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Hydrological characteristics of arid zone drainage basins in Western Rajasthan, India

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Abstract

Hydrological characteristics of Guhiya basin, a typical drainage basin of arid zone of Rajasthan (India) and consists of various type of landform and landuse was studied during 1988-94. Temporal and spatial rainfall variability of daily and annual rainfall were found to be very high. Data suggests that one wet spell once in five year has 98% probability, whereas, stormwise one wet spell of >200 mm annually has 50% probability. The probability of normal rainfall (75-125%) is nearly 34%. The typical depth-area curves for 1-day, 2-days and 3-days storms developed suggests that the maximum rainfall depth has decreasing trend with increase in basin area for each duration. Rainfall intensity-duration-frequency relationship developed predicts the rainfall intensity for different recurrence intervals and different duration storms with perfect accuracy. The correlation coefficient computed for the good fit between observed and computed values is 0.98.

Estimation of runoff and sediment yield is the prime need for planning, designing and management of any water resources project. Linear and multiple regression models have been developed for all the basins. The rational method has been used for computation of peak discharge and value of runoff coefficient (C) has been predicted. Synthetic hydrograph has been employed to estimate the runoff. The relationship between basin lag and physical parameters for mountainous, foothill and plain alluvial drainage areas has been established with considerable accuracy. Runoff, peak discharge and sediment yield have been modelled using linear and multiple regression models. Relationship between sediment concentration and antecedent dry period suggests that the first seasonal flow generates comparatively high sediment concentration than the subsequent flows.

INTRODUCTION

The problem of hydrology and water resources development, management and planning in arid zones are often very different from those in more humid regions. In arid regions the rainfall is low and erratic with high spatial and temporal variability. The flow of a stream may take place in few hours and then disappear in sandy bed (Khan, 1999). Flood and drought are the main features in the region and therefore difficult to manage. Rainfall results largely from sequel lines and convective cloud and lead to short duration and relatively high intensity rain in limited areas (Pilgrim *et al.*, 1988). The statistical characteristics of high intensity, short-duration, convective rainfall are essentially independent of location within a region and are similar in many parts of the world (Osborn and Renard, 1969, Khan and Bohra, 1990).

The high variability of storm rainfall causes differential runoff response within the complex drainage network of large drainage basins. The predominant runoff mechanism is the Hortanian overland flow where the rate of rainfall exceeds the potential rate of infiltration (Yair and Lavee, 1982). The flood peak generally occurs within a few hours of the start of a rise (Mabbutt, 1977). Their abruptness results from the nature of arid zone rainfall and sometimes from the steepness of the channels draining the runoff-generating zones. Flood peaks and volumes in the ephemeral streams typical of arid lands usually diminish during their passage downstream through infiltration into the channel bed and overbank spill (Pilgrim *et al.*, 1982, Khan *et al,* 1990). Transmission losses represent the single most important recharge mechanism for alluvial aquifers common to arid lands (Kotwicki, 1987).

Sediment transport in arid areas has a very high spatial variability. The amount of sediment that can be transported by a flow of water is a function of the discharge, channel geometry, mean velocity, composition of bed material, granulometry of the material transported, water temperature and other variables at any given time and cross-section of the flow (Jones, 1981). In view to have proper understanding of hydrological processes in Indian arid zone of Rajasthan a detailed study was carried out in Guhiya basin with its sub-basins of Guhiya are Modiya, Sukri, Guriya, Guhiya Nadi, Phupheriya, Guhiya Bala, Radiya, and Guhiya river. The results are discussed as under.

RAINFALL PATTERN

A perusal of 96 (1901-1996) years rainfall data for typical rain-gauging stations located in the basin area showed that the mean annual rainfall is 453.6 mm. The average highest annual rainfall of 1506 mm for these stations was recorded in the year 1959, which is 325 % of the normal rainfall. The year was exceptionally wet, resulting sever flood in the whole basin. It is interesting to note that the average lowest rainfall of 87.5mm (just 18.99 % of the average rainfall) was recorded in 1918 preceded by highly wet year of 1917 with the station average rainfall of 1070 mm (232 % of the average rainfall). The ratio (station average) of maximum to minimum rainfall amount was very high (over 1054 %). The distribution of this ratio becomes increasingly skewed with increasing aridity from east to west. The coefficient of variation (Cv) of annual rainfall in the basin was very high and exceed 50 %.

