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Water Resource Development in Jamnagar District, Gujarat, India

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Abstract: Regression models for rainfall-runoff-drainage basin area relationship, based on past 30 years' observations, have been developed for Jamnagar district in arid Gujarat, India. The runoff coefficient varies from 0.07 to 0.29 and the runoff efficiency decreases with the increasing area of drainage basin, since larger the basin, longer the flow paths and longer the opportunity time for rainwater infiltration. The probability of a severe drought by 2020 varies from 19 to 35% in various *talukas* in the district. The risk of failure of water control structures by a storm having 100 years as a return period is 63%. The study is useful in predicting the peak flows, water yield, rainwater infiltration, sediment transport and channel stability in the arid regions.

Key words: Rainfall probability, ephemeral channels, threshold rainfall, runoff efficiency, recharge velocity, hydrologic design, risk analysis.

Jamnagar district of Gujarat has scarce natural resources, where shallow soils interspersed with gravelly uplands, vast saline stretches and meagre surface/ground water resources are the characteristic features (Joshi, 1999). Irrational land use has resulted in accelerated water erosion, salinization, denudation of the agricultural lands and degradation of vegetation cover of grazing lands, mangroves and forests. The district is a water-scarcity area. Droughts are common in this region; droughts of moderate to severe intensity occur once in 2 to 3 years. Although the integrated drainage system from the stony/rocky/gravelly surfaces and torrential nature of precipitation generate 40 to 60% of rainfall as runoff, steeper slopes and absence of checks allow the water to quickly flow to the sea. Additionally, the failure of monsoon rainfall dwindles the surface water supply to the extent that even the shallow dug wells are dried up. Being a hard rock terrain, the groundwater potential is very low; it is already overexploited and mined, resulting in either the saline water ingress in the coastal aquifer, or drying up of the groundwater even up to a depth of 100 m. Consequently, a need for holistic approach to water resource development in the district is being felt in recent years.

Study Area

Jamnagar district (21.8-22.0°N, 69.0-70.7°E) occupies 14,125 km^2 area in the west of Gujarat State (Fig. 1). The climate is arid with a mean moisture index of -67.5. The average annual rainfall varies from 338 mm at Dwarka in the west to 667 mm at Dhrol in the east. About 95 to 98% of annual rainfall comes during the monsoon months of June to October, July and August being the rainiest months. The coefficient of variation ranges between 50 and 82%. The annual potential evapotranspiration ranges between 1500 and 1650 mm, three times the precipitation, resulting

