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ESTIMATION OF RAINFALL-RUNOFF RELATIONSHIP IN EAST SINGHBHUM DISTRICT, JHARKHAND, INDIA

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ABSTRACTS

The relationship between climatic parameters of the East Singhbhum district was analyzed by compilation of rainfall data from 2001to 2013 annually to extract the runoff data and along with this the data of temperature from 1991to 2002 was taken to correlate the relationship between temperature and runoff of the study area. The long-term trend of the hydrological time series including temperature, rainfall and runoff were studied using correlation analysis. Rainfall and runoff patterns affect mans activities in so many ways so these two form an important climatic parameters storm water management. This paper has used some of the statistical analysis method to study the relationship between climatic elements (rainfall, infiltration rate and temperature) with runoff. The study was found that the relation between runoff and infiltration, between rainfall and runoff was correlated strongly. Whereas the correlation between temperature and runoff was found weak. Therefore, the role of climatic elements such as temperature, rainfall and runoff in the study area is quite concrete.

KEYWORDS: Climatic Parameters, Environment, Correlation, Rainfall, Runoff

INTRODUCTION

The most important relationships for any watershed are the relationship between rainfall and runoff. This relationship is basically depends on some factors such as characteristics of rainfall, runoff, temperature and infiltration. Though the factors which are mentioned about it have a major impact on volume of runoff. A consistent correlation between rainfall-runoff enables to increase more in sufficient time for formulation of appropriate decision making for the local authority. Runoff is generally generated by rainstorms whose occurrence and quantity are reliant on the characteristics of the rainfall. The relationship of rainfall-runoff is one of the most used procedures in hydrology. Different methods have been developed by different researchers for simulation of rainfall runoff process. Tandon and Nimbalkar (2014) have developed a relationship of runoff and rainfall and validated by using statistical model. This process is similar to those in rural areas but they generally occur at smaller time and space of urban areas than in rural areas (Delleur, 2003). This is an important component which contributes extensively to the hydrological cycle, hydrological structures and drainage morphology. Runoff is generally generated by rainstorms whose occurrence and quantity are reliant on the characteristics of the rainfall. Along with these rainfall characteristics, there is also a number of precise factors on the event and volume of runoff as direct effect (Pradhan et al. 2010). Due to the outstanding spatial and temporal variability of watershed characteristics, this relationship form one of the most intricate hydrological phenomenon in concerned with the physical processes. The model of rainfall-runoff also plays a important role in management and planning of water resources (French et al. 1992; Karunanithi et al.1994). Direct rainfall-runoff is estimated efficiently but is not possible for most of the location at desired time. This run-off is actually the drainage or flow of precipitation from a catchment area of the surface canal which present the output from the catchment at a given time. Before the instigation of runoff there is need of precipitation, evapotranspiration, initial loss, infiltration and detection storage which has to be fulfilled first, then the excess precipitation moves to the land surfaces through smaller channels as overland flow which forms storage surface. Flows from several small channels join to form larger channels which ultimately flow into a larger stream of the catchment. A part of the precipitation that infiltrates into the soil of the upper crusts of the surface which returns to the surface at some location that is away from the point of entry into the soil. The amount of interflow depends on the geological conditions of any catchment (Subramanya, 2009). It is hope that this study will provide basic idea of runoff generation in relation to climate conditions (rainfall, temperature and infiltration).Therefore, the main objectives of this paper is to study about correlation between infiltration, rainfall, temperature with runoff and their relationship.

