy if then rules forms the key components of a fuzzy inference system that can be effectively model human expertise in a specific application. Although the fuzzy inference system has a structured knowledge representation in the form of fuzzy if-then rules. A fuzzy inference system (FIS) is an inference mechanism establishing a relationship between a series of input and output sets. The inference system uses fuzzy sets theory, fuzzy logic principles when establishing such a relationship. Fuzzy inference system (FIS) is a rule based system consisting of three conceptual components. These are: (1) a rule base containing fuzzy if– then rules, (2) defining the membership functions(MF) and (3) an inference system, combining the fuzzy rules and producing the system results. Reports were found using different fuzzy inference system such as Mamdani fuzzy inference system and Sugeno Fuzzy inference system in urban water demand prediction. The general structure of the Mamdani fuzzy inference system is shown in figure1.

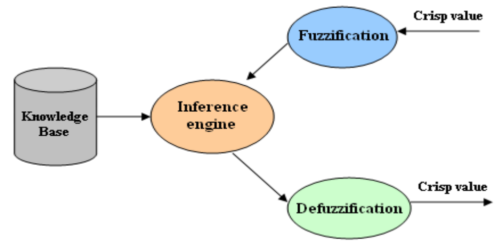

Figure 2: Structure of a fuzzy inference system

In fuzzy logic method, different models are developed using trapezoidal membership function and triangular membership function and also different rules criteria like three rules and nine rules. From the results comparison it is found that three rules triangular membership function is performed better, hence it is adopted for fuzzy modelling. It is also known that all water resources data are ambiguity in nature, exact division of fuzzy set is not possible. So assuming fifty percent as over lapping different fuzzy set are employed in the analysis.

Fuzzy Rule Based System

In the fuzzy inference method, sets of corresponding input and output measurements are provided to the fuzzy system and it learns how to transform a set of inputs to the corresponding set of outputs through a Fuzzy Associative Map (FAM) which is also called the Fuzzy Associative Memory. Fuzzy logic does not provide a rigorous way for developing or combining fuzzy rules which can be achieved through many ways. The method adopted in this paper is outlined below. First the input and output variables are divided into a number of subsets with simple triangular fuzzy membership functions.

ISSN 2229-5518

Generally, there are m*n fuzzy rules where m and n are the numbers of subsets and input variables, respectively. In the case, say, of two inputs X1 and X2 with m subsets each, the rule base takes the form of an output Y $_k$ (k=1, 2 . . . m2). If there are two input variables as X1 with "very small" and "small" fuzzy subsets and X2, say, "Medium" and "large" 2 subsets, then consequently there will be four rules as

R1 IF X1 is very small and X2 is medium THEN Y1

R2 IF X1 is very small and X2 is large THEN Y2

R3 IF X1 is small and X2 is medium THEN Y3

R4 IF X1 is small and X2 is large THEN Y4

$$Y = \frac{\sum_{k=1}^{4} W_k Y_k}{\sum_{k=1}^{4} W_k}$$

For each triggered rule the membership degrees for both X1 and X2 are computed and these are multiplied to give the weight W_k to be assigned to the corresponding output Y_k. Hence the weighted average of the output from four rules is a single output Y as,

Thus, once the rule base is set up, values of the output can be computed from the equation for any combination of input variables fuzzy subsets. A very common method in deciding about the fuzzy rule base is to use sample data and derive the necessary rule base by the fuzzy inference procedure. This involves computing the weight of each rule triggered, accumulating weights and outputs for each rule and finally computing the weighted output for each rule.

5. CHARACTERISTIC DATA

Table 1 represents the Characteristics of the data set. From the table we can identify the maximum, minimum and average value of rainfall during the selected period.