Frequency Distribution of Rainfall

The spatial distribution of highest annual rainfall amount was not uniform in the basin. The highest annual rainfall in western region was recorded in the year 1917 (1152.6) mm), whereas, in central and eastern regions it had occurred in 1959 (1731.3 mm) and 1908 (1302.9 mm), respectively. The highest rainfall depth of 634 mm for a single storm of 5 days duration was recorded at one station in the year 1979. Other stations had also recorded rainfall over 400 mm. The spells associated with such higher depth may continue for period up to five days providing rainfall in the order of 400-600 mm, thus contributing to flash flood conditions. The high rainfall in the area is associated with low pressure systems and is received in few spells of high intensity and prolonged duration. The long term rainfall data suggests that such situation of high rainfall occur over the region in good numbers, creating favourable conditions for runoff which can be harnessed for development of surface water resources and recharge of aquifers.

Frequency distribution of normal (+25% of normal) , surplus (126-150%), highly surplus (>150%), deficit (51-75%), and highly deficit (<50%) reveals that the percentage of year in the category of normal rainfall (75-125%) vary from 28 % to 37 %. The distribution of rainfall of different magnitude is highly variable in the basin viz. surplus rainfall ranges from 16% to 52%. Similarly, the variability in the occurrence of annual rainfall under the category of highly surplus (>150%), normal, deficit and highly deficit are very high. However the distribution do not follow the set pattern. Data on frequency distribution of stations average indicate that the normal rainfall (± 25% of normal) accounts over one third of period (34.7%), whereas surplus, highly surplus, deficit and highly deficit account 9.33%, 26.94%, 21.05%, and 16.4% of the years, respectively. Daily rainfall data indicates that 63.8 % of rainfall is less than 10 mm, 16.6 % in the range of 10-20 mm, and 1.8 % are in the range of 20-40 mm. Occurrence of daily rainfall in higher depth class (>40 mm) is only 7.8 % of the total rainfall events. However, the daily rainfalls of high magnitude are not uncommon in the basin. In few cases during very high wet spells the one-day rainfall exceeds 50 % of annual normal rainfall of that station (Table 1).

Table 1. Frequency distribution of surplus and deficit rainfall years in Guhiya basin (1901-1996).

Station	No. of year	Mean annual rainfall (mm)	Frequency distribution							
			>50	50-75	76-100	101-125	126-150	151-175	176-200	>200
Rohit	96	391.3	16.7 (16)	25.0 (24)	27.1 (26)	10.4 (10)	9.4 (9)	6.3 (6)	1.0 (1)	4.2 (4)
Sardar Samand	96	436.5	9.4 99)	27.1 (26)	19.8 (19)	18.8 (18)	5.2 (5)	7.3 (7)	8.3 (8)	4.2 (4)
Bilara	32	418.3	18.8 (6)	21.9 (7)	15.6 (5)	12.5 (4)	5.6 (5)	3.1 (1)	9.3 (30	3.1 (1)
Jadan	25	464.8	20.0 (5)	16.0 (4)	24.0 (6)	4.0 (1)	16.0 (4)	12.0 (3)	8.0 (2)	-
Sojat	96	468.4	17.7 (17)	17.7 (17)	20.8 (20)	17.7 (17)	10.4 (10)	8.3 (8)	2.1 (2)	5.2 (5)
Raipur	32	542.6	15.6 (5)	18.6 (6)	25.0 (8)	12.5 (4)	9.4 (3)	12.5 (4)	3.1 (10	3.1 (1)

Depth –Area –Duration (DAD) Curve

Storm rainfall distribution even in meteorologically homogenous regions has spatial variability. The areal distribution characteristic of storm of a given duration is reflected in its depth-area-duration relationship. For a rainfall of a given duration, the average depth decreases in an exponential form given by

$$P = P0 \text{ exp. } (- K An) \qquad (1)$$

where, P is the average rainfall (cm), P0 is the highest amount of rainfall (cm) at a storm center, A is the area (km2), and K & n are the constants.