Rainfall can be viewed as the dynamic potency in a rainfall - runoff relationship. After a certain period of time of rainfall, that runoff is seen. As soon as the rainfall occurs, some part of the rainfall is intercepted by leaves and stems of trees and rest of them are absorbed by the ground surface which infiltrate into the soil. After certain period of infiltration the soil started to become saturated and when the rainfall intensity exceeds the infiltration rate, water flows on the surface which actually known as surface runoff. Rainfall is one of the major elements of the hydrologic cycle and primary source of runoff (Beven, 2001b). It is effectively required for fulfillment of various demands such as agriculture, industries, ecology etc. It is understood that the rainfall is a natural process which occurred due to atmospheric circulation and has large variability at different space and of time .Many attempts have been made worldwide to model and predict rainfall behaviour using different types of empirical, statistical, and numerical techniques (Namias, 1968; Koteshwaram and Alvi, 1969; Ramamurthy et al. 1987; Jha and Jaiswal, 1992; Chiew et al, 1993; Kuo and Sun, 1993; Langu, 1993; Meher and Jha, 2011(a); Meher and Jha, 2011(b)). Still there are more research are needed to focus on the empirical approaches for estimation and prediction of rainfall exactly. Generally data are collected by using rain gauges which are considered as point precipitation data. Still, the use of a single rain gauge as precipitation input carries lots of uncertainties related to estimation of runoff (Faur`es et al., 1995 and Chaubey et al., 1999).That creates a lot of problem for the discharge prediction, especially when the rain gauge is located outside the basin (Schuurmans and Bierkens, 2007). As a result, some utilities such as hydrological modelling (Syed et al., 2003; Kobold and Suˇselj, 2005; Gabellani et al., 2007; Cole and Moore, 2008; Collischonn, et al., 2008; Ruelland et al., 2008; Moulin et al., 2009) need rainfall data that are spatially continuous. The result is therefore estimated by the quality of the continuous spatial rainfall (Singh, 1997; Andr´eassian et al., 2001; Kobold and Suˇselj, 2005; Leander et al., 2008; Moulin et al., 2009). In the past there are also various spatial interpolation techniques which have also been used to obtain representative rainfall over the entire basin or sub-basins for the calculations of runoff.

STUDY AREA

East Singhbhum District is situated at the extreme corner of the southeast of Jharkhand. From the industrial growth and mining quarrying point of view district has a leading position in Jharkhand. Occupying an area of 3533 sq. km which is about 2.03% of the whole state. About 53% of the total area of district is covered by residual mountains and hills consisting of granite, gneiss, schist and located in the Chotanagpur Plateau in Jharkhand State. The Dalma range extends from west to east covered by dense forest on the northern side. The Subernarekha River flows from west to south-east direction. The district is rich in minerals and these are found abundantly. The district encompasses 86° 04' and 86° 54' East Longitudes and 22°12'and 23 °01' North latitudes. It falls under survey of India toposheet No. 73 J/01-03, J/05-12, J/14-16. The district headquarter is at Jamshedpur. The district comprises of eleven blocks, 200 Gram Panchayat and 1788 villages. It has 11 developed blocks namely Patamda, Jamshedpur, Potka, Ghatshila, Musabani, Chakulia, Dalbhumgarh, Baharagora and Dumaria, Boram and Gurbandha. Figure 1. shows the location map of study area which comprises of thirty sampling points.

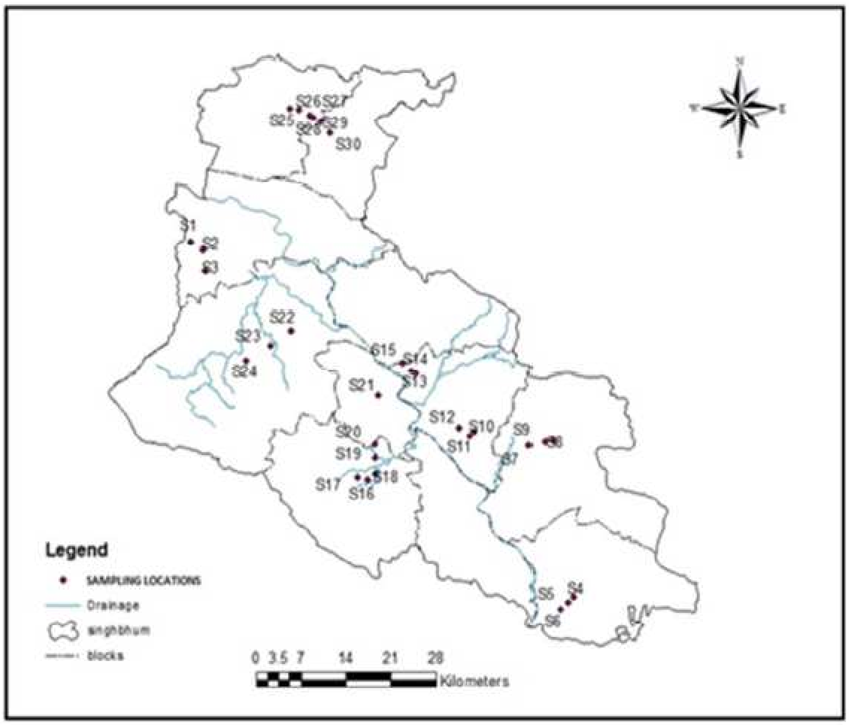

Figure 1: Location Map of Study Area (East Singhbhum, Jharkhand, India)