Table 1: Characteristics of the data set

Years	Xmax	Xmin	Average	S . D	Skewness
2000	222.7	0	82.6	77.02	0.48
2001	332	0	88.33	107.21	1.39
2002	184	0	63.87	74.78	0.9
2003	208	0	60.55	66.77	0.99
2004	285	0	95.39	106.54	0.89
2005	606	0.2	132.99	168.21	2.24
2006	164	0	56.75	54.67	1.12
2007	271	0	104.3	97.31	0.47
2008	310	0	107.65	106.31	0.92
2009	259.8	0	67.4	76.72	1.66
2010	166	0	84.33	65.08	-0.28
2011	265.2	0	70.1	81.61	1.49
2012	138.5	0	49.54	51.92	0.55
2013	410.5	0	69.45	111.88	2.98
2014	383.5	0	81.78	107.99	2.19
2015	254	0	112.58	92.6	0.19

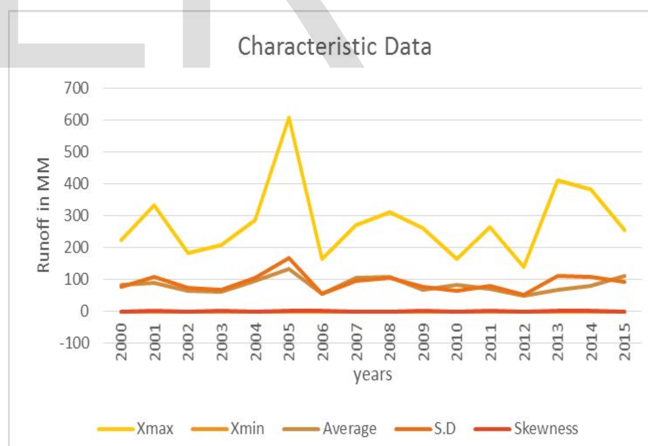

Figure 3: variation of rainfall

6 RESULTS AND DISCUSSIONS

Table 2 shows the values of runoff using different empirical methods and Fuzzy logic method. From the results we found that Khosla and Khuzla methods of estimating the runoff are closer compare to other empirical methods. Since fuzzy Logic is based on rule based and membership function, the obtained runoff value is low. Hence rules must be modified for further improvement in the result.

Table 2: Showing results of runoff using various methods

Years	Khuzla	Inglis	IRD	Khosla's	Fuzzy logic		
					3 rule	6 rule	8 rule
2000	215.21	179.65	100.45	209.26	80.5	50.2	50.2
2001	238.78	410.68	159.66	233.04	128	79.8	79.8
2002	175.97	120.39	78.72	166.744	64.4	40.1	40.1
2003	200.8	155.75	92.72	195.088	74.3	46.4	46.4
2004	277.51	299.81	133.86	255.944	107	66.9	66.9
2005	599.39	1403.34	316.85	594.144	158	158	158
2006	156.24	94.39	70.08	150.08	56.2	35	35
2007	263.72	270.14	126.27	257.944	101	63.1	63.1
2008	302.67	356.63	147.53	296.848	82.6	73.8	73.8
2009	251.88	247.52	120.23	245.592	60.1	60.1	60.1
2010	158.48	96.85	71.05	152.516	66.9	35.5	35.5
2011	258.43	258.3	123.14	253.056	61.6	61.6	61.6
2012	130.9	65.8	57.24	124.868	45.8	28.6	28.6
2013	403.01	634.65	203.65	397.06	102	102	102
2014	378.15	552.14	188.44	373.9	151	94.2	94.2
2015	247.23	236.2	117.11	241.336	93.5	58.6	58.6