Analysis of 10 very high magnitude rainfall data exhibited following depth-duration relationship.

1 day storm $P = P0 \exp (- 0.000758 A0.736)$ (2)
2 days storm $P = P0 \exp (- 0.000827 A0.718)$ (3)
3 day storm $P = P0 \exp (- 0.000987 A0.682)$ (4)

The values of K and exponent n of area A are different for different duration, reflecting storm characteristics in a particular area. The DAD curves show that the maximum rainfall depth has decreasing trend with increase in basin area for all the duration. The one-day maximum rainfall for 100 km2 area is 152 mm, which is reduced to 106 mm for whole Guhiya basin (3050 km2). Similarly, the reduction in maximum rainfall depth for 100 - 3050 km2 basin area for 2 days and 3 days duration ranges from 215 to 153 mm, and 328 to 251 mm, respectively. This indicates that the variability in the maximum rainfall depth is large in higher duration group.

Intensity-Duration-Frequency Relationship

Analysis of rainfall data of self-recording raingauges indicates that for 15, 30, 45, 60, 90, 120 180 min duration the maximum intensities recorded are 56 mm, 25 mm, 21 mm, 19 mm, 17 mm, 14 mm and 7 mm whereas the average intensities are 33 mm,16 mm, 11 mm, 8 mm, 6 mm, 4 mm, and 3, mm, respectively. This indicates that for higher duration the variability in rainfall intensity is comparatively less. The rainfall intensity-duration-frequency relationship has been developed in the following form;

$$I = \frac{7.962\ T^{0.373}}{t^{0.627}} \qquad (5)$$

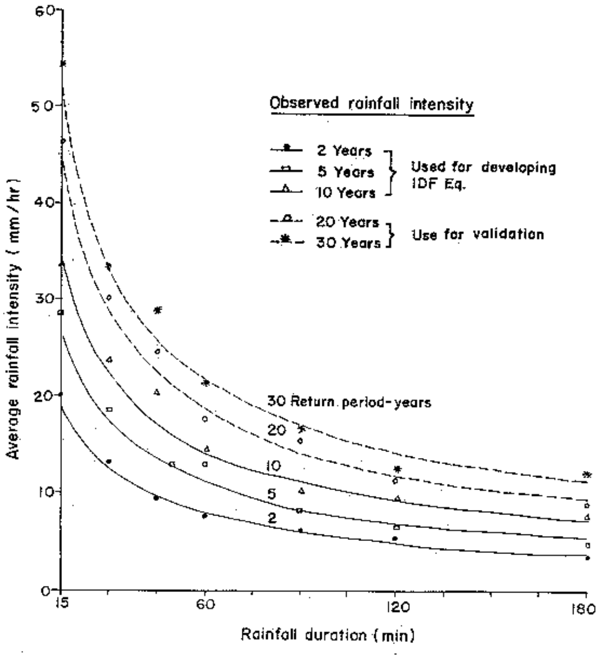

Figure 1. Intensity-duration-frequency curve.

The intensity-duration-frequency (IDF) curves (Fig.1) shows a steep fall upto 60 mm of rainfall and thereafter become straight line. This indicates that the variability in rainfall intensity for higher duration and for all recurrence intervals is less and for storm of shorter duration the variation in rainfall intensity is large. The above results validated using intensity-duration data for 20 years and 30 years recurrence intervals indicate that the curves follows the similar pattern to curves developed using data of 2 years, 5 years and 10 years recurrence intervals (Fig.1).