East Singhbhum district has remarkably unique geological history. From Beharagora in the South East up to East of Jamshedpur a major thrust zone is present which further enters in to Saraikela Kharsawan district. The shear zone separates a northern terrain of highly metamorphosed rocks and southern terrain of relatively less metamorphosed rocks. Sarkar and Saha (1977) have shown that this shear zone separates two Precambrian provinces of the Indian shield: an older province in the south which stabilized after the Iron ore orogenic cycle closing about 2900 million years ago and younger province in the north that underwent the Singhbhum orogenic cycle closing at about 850 million years ago. The study area is situated in the south of this thrust zone and a general stratigraphic sequence of this area (CGWB, 2013).

CLIMATE

The district receives an annual rainfall of 1500 mm. and most of it occurs during the rainy season. Mean annual temperature is above 260 C. The temperature ranges from 160 C in winter month to 440 C in summer months.

RELATIONSHIP BETWEEN RUNOFF AND INFILTRATION RATE

According to K. Subramanya (2009), the relationship between runoff and infiltration rate can be correlated from past thirteen years of average monthly rainfall data for estimating correlation coefficient which gives the relation between runoff and infiltration rate. The ϕ-index for any catchment, during a storm depends upon the soil type, vegetal cover, initial moisture condition, storm duration and intensity. Complete information is achieved for the interrelationship between these factors, a thorough exclusive study of the catchment is necessary. As such, for practical use in the estimation of flood magnitude due to critical storm a simplified relationship for ϕ-index is adopted. As the maximum flood peaks are consistently produced due to long storm and a usually in the wet season, the initial losses are assumed to be negligibly small. Further, only the soil type and rainfall are found to be critical in the estimate of the ϕ-index for maximum flood producing storms.

Method for Runoff-Infiltration Relationship

On the basis of rainfall and runoff correlation, the following relationship has been given by the (CWC, 1973) for the estimation of ϕ-Index:

Table 1: Variation of Coefficient α According to (CWC, 1973)

S. No.	Type of Soil	Coefficient α
1	Sandy soils and sandy loam	0.17 to0.25
2	Coastal alluvium and silty loam	0.25 to 0.34
3	Red soils, clayey loam, grey and brown alluvium	0.42
4	Black-cotton and clayey soils	0.42 to 0.46
5	Hilly soils	0.46 to 0.50

R=αI1.2 (1)

ϕ=I-R/24 (2)

Where R = runoff in cm

I = rainfall intensity from 24-h (cm/h)

And α= a coefficient which depends upon the soil type as indicated in table.1.

The value of a ϕ-Index can be assumed as 0.10 cm/h.

Based on the table.2, estimation of average runoff was calculated from average rainfall intensity which is represented in table.3.

Table 2: **Monthly Average Rainfall data of Study Area (2001-2013)**

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Avg (cm)
2001	0	15.5	49.8	35.1	164.4	469.4	480.1	388.7	184.6	90.8	0	0	15.65
2002	16.7	0	4.3	21.8	61.5	315	149.8	319	280.7	0	3.6	13.4	9.88
2003	0	45	26	5.8	31.7	82.3	203.1	153.3	94	114.9	0	6	6.35
2004	0	15.5	11.5	61.1	64.8	191.8	249.2	516.8	161	75.2	0	0	11.22
2005	25.5	24.8	21.1	7.2	68.9	156.6	246.8	163.4	152.8	137.3	0	67.3	8.93
2006	0.3	0	2.3	42.5	193.5	351.8	706.3	331.2	377.5	29.6	17.4	0	17.10
2007	0	64.8	30.11	40.9	10.8	146.5	646.4	498.5	374.4	27.2	32.3	0	15.60
2008	30.8	7.5	8.6	46.4	85.4	655.1	275.6	313.2	200.3	5.4	0	0	135.69
2009	2.9	0	11	0.4	130.8	66.8	396	228.1	268	153.5	22.3	6.3	10.72
2010	0.5	6.2	5.8	10.4	74.1	51.7	99.6	133.1	137.2	48.3	10.6	38.6	5.13
2011	3.4	1.2	27.1	42.4	66.5	400.8	140.2	437.4	365.8	24.1	0	0	12.57
2012	42.4	17.6	0	50.4	34.8	189	418.3	291.4	268.6	40.6	50.2	22.1	11.88
2013	0	12.4	1.8	37.4	184.4	229.5	334.2	372.3	327	349	0	0	15.40