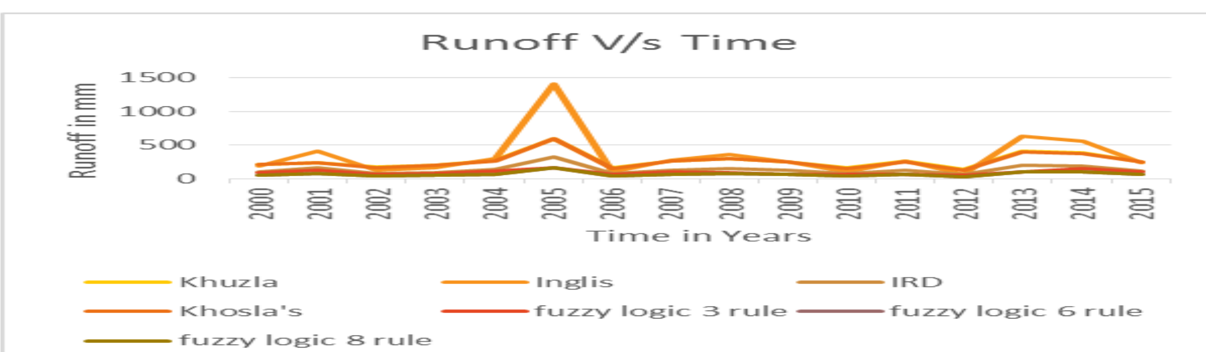

Figure 4: Runoff values for different methods

7. CONCLUSION

In the present study, various empirical methods like Khuzla's, Inglis and Desouza, Indian Irrigation Department, Khosla's formula and fuzzy logic model has been adopted to estimate the runoff for the Yelahanka region using the rainfall data of 16 years [2000-2015] taken from the Metrologic Department of Yelahanka, Bangalore. Using empirical methods and fuzzy logic method, 16 years of rainfall data were analyzed. From the Table No 2 we can conclude that the Khuzla's and Khosla's method of estimating the runoff are closer, Inglis formula found to have higher values of runoff. Fuzzy Logic method gave low values of runoff, but using optimum rules and proper membership function, results can be improved.

8. REFERENCES

- **A.Candela**., **G.Brigandi**., and **G.T.Aronica.,** (2014), "Estimation of rainfall- runoff by design hydrographs using a distributed rainfall–runoff model coupled with a copula-based single storm rainfall generator". Nat. Hazards Earth System Science. Volume-14, ISSN: 1819–1833.
- **Ahmed Abu El-Nasr., Patrick Willems., Luis Timbe., Karen Christianes** and **Jan Feyen.,** (2010), **"**Comparative Analysis of the Runoff-Generation Using Lumped and Distributed Approaches, with Application to the Jeker Catchment in Belgium".
- **Ali Mahmoudi., Mojtaba Hamzeh Ghassabsaraei** and **Mohsen Nasrollahi.,**(2011), "A comparative evaluation of Artificial Neural Network models and Empirical methods". International Congress on Irrigation and Drainage, PP 485-497.
- **Anand B Kudoli** and Prof**. R.A.Oak.,** (2015), "Runoff Estimation by using GIS based Technique and its comparison with different methods- A Case Study on Sangli Micro Watershed". International Journal of Emerging Research in Management and Technology, ISSN: 2278-9359, Volume-4, Issue-5, PP 131-137.
- **A.Sarangi.,C.A.Madramootoo., P.Enright., S.O.Prasher** and **R.M.Patel., "**Performance evaluation of ANN and geomorphology-based models for runoff and sediment yield prediction for a Canadian watershed". Indian Agricultural Research Institute, New Delhi 110 012, Volume-5, Issue-4.
- **Asmita.B.L., B.V.Khode** and **N.Z.Baisware,**(2014),"Estimation of Runoff for Agriculture Watershed and Silt Load Assessment". International Journal of Innovative Research in Advanced Engineering (LIJRAE), Volume-1, Issue-3, ISSN: 2278-2311.
- **A.Viglione., A.Castellarin., M.Rogger., R.Merz** and **G.Bloschl.,**(2012), "Extreme Rainstorms: Comparing Regional Envelope curves to Stochastically generated events". Water Resources Research, Volume-48, W01509, PP 1-16.
- **B.Yu and Ciesiolka.,**(1999), "Comparison of GREEN-AMPT and SPATAILLY Variable Rainfall model for natural storm events". American Society of Agricultural Engineers 0001-2351 / 99 / 4201-89, Volume-42(1), PP 89-97.
- **C.L.Wu** and **K.W.Chau.,** (2011), "Rainfall-Runoff Modelling using

Artificial Neural Network coupled with Singular Spectrum Analysis". Journal of Hydrology, Volume-399, Issue-3-4, PP 394-409.