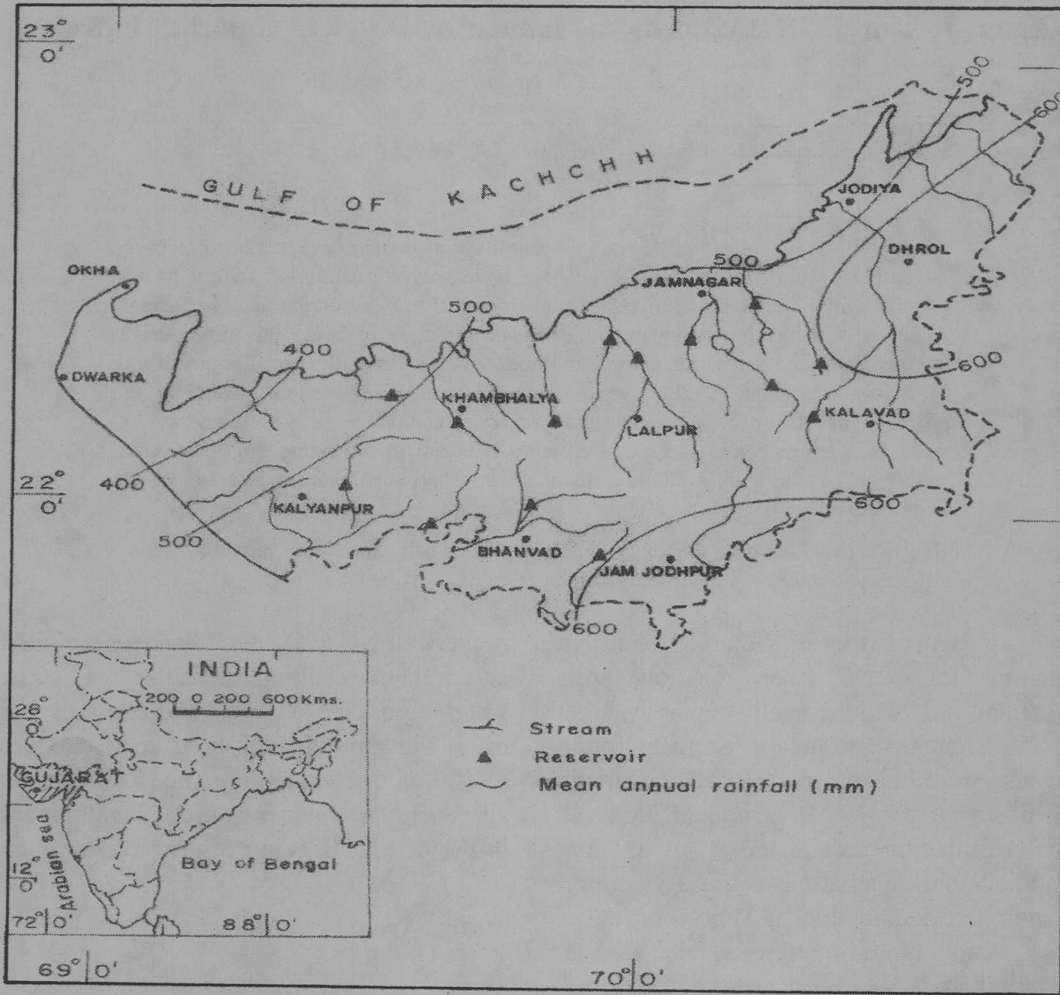

Fig. 1. Jamnagar district, Gujarat.

in no flow in the ephemeral channels for much of the year.

Deccan Trap basalt occupies a major part of the district. These are compact, crystalline in general and amygdoloidal at places. The western part is covered by the fossiliferous Gaj bed, overlain by the Dwarka bed of marl and limestone. The Quaternary formations include Milliolite limestone, alluvium and aeolian sediments. The dominant landforms are colluvial plains and rocky uplands. Low hills occur in the south and are dissected by numerous large and small seasonal streams, most of which drain towards north and form potential drainage basins. The district is characterized by shallow, black soils with large variations in depth, texture, salinity and water erosion.

Table 1. Rainfall analysis in Jamnagar district, Gujarat

Location	Rainfall (mm)					Mean rainfall (mm)	CV (%)
	Return period (years)						
	1.01	1.25	2.50	5.00	10.00		
	Probability (%)						
	99	80	40	20	10		
Bet Dwarka	1	5	24	100	275	104	202
Dwarka	105	147	344	540	760	364	65
Kalyanpur	142	196	407	640	875	533	77
Khambhalia	82	227	465	690	935	450	58
Lalpur	92	290	680	900	980	605	47
Bhanwad	84	331	567	850	958	577	52
Jam Jodhpur	82	329	721	881	1044	652	57
Kalawad	98	225	490	744	811	487	56
Jodia	76	210	450	630	850	467	61
Dhrol	59	220	630	1050	1100	597	62

Nearly two-third area of the district is under cultivation. The major factors of land degradation are accelerated water erosion and salinization.