Table 3: Estimation of Runoff from Rainfall Intensity

S. No.	α (Coefficient)	I(Rainfall of intensity) (cm)	Runoff (cm)
1.	0.19	15.65	5.16
2.	0.21	9.88	3.28
3.	0.18	6.35	1.65
4.	0.12	11.22	2.18
5	0.22	8.93	3.04
6.	0.17	17.10	5.13
7.	0.18	15.59	4.86
8.	0.18	135.69	65.21
9.	0.17	10.71	2.93
10.	0.18	5.13	1.28
11.	0.17	12.57	3.55
12.	0.17	11.87	3.31
13.	0.18	15.40	4.79

The infiltration rate is the average rainfall above which the rainfall volume is equal to the runoff volume. The ɸ-index is derivative of rainfall hyetograph with the resulting runoff volume. The initial loss is also considered as infiltration. The ɸ value is found by treating it as a constant infiltration capacity. If the rainfall intensity is less than ɸ, then the infiltration rate is equal to the rainfall intensity, and if the rainfall intensity is larger than ɸ the difference between the rainfall and infiltration in an interval of time represents the runoff volume. So the relationship between runoff and infiltration rate can be obtained which has been presented in table.4.

Table 4: Relation between Runoff and Infiltration Rate (2001-2013)

S. No.	Year	I (Rainfall of Intensity) (cm)	Runoff (cm)	(Infiltration Rate) ɸ
1.	2001	15.65	5.15	0.44
2.	2002	9.88	3.28	0.28
3.	2003	6.35	1.65	0.20
4.	2004	11.22	2.18	0.38
5.	2005	8.93	3.04	0.25
6.	2006	17.10	5.13	0.50
7.	2007	15.60	4.86	0.45
8.	2008	135.69	65.21	2.94
9.	2009	10.72	2.92	0.32
10.	2010	5.13	1.28	0.16
11.	2011	12.57	3.54	0.38
12.	2012	11.88	3.31	0.36
13	2013	15.40	4.79	0.44

Based on data of the above Table.4, the relationship between runoff and infiltration rate can be obtained in the figure 2. As the value of r is nearer to unity the correlation is said to be good so figure 2 represents the best fit straight line.

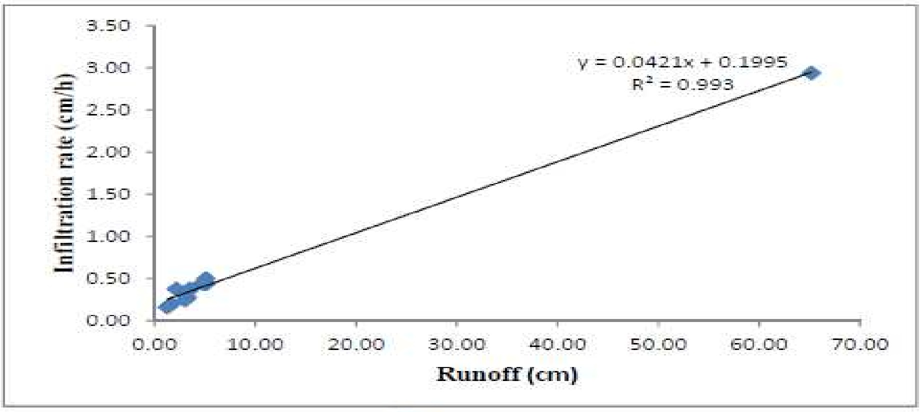

Figure 2: Correlation between Runoff and Infiltration rate (2001-2013)

METHOD FOR ANNUAL RAINFALL-RUNOFF RELATIONSHIP

This method (or formula) is adopted by Subramanya (2009) for formulation of linear regression line, it is a line adopted between R and P to show the result of correlation coefficient whose result is considered as nearer to unity which is known to be good result. The equations for the straight-line regression between runoff R and rainfall P is given as following:

$$R = aP + b \quad (1)$$

And the values of a and b are given by

$$a = \frac{N(\sum PR) - (\sum P)(\sum R)}{N(\sum P^2) - (\sum R)^2} \quad (2)$$

$$b = \frac{\sum R - a(\sum P)}{N} \quad (3)$$

Where, N= number of observation of sets R and P. The coefficient of correlation r can be calculated as

$$r = \frac{N(\sum PR) - (\sum P)(\sum R)}{\sqrt{[N(\sum P^2) - (\sum P)^2][N(\sum R^2) - (\sum R)^2]}} \quad (4)$$

The value of r lies between 0 and 1 as R can have only positive correlation with P. The value of $0.6<r<1.0$ indicates good correlation. Further, it should be noted that $R\geq 0$.