RUNOFF CHARACTERISTICS

Stormwise runoff had high variability among sub-basins. Each sub-basin exhibited micro-hydrology which could be related to land features discernible on remote sensing landsat imageries. The surface characteristics, and hence runoff potential of basin with different characteristics was quite different. In the present case Modiya sub-basin, a hilly and rocky pediment with high relief generated higher runoff ranging from 1.06 mm to 67.28 mm. Lilri and Guriya basins, characterised with hills and shallow alluvial plains generated runoff ranging from 0.01-53.80 mm and 0.43-50.88 mm, respectively. Guhiya Nadi basin where stream originate from isolated hills and after travelling few km drains in Sardar Samand reservoir, generated abnormally very high runoff of 72.19 mm during torrential rainfall of July 2-4,1994, a rare phenomena in desert. Sukri which originates in the mountainous terrain and travels through deep alluvium flood plains had high transmission losses and generated low runoff ranging from 0.22 - 31.30 mm. Phupheriya, Guhiya Bala, Radiya and Guhiya river sub-basins, characterised with deep alluvium generated comparatively lower runoff ranging from 0.22 - 43.08 mm, 0.36 - 20.87 mm, 0.20 - 28.55 mm and 0.05 - 17.49 mm, respectively. Very low runoff in these basins could be associated with high transmission losses of runoff in deep alluvium soils. It is interesting to note that 50 – 78% flow events in all the sub- basins had runoff less than 10 mm. High magnitude runoff were rare and occurred during torrential rain of prolonged duration.

Table 2. Variation in runoff coeficient with recurrence interval for drainage basins.

Recurrence interval (T) years	Runoff coefficient ©								
	Time of concentration (Tc) min.								
	31.8	31.6	59.8	29.0	24.8	22.0	19.3	33.3	99.0
	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9
8.00	0.39	0.11	0.07	0.24	0.31	0.15	0.10	0.42	0.17
4.00	0.36	0.10	0.06	0.23	0.26	0.14	0.09	0.37	0.17
2.67	0.34	0.09	0.05	0.22	0.19	0.12	0.06	0.31	0.16
2.00	0.34	0.08	0.04	0.20	0.06	0.10	0.06	0.26	0.16
1.67	0.27	0.07	0.04	0.19	0.06	0.10	0.06	0.18	0.04
1.33	0.23	0.07	0.04	0.14	0.04	0.098	0.05	0.15	0.03
1.14	0.20	0.04	0.04	0.12	0.03	0.08	0.05	0.09	0.02
Average	0.31	0.08	0.05	0.19	0.14	0.11	0.07	0.25	0.11

WS1: Modiya basin, WS2: Lilri basin, WS3: Sukri basin, WS4: Guriya basin, WS5: Guhiya basin, WS6: Phupheriya basin, WS7: Guhiya Bala basin, WS8: Radiya basin, WS9: Guhiya river basin

Runoff Prediction

In hydrological analysis and design, it is often necessary to develop relations between precipitation and runoff, using some of the factors affecting runoff and precipitation. The relation between precipitation and runoff differ with the type of precipitation, the considerations of the volume or peak of runoff, or the time of distribution of runoff. Some of the commonly used methods for the prediction of runoff are discussed as under.

Rational method

Runoff coefficient has been estimated from rational formula, Q_p = CIA. Where, Q_p is the peak discharge ($m^3\ s^{-1}$), C is the runoff coefficient, I is the rainfall intensity (mm h^{-1}), and A is the basin area (km^2).The computed runoff coefficient was found to vary with the recurrence interval in case of all the sub-basins. From the plot of rainfall intensity and runoff frequency distribution it is observed that the rainfall intensity-frequency curve and peak runoff-frequency curves are not parallel to each other. Whereas, in the rational method the runoff frequency curve are assumed to be parallel to rainfall frequency curve. This suggests that in rational method runoff coefficient independent of recurrence interval cannot be used for prediction of peak runoff rate for arid zone drainage basins. Values of runoff coefficient was found to increase with increase in recurrence interval. Among the sub-basins, overall higher value of runoff coefficient (0.20- 0.39) at different level of recurrence interval (1.14- 8.00 years) were obtained from hilly catchment of Modiya. Although Radiya basin had runoff coefficient of 0.42 at 8 years recurrence interval but reduced to 0.09 at 1.14 years recurrence interval. Lower value of runoff coefficient (0.04 to 0.07) were obtained for Sukri basin having deep alluvium formation at lower reach. For Lilri Guhiya Guhiya Nadi, Phupheriya and Guhiya Bala basins runoff coefficient varied from 0.04 – 0.11, 0.12- 0.24, 0.03- 0.31 and 0.08-0.15, respectively for the same level of recurrence interval as of Modiya and Sukri basins (Table 2). Although, runoff coefficient of rational formula is not independent of recurrence interval but in some cases where variation for different recurrence interval is small, it is possible to assign the average value for the range of recurrence interval studied (1.14-8 years).

