THE DISTRIBUTION OF RAINGAUGES IN THE DAMODAR RIVER CATCHMENT

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A GOOD estimate of the probable discharge of a river is essential for designing any project to harness its water resources. Since the discharge is calculated from the total quantity of water that has fallen as rain in the catchment, it is essential that the number and location of the raingauge stations in the catchment should be so designed as to give the best estimate of the average rainfall in the area. The total quantity of water would then be the average rainfall of the stations in the area multiplied by the area of the catchment.

It was pointed out in a previous note[1] that a non-uniform distribution will give a higher weightage to the rainfall recorded in the regions with a denser distribution of raingauges and less weightage to that in the regions with sparser distribution. For example, the average normal rainfall during June to September over Hyderabad State calculated as the average of the rainfall recorded at different number of raingauge stations has been worked out and compared with the weighted mean calculated on the assumption that all the districts have approximately equal areas. Even if the areas are not equal, it is always possible to allot to each district mean an average area from or including the district. The normal rainfall data of Hyderabad stations have been taken from the *Memoirs of the Indian Meteorological Department*, Vol. 27, Part 5.

1. Average of 20 stations that have records from dates prior to 1920	.. 25·9"
2. Average of 65 stations that exist now	.. 27·7"
3. Average of 45 newly added stations	.. 29·7"
4. Average of 31 of these newly added stations which are situated in the Godaveri basin in the northern part of Hyderabad where the rainfall is comparatively more	.. 33·6"
5. Average of 17 stations chosen one in each district	.. 26·3"
6. Average of the district means	.. 26·6"

The district means are calculated as the average of all the stations in the district. Assuming that the areas of all the districts are equal, the average of the district means will be the weighted average and hence may be taken to be a good estimate of the average normal rainfall over the State. It will be seen that the average normal rainfall calculated from the 17 evenly distributed stations, one in each district, gives almost as good an estimate. The difference is only 0·3 in., about 1% of the weighted average. The average of 65 stations is too high by 1·1 in ; that of 45 newly added stations by 3·1 in., and that of 31 new stations by as much as 7 0 in. Therefore it is evident that an increase in the number of raingauge stations does not necessarily give a more accurate estimate of the average rainfall.

In the following note it is proposed to consider the number and the distribution of raingauges necessary in the Damodar river catchment so that an unbiased estimate of the average rainfall may be arrived at with a reasonably small standard error. That the distribution of raingauges should be uniform is brought out in the following analysis also.

The Damodar river* rises in the hills of Chota Nagpur and flows in a generally southeasterly direction till it changes its course abruptly to a southerly direction below Raniganj. Its principal tributary stream is the Barakar river. The origin of the river is approximately at 2,000 feet above mean sea-level. At the point of junction of its two prongs on the western border of Hazaribagh district, the united stream starts at an elevation of 1,326 feet above mean sea-level; but in its course of 93 miles through Hazaribagh district, its fall averages 8 feet per mile and leaves the district with an elevation of only 582 feet.

The above description of the course of the river gives also an idea of the ruggedness of the basin.

Rainfall data are available for 22 stations in the Damodar river catchment down to Asansol from the year 1923 onwards. The figure below shows the catchment area, the location of the raingauges and the normal

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* Vide *The Imperial Gazetteer of India*, 1908, **11**, 132-33.