For accurate results, the sophisticated methods are adopted for synthetic generation of runoff data. Many improvements have been attempted for the above basic rainfall-runoff correlation Antecedent rainfall influences the initial soil moisture and hence the infiltration rate at the start of the rainstorm. The calculation of annual rainfall-runoff has been shown in table.5.

Table 5: Calculation of Annual Rainfall-Runoff (2001-2013)

Year	Annual Rainfall P (cm)	Annual Runoff R (cm)	P^2	R^2	PR	Rank (m)	R(Sorted Annual Runoff) (cm)	Exceedence Probability (*p*)
2001	15.7	7	246.49	49	102.61	23	4	0.6389
2002	9.9	4	98.01	16	38.76	24	4	0.6667
2003	6.4	2	40.96	4	14.84	25	4	0.6944

Table 5 Continue…….								
2003	11.2	5	125.44	25	50.84	26	4	0.7222
2004	8.9	3	79.21	9	30.66	27	4	0.7500
2005	17.1	7	292.41	49	123.82	28	4	0.7778
2006	15.6	6	243.36	36	101.18	29	4	0.8056
2007	13.6	6	184.96	36	77.93	30	3	0.8333
2008	10.7	4	114.49	16	45.98	31	3	0.8611
2009	5.1	2	26.01	4	9.01	32	3	0.8889
2010	12.6	5	158.76	25	63.25	33	3	0.9167
2012	11.9	5	141.61	25	58.10	34	2	0.9444
2013	15.4	6	237.16	36	98.35	35	2	0.9722
Sum	**154.1**	**63**	**1988.87**	**330**	**815.32**			

The coefficient of the best fit straight line for the data are obtained by the least square error methods as mentioned in table.1. According to the data given in table.5, the following calculation has been done.

a = 0.422

Based on above calculation annual rainfall and runoff was presented in table.6.

Table 6: **Annual Rainfall and Runoff (2001 -2013)**

Year	Annual Rainfall (cm)	Annual Runoff (cm)
2001	15.7	7
2002	9.9	4
2003	6.4	2
2004	11.2	5
2005	8.9	3
2006	17.1	7
2007	15.6	6
2008	13.6	6
2009	10.7	4
2010	5.1	2
2011	12.6	5
2012	11.9	5
2013	15.4	6

b = -0.156

R = 0.422

P = -0.156

Therefore the required annual rainfall- runoff relationship of the study area is given by

R=0.476

P= -0.842 (both P and R are in cm and R $\geq$0.

From Eq. (4) coefficient of correlation is:

r = 1.082

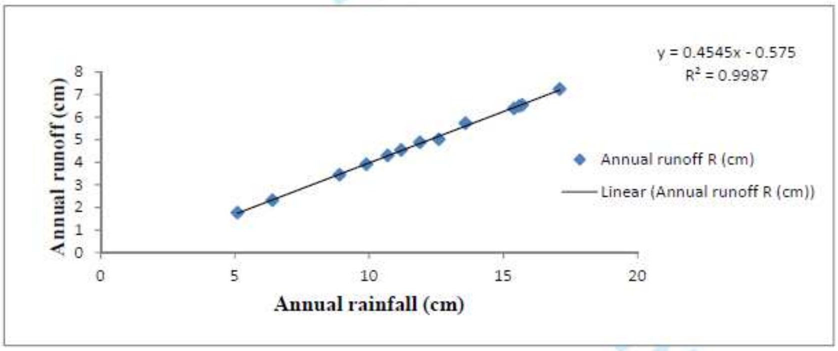

Figure 3: Annual Rainfall-Runoff Relationship of Study Area (2001-2013)