Synthetic unit hydrograph method

Synthetic unit hydrograph is one of the method to compute runoff from ungauged basins. The equations (6 & 7) suggested by Linsley et al. (1988) were employed to work out peak discharge (Qp), basin lag (tp), time to peak (tpk). For the prediction of basin lag (tp), and peak discharge (Qp) of synthetic-unit hydrograsphs for ungauged basins it is essential to work out values of exponent (n) and coefficients, Cp and Ct of the following equations which for arid zone drainage basins are not available.

$$Qp = \frac{2.78\ Cp\ A}{tp} \tag{6}$$

$$tp = Ct \left[\frac{L\ Lc}{\sqrt{S}}\right]^n \tag{7}$$

Where, A is the catchment area (km2), L is the basin length measured along the water course from the basin divide to the gauging station (km), Lc is the distance along the main water course from the gauging station to a point opposite the watershed centroid (km), and S is the slope (%).

The basin lag varied from 4 hours in Gurhiya basin to 18.2 hours for Guhiya Bala basin for the rainfall-runoff event of August 26-28,1989, whereas, for the event of August 4-8,1990 it varied from 6.2 hours for Guhiya Nadi basin to 62.0 hours for Guhiya Bala basin. The value of n and Ct were determined by analysing basin lag data and correlating with physical features of drainage basins. The value of n on an average basis has been estimated to be 0.399, which is little higher than the value (n=0.38) reported for drainage basins in USA (Linsley et al.,1988). The same value of n (0.38) has been used in the subsequent studies by the research workers in developing synthetic hydrographs for drainage basins of humid and semi-humid regions. The values of Ct for hilly/mountanous, foot-hill and plain drainage area were worked out as 1.20, 0.75 and 0.65, respectively. The value of n and Ct obtained for Guhiya basin is reasonably accurate and therefore, can be used for estimation of basin lag for developing synthetic hydrograph for arid zone drainage basins. Based on the average values Ct and n the following Eqs. have been developed.

(i) Hilly/mountainous drainage area

$$t_p = 1.20\, [\, L.L_c / \sqrt{S}]^{0.399} \quad (8)$$

(ii) Foot-hill drainage area

$$t_p = 0.75\, [\, L.L_c / \sqrt{S}]^{0.399} \quad (9)$$

(iii) Plain alluvial drainage area

$$t_p = 0.65[\, L.L_c / \sqrt{S}]^{0.399} \quad (10)$$

The Eq. 8-10 can be used with a reasonable accuracy for ungauged arid zone drainage basins. The value of coefficient Cp has been determined using data of tp and Qps (peak discharge of unit hydrograph) for all the nine drainage basins. Values of Qps have been obtained by dividing the peak discharge of direct runoff hydrograph (DRH) with excess rainfall (ER). The value of Cp has wide variability among the basins as well as between rainfall storms. However, Cp = 0.70 (average value) obtained was found suitable to determine value of Qps. The corresponding values of unit hydrograph duration (tr =2/11 x tp) and time base (tb = 72+tp) were also determined.