Materials and Methods

In view of the limited number of rainy days in a year and high potential evapotranspiration, frequency analysis of seasonal rainfall data (June-October) for 30 years (1966-95) has been attempted on annual time series basis through log Pearson type III distribution. Jones (1981) reported that this distribution fitted the best to the rainfall probability analysis in the arid regions. The return period values were obtained by the Weibull's formula (Jones, 1981). Seasonal rainfall-runoff data from 13 representative drainage basins for 30 years were collected, analyzed and regression models were fitted. The regression models have been used extensively in flood and low flow studies, catchment's modelling and rainfall-runoff analysis (Holder, 1985). These drainage basins vary between 31 and 597 km^2, have rocky/gravelly surfaces and generate between 3 x 10^6 and 258 x 10^6 m^3 runoff per year.

Results and Discussion

Rainfall analysis

Rainfall analysis for the last 30 years revealed a high coefficient of variation, ranging from 0.47 to 2.02, that increases from south-west to north-east. An analysis of rainfall probability in the district revealed the following (see also Table 1):

- At 99% probability (return period of 1 year) the seasonal rainfall varies from 59 to 142 mm in various *talukas* of the region except at Bet Dwarka. This rainfall can be harvested in check dams, anicuts and percolation tanks for meeting the drinking water demand.

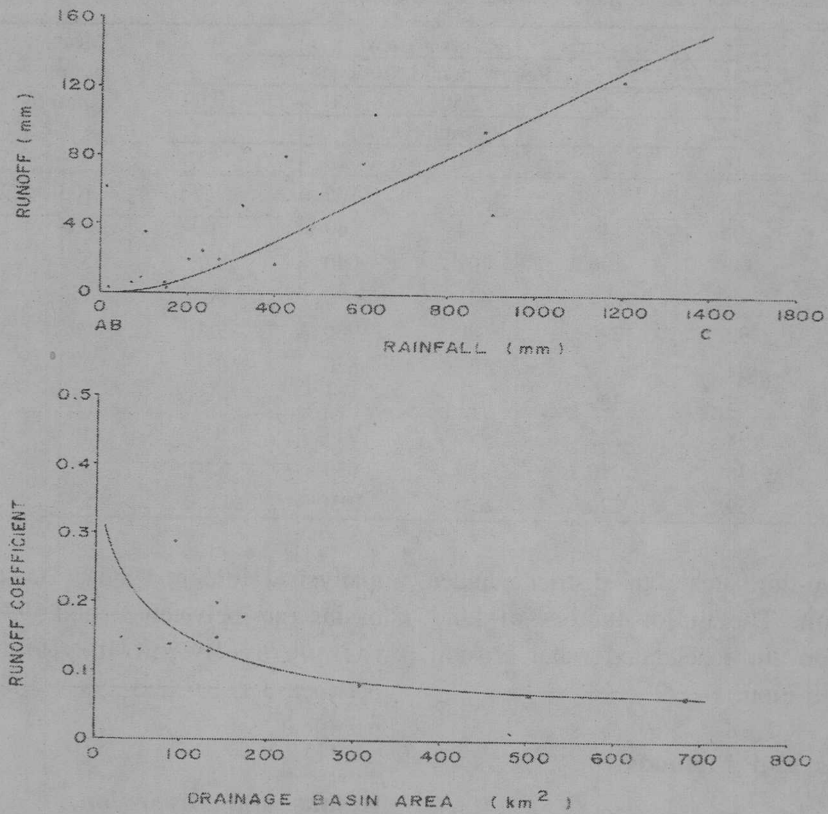

Fig. 2. Rainfall-runoff-drainage basin area relationship in Jamnagar district.

- The return period for the design of soil and water conservation measures is normally taken up once in 10 years. The probability of occurrence of this rainfall is 10% and the seasonal rainfall varies from 275 mm at Bet Dwarka to 1100 mm at Dhrol.

- With an average coefficient of runoff as 0.07, about 24,080 to 50,470 m^3 of runoff per km^2 can be harvested at 40% probability, i.e., twice in a period of five years. This water could be used to meet the requirement of crops, and also could be used for artificial recharge of the groundwater.