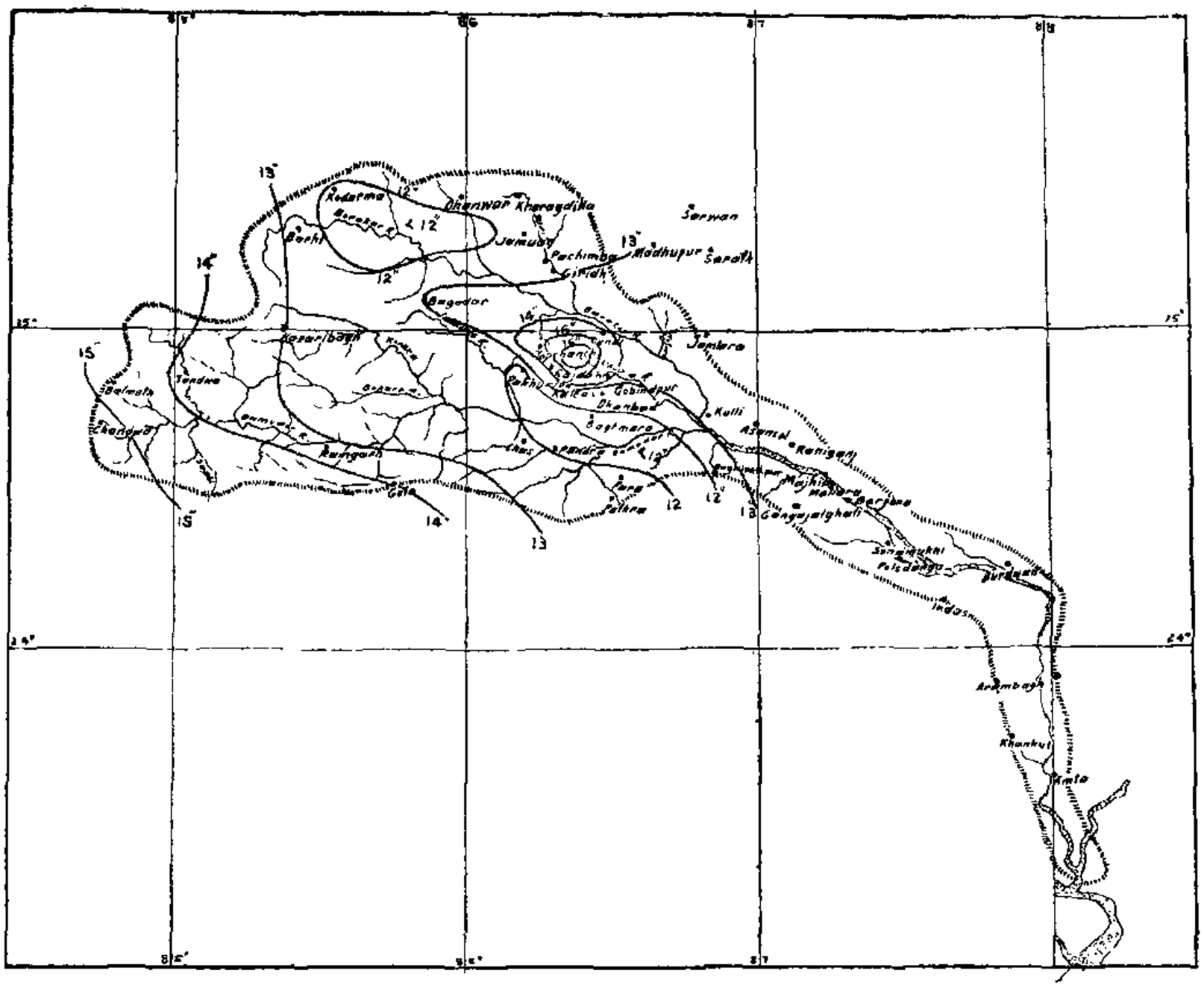

FIG. 1. Catchment of the Damodar river
Normal rainfall in July

isohyets for July. July rainfall of these stations for the years 1923 to 1940 have been used in the following analysis.

Analysis of variance of the rainfall during July for the years 1923 to 1940 in the Damodar river catchment

S. S. due to	D.F.	S.S.	Mean S.S.	F.
Year ..	17	4,219·70	248·2176	18·2214*
Space ..	21	962·32	45·8247	3·3639*
Residual ..	357	4,863·18	13·6223	
Total ..	395	10,045·20		

* Significant at 0·1% level

Note.—S.S.—sum of squares, D.F.—degrees of freedom, F.—variance ratio.

The variance due to years as well as that due to space are significant. That is, the variation of rainfall from year to year as well as the variation due to orography are significantly more than the residual variation. Now let us consider the best design for sampling rainfall in space. The intra-class correlation coefficient, ρ is equal to $\frac{M_{\bar{x}} - M}{M_{\bar{x}} + (n-1)\,M}$, where $M_{\bar{x}}$ is the unbiased estimate of variance or the random variation present in the material sampled, M is the variation within the sample or the systematic variance, and n the number in the sample. Since $M_{\bar{x}} < M$, ρ is negative and significant. Madow and Madow (1944) have shown that if the serial correlations have a negative sum, systematic sampling is better than random sampling. It is also shown that the sum of the serial correlations is $(n-1)\,\rho$. Since ρ is negative in the case of spatial distribution of rainfall in the Damodar river catchment, a better unbiased estimate of the average rainfall could be got by employing systematic sampling design than random sampling design. The variance of the mean is given by

$$\sigma^2_{\bar{x}} = \frac{\sigma^2}{n}\{1+(n-1)\,\rho\},$$

where σ is the standard deviation of any observation.