Regression models

Regression models have been employed for developing relationship between different hydrological using seven years of observed data of Guhiya basin. The following relationship have been obtained.

$$R = 0.00622\, P^{1.84}\, A^{-0.22} \quad (11)$$

$$I_f = 1.12\, P^{0.93}\, Ac^{0.69} \quad (12)$$

$$Qp = 0.0542 P^{1.428} A^{0.19} \quad (13)$$

The Eq. 11 suggests that runoff has a definite correlation with the depth of rainfall. Contrary to the humid regions, it has an inverse relation with basin area (c= -0.22). The decrease in water yield per unit area with increase in basin area is associated with high transmission losses. The graphical plot of relationship (Fig.2) shows that the runoff for rainfall less than 50 mm is very low as virtually major portion of rain is absorbed by basin soil in form of infiltration. Increase in runoff volume with increase in rainfall upto 150 mm is low. However, with rainfall more than 150 mm the basins get sufficiently wet and infiltration occur to its potential rate for most of the time. This results runoff-rainfall curve to follow almost a straight line parallel to the line of equality.

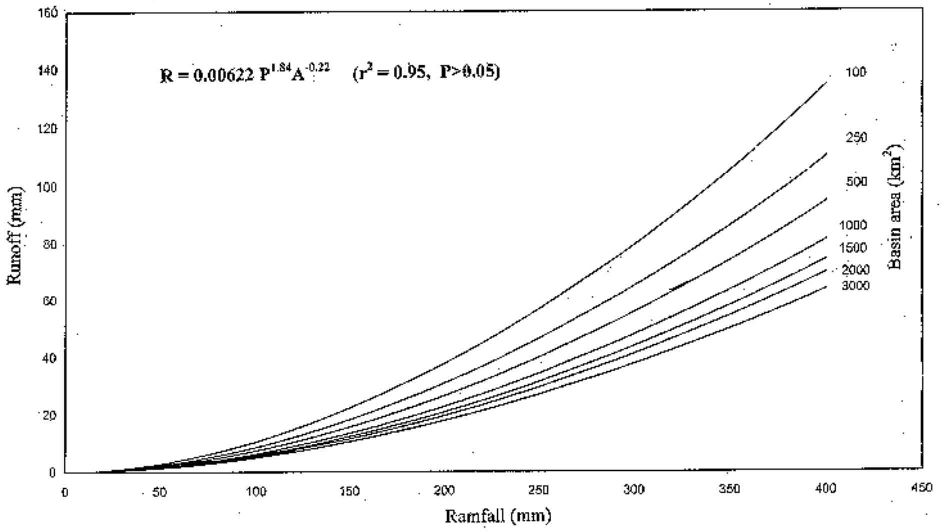

Figure 2. Runoff as a function of rainfall and basin area.

In the multiple linear infiltration regression model (Eq. 12), value of coefficient a, b and c found are 1.12, 0.93 and 0.69, respectively. This suggests that there is a positive relationship between infiltration losses and basin area. The higher infiltration losses for the larger basins is possible due to higher opportunity time for rainfall to infiltration in the soil than as the smaller size of basin. Similarly, for a known quantity of rainfall the peak discharge has increasing trend with increase in basin area (Eq. 13).

SEDIMENT TRANSPORT

Sediment flow in a drainage basin is an active component of system processes and forms as well as serves as a passive record. Sediment flow is shed from basins land surfaces into channel network in varying quantities depending upon rainfall, geomorphology and vegetational characteristics. Therefore, properties on the generation, transportation, storage and ultimate deposition of sediment flow through fluvial processes are diverse (Graf, 1988).

Sediment Concentration

Sediment concentration data (1988-1994) for sub- basins indicates that almost in all the cases a peak sediment concentration has occurred just before peak discharge. Thereafter, the sediment concentration decreases gradually throughout that particular event (Fig. 3). However, small fluctuations in the discharge have not altered the concentration pattern significantly. This confirm the findings in Negev desert (Schick, 1970) and dry rivers in Central Australia (Mabbutt, 1977). The sediment concentrations peak subsequent to the peak discharge of first flow have not been only closer to their respective flow peaks but also of much reduced in size for later flows. These observations reflect the rapid exhaustion of the immediate in-channel sediment flow and the unimportance of surface erosion in arid zone drainage basins(Khan, 1993).