As the value of r is equal to +1 which is a positive correlation, signifies that both variables move in the same direction. It also signifies that the two variables being compared have a perfect positive relationship; that means these two are strongly related. The closer the value of r is to +1, the stronger the linear relationship. Positive values indicate a relationship between rainfall and runoff such that as the rainfall increases, runoff also increases. As the value of r is nearer to +1 the correlation is said to be good, figure. 2 represent the data points and the best fit straight line. Using the average annual rainfall along with annual runoff scatter diagram is drawn. The rainfall-runoff relationship for East Singhbhum district indicates a good correlation between both properties with R^2 of 0.99 ($p<0.05$). The linear regression is presented in figure 3. Of rainfall-runoff relationship. As we can expect a direct relationship between annual rainfall and runoff of the district. If the coordinates of the annual rainfall and runoff can be plotted in a coordinate system, parts of them can be fitted to a line or curve. Figure.3. shows the relationship between annual rainfall (cm) and annual runoff (cm) for East Singhbhum district. From the slope of the line which is 0.998, a mathematical relationship between rainfall and runoff can be achieved. It can be seen that the curve has crossed the center coordinates but have 0.575 mm intercept that is, in the year 2010 the annual rainfall was less than 6 mm, and there is virtually no runoff. Also from mathematics point of view using this relationship between rainfall and runoff is concluded that except year (2010), in the remaining year with increased rainfall, the annual runoff is high. The equation can be written as:

So the equation can be written as:

$Y = 0.4545x - 0.575$

$R^2 = 0.998$

The amount of annual rainfall and runoff can also be presented in form of line graph represented in figure.4.

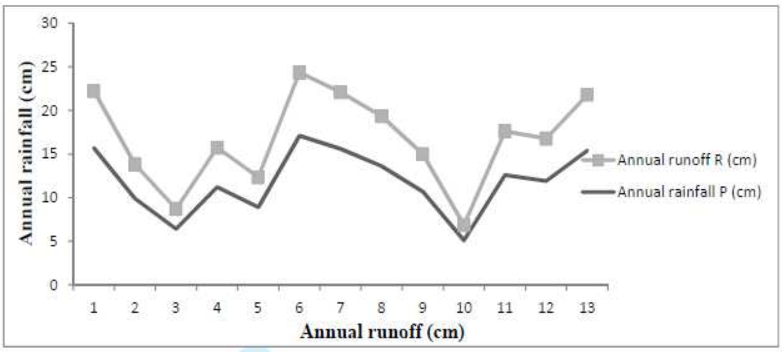

Figure 4: **The Amount of Annual Rainfall and Runoff Data in the Study Area**

THE RELATIONSHIP BETWEEN TEMPERATURE AND RUNOFF

Temperature and Rainfall are the two most important dynamic factors for the crop production and the available water resources for year-to-year variability. Moreover, agriculture directly depends on the magnitude and temporal distribution of the rainfall (Garrousi and Chandrashekara, 2012). The area receiving rainfall is also an important factor in determining the water availability to meet different demands, such as agriculture, industrial, domestic water supply and for hydroelectric generation of power (Jain and Kumar, 2012). The altering of temperature and radiation balance together changes rainfall pattern which change the hydrological cycle of the earth–atmosphere system (Subash and sikha, 2014). Simulation of empirical evidences and climate model demonstrate warmer climates, which lead to extreme precipitation, due to increased water vapor, therefore increases the risk of floods (Hennessey et al. 1997; IPCC 2007). The report given by the Intergovernmental Panel on Climate Change (IPCC), the Indian subcontinent will be adversely affected by improved variability of climate, rising temperature and considerable reduction of summer rainfall in some parts and there will be water stress by the 2020s (Cruz et al. 2007). Numerous studies were undertaken for investigation of the trends in long term precipitation and temperature, its interannual, seasonal and decadal variability at different scales such as local, regional, national, continental spatial scales (Chen et al. 1992; Chaudhari 1994; Kadioglu 1997; Izrael et al. 1997; Mirza and Dixit 1997; Rankova 1998; Ren et al. 2000; Brunetti et al. 2000a,b; Salinger and Griffiths 2001; Wibig and Glowicki 2002; Lu et al. 2004; Domroes and ElTantawi2005; Gadgil and Dhorde 2005; Tomozeiu et al. 2006; ElNesr et al. 2010).

Table 7: The Monthly Temperature and Runoff Data of Study Area (1991-2002)

Month	Temperature	Runoff
Jan	25.20	4.82
Feb	27.97	10.46
Mar	33.15	9.42
Apr	36.63	8.13
May	37.83	43.69
Jun	34.67	97.40
Jul	30.72	129.05
Aug	30.03	180.17
Sept	30.49	110.86
Oct	30.27	49.31
Nov	27.88	2.84
Dec	25.38	0.55

The following table.7 compares the amounts of temperature and runoff in the East Singhbhum District. Based on data of the above table, the relationship between temperature and runoff can be obtained in figure 5.