Rainfall-runoff relationship

The ephemeral channels convey runoff only in direct response to the sporadic, torrential rainfall in their drainage basins and remain dry for about 90% of the year. The base flow is absent. The runoff is flashy, short-lived and is of rapid rising/falling nature. The runoff coefficient (a ratio of runoff to rainfall) varies from 0.07 to 0.29, i.e., 36,820 to 152,540 m^3 km^{-2} of runoff is expected during the average rainfall year. The rainfall-runoff relationship assumes the form:

$$Q = 0.07 \ (P - 132.57); \quad (r=0.57, \ p > 0.05, \ n=13) \qquad .....(1)$$

Table 2. Probability of occurrence of critical drought in Jamnagar district, Gujarat

Location	Length of past recorded (years)	Probability of critical drought (%)
Bet Dwarka	32	33
Dwarka	54	22
Kalyanpur	13	29
Khambhalia	62	19
Bhanwad	44	26
Jam Jodhpur	30	35
Lalpur	18	25

Where Q (mm) is the seasonal runoff and P is the seasonal rainfall (mm). The threshold rainfall – the minimum rainfall to initiate runoff, is 133 mm with a runoff efficiency of only 7%. The runoff efficiency (η) relates to the drainage basin area (A, km^2) by the relationship:

$$\eta = 0.42 \ A^{-0.22}; \quad (r=0.55, \ P> 0.05, \ n=13). \quad .....(2)$$

It is apparent that under arid conditions, the runoff efficiency, η, decreases with the increasing area of the drainage basin (equation 2). This is because larger the basin, longer the flow paths and longer the opportunity time for rainwater infiltration.

Figure 2 shows the rainfall-runoff-basin area relationship in Jamnagar district. The rainfall-runoff relationship has two segments of interest. Over the range A-B of very low rainfall, virtually all rain is infiltrated. In the range B-C runoff occurs because rainfall is more than rainwater infiltration. The volume of rainwater infiltration increases at a lower rate than the increasing rainfall. Point B is the threshold rainfall. Also, the runoff coefficient decreases with increasing drainage basin area. In the arid regions, the runoff coefficient has an inverse relationship with the drainage basin area, contrary to that in humid zones. Smaller water yields per unit area due to the effects of transmission losses have been documented in the arid regions of Australia (Pilgrim *et al*., 1988), India (Sharma, 1986) and south-west United States of America (Boughton and Stone, 1985).

Drought analysis

Jamnagar district faces extremes of rainfall. Therefore, hydrologic design for water use is of paramount importance. A common basis for the design of drinking water supply is the worst recorded drought i.e., critical recorded drought. The hydrologic design is considered satisfactory if it will supply drinking water at the required rate throughout an equivalent critical period. In the present analysis a critical drought of 5-year duration is considered and the design period is taken up to the year 2020. Table 2 shows that the chance of a more severe drought in the forthcoming 20 years varies from 19 to 35%.

Risk analysis

Water control design (check dam, anicut, percolation tank, etc.) involves consideration of risk. A water control structure might fail if the magnitude for the design return period is exceeded within the expected life of the structure. Assuming 100 years as the life of the water control structures, the risk of failure by a severe storm having 100 years as return period is 63%. The equation for natural or inherent hydrologic risk is given as:

$$R = 1 - [1 - P (X > X_T)]^N \quad .....(3)$$

Where R is the risk factor, $P (X > X_T) = 1/T$ where T is the return period in years, and N is the expected life of the structure.

Groundwater recharge

The recharge velocity from stream flows in the hard rock terrain of the district was found to be about 0.1 mm s^{-1}. As a result, before a significant amount of groundwater recharge takes place the ephemeral flow runs off to the sea. A series of check dams would conserve this water and enhance the groundwater recharge, thereby mitigating the scarcity of water within the region. Extraction of water from dry ephemeral stream beds is also a potential source in the region.

Conclusions

The rainfall-runoff models are regionalized and applicable for water resource development in Jamnagar district. These models, in combination with the understanding of physical processes, are useful in predicting the peak flows, water yield, rainwater infiltration, sediment transport and channel stability in the arid regions.

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