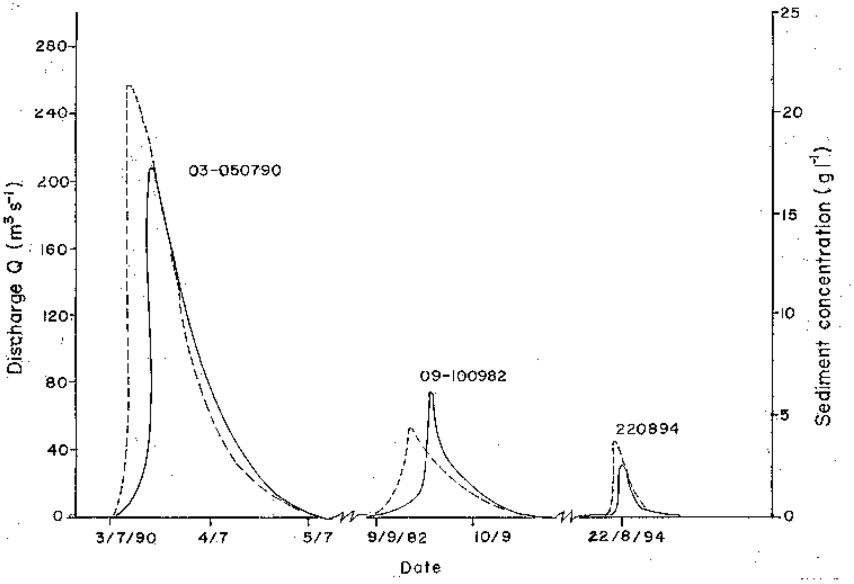

Figure 3. Sediment concentration at different stages of discharge.

Sediment concentration during first effective seasonal flow events of each year has been significantly higher from the hilly/mountainous terrain of Modiya, Lilri and Guriya basins in comparison to alluvium flood plains of Guhiya Bala, Phupheriya, Radiya and Guhiya river basins. However, in the subsequent flow events the reduction in sediment concentration has been faster from mountainous terrain than from alluvium plains. The high sediment concentration during first flow event from rocky surface reflect the vulnerability of unvegetated and eroded rocky surfaces to water erosion, particularly by rain splash and overland flow. Bed material for erosion is exhausted and thus concentration is reduced progressively from such landforms. However, for alluvium the erosion processes are gradual.

Relationship between Rainfall-Sediment Concentration- Antecedent Dry Period

For a given basin suspended sediment is a function of rainfall and antecedent dry period. Using data from nine drainage basins recorded during the study period (1988-94) graphical relationship among the sediment concentration, effective rainfall and antecedent dry period has been developed. The following relationship has been obtained;

$$C_s = 0.181\ P^{0.691}\ D_p^{0.089} \tag{14}$$

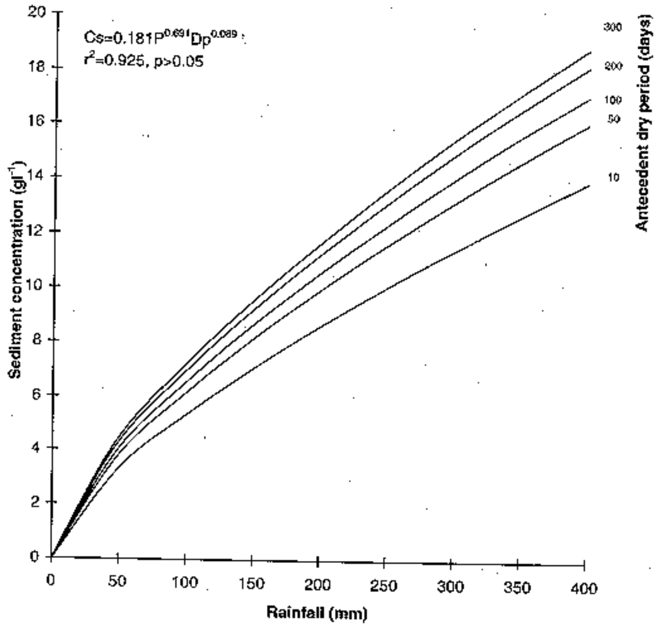

Figure 4. Sediment concentration as function of rainfall and antecedent dry period.