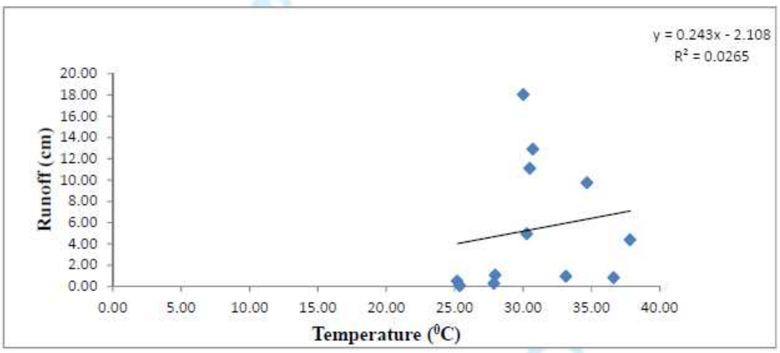

Figure 5: The Relationship between Temperature and Runoff in the East Singhbhum District (1991-2002)

According to the scattered figure 5, there is a reversed relationship between monthly temperature and runoff, since the regression value is very less which is not considered as good correlation, so it is not related to each other and there is no correlation between them. If the coordinates are drawn, there will be a grace line. This is a mathematical relation between temperature and runoff.

In this figure, curve won't cross the center of the coordinates, but it has -21.075 intercept, so the line equal can be written as:

$Y = 2.4299X - 21.075$

$R^2 = 0.0265$

The amount of temperature and runoff also presented in form of line graph in given figure 6.

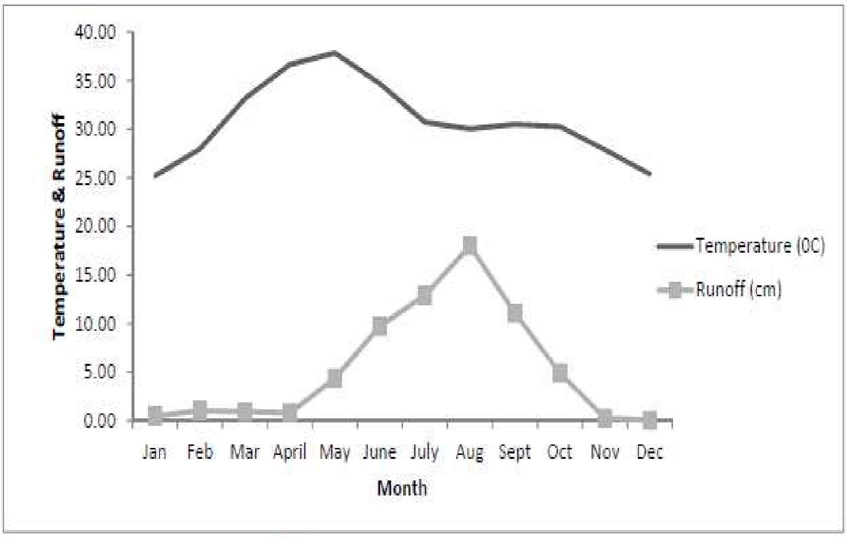

Figure 6: The Amount of Temperature and Runoff in the East Singhbhum

Figure 6 shows a relationship between monthly temperature (ºC) and runoff (mm). According to figure 6 runoff increases in Aug (because of temperature increasing). Also there are the maximum amounts of temperature is in May (37.83ºC and 43.69 mm runoff) and the minimum amount of temperature is in January (25.20ºC and 4.82 mm runoff). There are some reports about the same trends given by Alijani and Kavyani, 2002; Heidi and Siebers, 2007; Garrousi and Chandrashekara, 2012. This relation shows the correlation between temperature and runoff with the increase of temperature runoff decreases.

CONCLUSIONS

This event of rainfall and runoff play an important role in hydrological process. This study shows positive correlation between runoff and infiltration and rainfall and runoff. The correlation also between temperature and runoff was found weak however it shows positive correlation. A correlation is considered as strong when its value is equal to or greater than 0.8, whereas a correlation is weak when value is less than 0.5. These values can fluctuate depending upon the data type being used for analysis. Therefore scientific data that are developing for study may require a stronger correlation than for data for social sciences.

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