Therefore systematic sampling design, which was already suggested on the basis of computational convenience,[1] and found to be good in estimating the average normal rainfall of Hyderabad State, is better than random sampling design in the case of collection of rainfall data, as rainfall is generally

subject to certain systematic influences like lateral instability of the atmosphere, orography, etc.

The 22 stations in the catchment have been ranked according to the normal rainfall and were grouped into two samples by taking all the stations with odd ranks to form one sample and the rest another. The sample variance was calculated from each year's data. The 18 separate estimates of the between —sample variance thus calculated were tested for homogeneity by Bartlett's (1937) test. $-2 \log \mu$ works out to be 15·4838 and C the corrective factor is 1·35. For 17 degrees of freedom $-2 \log \mu$ is not significant at 50% level and the corrected value of it is not significant even at 90% level. Therefore, despite the fact that these individual variances are based on a single degree of freedom, it may be concluded that these are homogeneous. That is, the residual variance is due to chance causes which are independent of time and space effects. The pooled sum of squares of the 18 separate estimates, each with a single degree of freedom, is 9·932. The error variance has been estimated to be 13·623 based on 357 degrees of freedom (refer table). The value of F for these two estimates is 1·372. Hence the two estimates are not significantly different and we may assume 13·6223 to be the error variance of any observation.

The error variance of the average rainfall in the catchment based on 22 raingauge stations is therefore 0·6192 and the standard error 0·79 inch, which is 6% of the average normal rainfall (13·31 inches) in the catchment. Therefore, if the 22 stations are distributed evenly in the catchment, the average of these stations will be an unbiased estimate of the average rainfall in the catchment with a standard error of 6%. And this much accuracy is fairly sufficient for all practical purposes. It may also be mentioned that the distribution of raingauges in the Damodar river catchment is fairly uniform but for a small cluster of stations around Topchanchi (see fig.).

Though only the total rainfall of July has been used in the above analysis, it is felt that the results will be applicable to the total rainfall of a smaller number of days as well and that the 22 stations may be sufficient to calculate the average rainfall due to a storm, etc. However a verification is necessary.

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1. Ramamurti, K. S., "On estimating the average depth of rainfall over an area and the distribution of raingauges," *Curr. Sci.*, 1948. **17**, 317-18 2. Madow, William, G., and Lillian H. Madow," On the theory of systematic sampling, I," *Annals of Math. Stat.*, **1944**, **15**, 1-24. 3. Bartlett, M. S., "Properties of sufficiency and statistical tests," *Proc. Roy. Soc.*, London, 1937, **160A**, 268-82.

INDIAN SCIENTISTS' TOUR OF AUSTRALIA

KEEN interest in the scope of scientific investigation in Australia and in the facilities availbale for modern research, was shown by the four members of the Indian Scientists delegation who have just returned after completing their tour of Australia.

The tour was arranged by the Australian Council for Scientific and Industrial Research, a government authority organised on somewhat the same plan as the Indian Council with a central authority, and sections in the provinces.

The leader of the delegation, Dr. S. Krishna, C.I.E, Ph.D., D.Sc., F.I.C., F.A.Sc., Director of Forest Products Research, Forest Research Institute at Dehra Dun, and a foundation member of the National Institute of Sciences, represented India at the Fifth Empire Forestry Conference in London in 1947.

Another member, Dr. D. P. Pal, M.Sc., Ph.D, F.L.S., F.N.I., joint Director of the Agricultural Research Institute, is specially interested in the breeding and genetics of wheat, potatoes and tobacco.

Representative of Indian medical research was Lieutenant-Colonel M. L. Ahuja, M.B., Ch.B., M.D., D.P.H., Director of the Central Research Institute, Kasauli, and a member of the governing body and the scientific advisory body of the Indian CSIR.

The fourth member, Mr. V. P. Sondhi, M.B.E., M.Sc., F.G.S., F.N.I., is Deputy-Director of Geological Survey, New Delhi.

Visit to Canberra

On arrival at Darwin, Northern Territory, the scientists flew over the northern State of Queensland from Darwin, in Central Australia, to Brisbane and on February 21 they arrievd in Sydney.