Where, C_s is the sediment concentration (g l^{-1}), P is the rainfall depth (mm), and D_p is the antecedent dry period (days).

The sediment concentration has a direct correlation with the effective rainfall and antecedent dry period. Sediment concentration has increasing trend with increase in rainfall depth (Fig. 4). It is observed that upto 80 mm rainfall the increase in sediment concentration is sharp and thereafter the curves are depressed and follows straight line pattern. Further, the sediment concentration has increasing trend with increase in antecedent dry period. It is, thus, obvious that with longer antecedent dry lot of biotic degradation takes place in the basin area due to human intervention and natural processes. This results in ready availability of loose soil particles for water erosion successive during a storm event. However, in subsequent events with small intervening time interval the sediment concentration is low due to low availability of loose material. Heusch and Millies-Lacroix (1971) found exponentially increasing sediment concentration with precipitation and dry period between events in Morocco. Dunne (1979) made sediment study in drainage basins in Kenya and found that there was steadily increase in sediment concentration with increase in storm precipitation across the range of precipitation values.

Sediment Yield

Estimates of basin sediment yield are required for planning and designing of water resources projects. Design of dams and reservoir; transport of pollutants; design of soil conservation practices; design of stable channels; depletion of reservoir and lakes; determination of the effects of basin management, off site drainage evaluation, and cost evaluation of water resources project are some of the examples. America Society of Civil

Engineers (Graf, 1988) defines “sediment yield as the total sediment outflow from a watershed or drainage basin, measurable at a point of reference in a specific period of time”.

The sediment yield in arid zone drainage basin differs significantly from that of more humid environment due to difference in their hydromorphological characteristics (Mabbutt, 1977). In arid environment the erosional losses are high particularly during flash floods (Hadley, 1977, Khan, 1993) and therefore, there is considerable need for estimating sediment yield from drainage basins at the outlets.

An analysis of the sediment data reveled that there is high variability in sediment yield among basins for a storm and between storms for a basin. The sediment yield is influenced by rainfall, basin characteristics and antecedent dry period.

Frequency distribution of sediment yield for upland drainage basins indicates that out of total 333 events, the largest number of events, 76.3% has occurred in smallest group of 0-50 t km^{-2}. Sediment yield in the range of 51-100 t km^{-2} and 101-150 t km^{-2} have occurred in 7.2% and 6.6% cases, respectively. Sediment yield in higher class interval (>400 t km^{-2}) are very small and has occurred only during torrential rainfall events when the flow has been highly flashy, thus resulted heavy erosion from basin surface. This indicates that sediment yield of high magnitude occurs during catastrophic flood.

A multiple regression model (Eq. 14) for prediction of sediment yield in response to effective rainfall and basin area has been developed using seven years observed data of nine sub-basins in the following form.

$$E_s = 0.00014\, P^{2.868}\, A^{-0.3193} \tag{14}$$

The relationship has the negative exponent for basin area, which reflects the impact of transmission losses and related losses in sediment transport capacity. It has been observed that sediment yield due to rainfall of 150 mm is gradual and thereafter it is very fast and for rainfall of at 300 mm it follows almost straight line pattern for all the basins. Sediment yield per unit area declines as basin area increases. Graf (1978) quoted similar result for Cheyenne River drainage in semi-arid eastern Wyoming. The reason for the scale related decline in yield is that sediment eroded from basin surface does not immediately makes it way to the basin outlet. Temporary storage on lower reach of sediment eroded from upper reach is common to the dryland of the Arnerican West (Leopold, *et al.*,1966) and Tanzania (Rapp *et al*., 1972). Even that material which escapes the slope system is not likely to reach the exit of the large channel systems without some storage along channels (Khan, 1993).

CONCLUSION

In Indian arid region temporal and spatial variability of rainfall even on basin scale is very high. The runoff processes are complex and responds only during few high magnitude rainfall of prolonged duration. Sediment yield is influenced with terrain characteristics, channel geometry, antecedent dry period and rainfall intensity. Relationship developed between different hydrological variables can be used with reasonable accuracy for ungauged basins under similar situations.

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