- **Dhemi Harlan., Muljana Wangsadipura.,** and **Cecep Muhtaj Munajat.,**(2010), "Rainfall-Runoff Modeling of Citarum Hulu River Basin by Using GR4J". Proceedings of the World Congress on Engineering, Volume-2, ISSN: 2078-0958 (Print), ISSN: 2078-0966, PP 978-988.
- **D.K.Khopade** and Prof**.R.A.Oak.,** (2014), "Estimation of Runoff Yield for Nira Deoghar catchment using different Empirical equations". The International Journal of Engineering and Science (IJES), ISSN(e): 2319-1813 ISSN(p): 2319-1805, Volume-3, Issue-6, PP 75-81.
- **D.L.Ficklin** and **M.Zhang.,**(2013), "A Comparison of the Curve Number and Green-Ampt models in an Agricultural watershed". American Society of Agricultural and Biological Engineers, ISSN: 2151-0032, Volume-56(1), PP 61-69.
- **Dr.G.Venkataramana.,** (2014), "Regression Analysis of Rainfall and Runoff Process of a Typical Watershed". International Journal of Science and Applied Information Technology, ISSN: 2278-3083, Volume-3, Issue-1, PP 16-26.
- **Dr.G.V.Ramana., Dr.G.K.Viswanadh** and **Dr.N.C.Gautam.,** (2011), "Rainfall and Runoff process using by overland Time of Concentration Model and GIS Modules". 12th Ersi India User Conference.
- **E.K.Naseela., B.M.Dodamani** and **Chaitra Chandran.,** (2015), "Estimation of Runoff using NRCS-CN method and Shetran model". International Advanced Research Journal in Science, Engineering and Technology, ISSN: 2393-8021, ISSN: 2394-1588, Volume-2, Issue-8, PP 23-28.
- **Ismail Abustan., Ahmad Husaini Sulaiman., Nabsiah Abdul Wahid** and **Fauzi Baharudin.,**(2008),"Determination of Rainfall-Runoff characteristics in an Urban Area". 11th International Conference on Urban Drainage, Edinburgh, Scotland, UK.
- **Jamileh Farajzadeh., Ahmad Fakheri Fard** and **Saeed Lotfi.,** (2014), "Modeling of monthly rainfall and runoff of Urmia lake Basin using Feed-Forward Neural Network and Time Series Analysis model". Water Resources and Industry, Volume-7, Issue-8, PP 38–48.
- **Karim Solaimani.,** (2009),"Rainfall-runoff Prediction Based on Artificial Neural Network".American-Eurasian Journal, Agricultural and Environmental Science. Volume-5, Issue-6, ISSN: 1818-6769, PP 856-865.
- **Kazimierz Banasik** and **Donald Woodward.,** (2010), "By Empirical determination of runoff Curve Number for a small agricultural Watershed in Poland". 2nd Joint Federal Interagency Conference, Las Vegas.
- **Khabat Khosravi., Haidar Mirzai** and **Iman Saleh.,** (2013), "Assessment of Empirical Methods of Runoff Estimation by Statistical test (Case study: BanadakSadat Watershed, Yazd Province)". International journal of Advanced Biological and Biomedical Research, ISSN: 2322 – 4827, Volume-1, Issue-3, PP 285-301.

- **M.Latha** and **M.Rajendran.,** (2015), "An empirical Approach to Estimate Runoff of an Ungauged Catchment –Strange Table Method". International Journal of Research in Advent Technology, Volume-3, No 9, E-ISSN: 2321-9637, PP 125-128.
- Phd Scholar ***M.Latha*** and Prof. ***M.Rajendran.,*** (2012), "Comparison of GIS based SCS-CN and Strange table method of Rainfall Runoff models for Veeranam Tank, Tamil Nadu, India". International Journal of Scientific and Engineering Research, ISSN: 2229-5518.
- **Mohammad Golshan** and **Payam Ebrahimi.,** (2014), "Estimation of the Runoff by Empirical Equations in Dry and mid-dry Mountains area without stations. Case study: Madan Watershed, Qazvin province-Iran". Bulletin of Environment, Pharmacology and Life Sciences, Volume-3, ISSN: 2277-1808, PP 77-85.
- **M.R.Yazdani., B.Saghafian., M.H.Mahdian** and **S.Soltani.**, (2009), "Monthly Runoff Estimation Using Artificial Neural Networks". J. Agric. Sci. Technol. Volume-11, PP 355-362.
- **M.R.Yazdani., B.Saghafian., M.H.Mahdian., and S.Soltani.,** (2009),"Monthly Runoff Estimation Using Artificial Neural Networks". Journal of Agricultural Science and Technology. Volume-11, PP 355-362.
- **Narasayya** and **Kamuju.,** (2015), "Rainfall-Runoff Estimation and Comparative Analysis Using Advanced Geospatial Digital Hydrological Modelling Tools, Arc-CN & Arc-SWAT model".SSRG International Journal of Geo informatics and Geological Science (SSRG-IJGGS), Volume-2, Issue-4.
- **Nikola Zlatanovic** and **Sonja Gavric.,** (2013), "Comparison of an Automated and Manual Method for Calculating Storm Runoff Response in Ungauged Catchments in Serbia". J. Hydrol. Hydromech, Volume-3, DOI: 10.2478/johh-2013-0025, PP 195-201.
- **P.N.Tandon** and **P.T. Nimbalkar**., (2014), "Rainfall- Runoff Relationships Using Curve Number Method: A Case Study". International Journal of Advanced Engineering Research and Studies, Volume-4, Issue- 1, E-ISSN: 2249-8974.
- **Ravindra Yaligar., R.K.Isaac, P.S.Kanannavar., Mallappa.J.M and Shashireka.,** (2015), "Estimation of Runoff using SCS-CN method for Chaka block Allahabad district of Uttar Pradesh". International Journal of Agricultural Science and Research, Volume-5, Issue-1, ISSN(P): 2250-0057, ISSN(E): 2321-0087, PP 81-86.
- **Rathika Pradhan.**, **Mohan P.Pradhan., M.K.Ghose., Vivek S.Agrawal** and **Sakshi Agrawal.,** (2013), "Estimation of Rainfall Runoff using Remote Sensing and GIS in and around Singtam, East Sikkim". International Journal of Geo-matics and Geosciences, ISSN: 0976-4380, Volume-3, PP 466-476.
- **R.K.Suryawanshi., S.S.Gedam** and **R.N.Sankhua.,** (2012), "Comparative Analysis of Spatial Rainfall and Runoff estimation using Geospatial Tools, ANN and Empirical approach". International Journal of Emerging Technology and Advanced Engineering, ISSN: 2250-2459, Volume-2, Issue-10, PP 295-299.
- **Sameer Shadeed** and **Mohammad Almsari.,**(2010),"Application of GIS-

based SCS-CN method in West Bank catchments, Palestine". Water Science and Engineering, Volume-3, Issue-1, ISSN: 1674-2370, PP 1-13.

- **Setionoa and Rintis Hadiani.,** (2015), "Analysis of rainfall-runoff neuron input model with artificial neural network for simulation for availability of discharge at Bah Bolon Watershed". The 5th International Conference of Euro Asia Civil Engineering Forum (EACEF-5), PP 150-157.
- **Sharbanu Firuzi., Mohamadbagher Sharifi** and **Kambiz Borna.,** (2011), "Using Empirical relationships and Neural Network in GIS for developed rainfall-runoff modelling". TS09E-Engineering Surveying-Software, 5264, Bridging the Gap between Cultures Marrakech, Morocco.
- **V.Livina., Z.Kizner., P.Braun., T.Molnar., A.Bunde** and **S.Havlin.,**(2007), "Temporal scaling comparison of real hydrological data and model runoff records". Journal of Hydrology, Volume-336, PP 186-198.