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ASSOCIATION BETWEEN DRAINAGE BASIN CHARACTERISTICS OF SMALL DRAINAGE BASINS OF THE RANCHI PLATEAU, INDIA.

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ABSTRACT : The study of association between certain morphometric variables of drainage basin is of paramount significance because such relationships exhibit cause and effect of terrain development of basin watershed morphology. Basin perimeter, basin area, basin shapes, channel lengths, standard sinuosity index, bifurcation ratio, length of overland flow, absolute reliefs, relative reliefs, dissection index, average slopes, drainage density, drainage texture and stream frequency have been chosen for the correlation study of 23 small drainage basins of the 6th and the 5th orders of the Ranchi plateau. Correlation analysis reveals significant relationships between certain variables while some of the variables have been secluded as they have no influence on basin development processes. Average slope has emerged as the most significant variable because it affects majority of the selected variables. It acts sometimes as an independent variable and some time as a dependent one.

Introduction

The study of associations between morphometric variables of drainage basins is of paramount significance for proper understanding of landscape ecology and landscape evaluation. Since a drainage basin is an open system as it receives energy or input from the climate and loses energy or output through the water and sediment through its mouth, it becomes apparent that interrelationships between the morphometric variables do exist at different levels. The appreciation of these relationships leads to critical evaluation of cause and effect of terrain components. Based on above connotation, 23 small basins of 6th and 5th orders of the Ranchi Plateau having granitogneissic structure apart from basaltic cover over gneissic floor of the Western High lands or Patlands and weak Dharwarian formations in the southern marginal areas, have (fig·1) been selected from the five physiographic regions (Singh 1978–A) viz.. (1) Western High lands or Patlands–Sen, Ghaghra and Dhopad basins, (ii) Central Ranchi Plateau-Sankh, Banki I, Lobagra, Birgora, Saphi, Jumar and Ganga basins, (iii) Southern Dissected Lower plateau-Ambajharia, Jamjor, Dongajor, Banki II, Udiagara, Salegutu, Khakrajar and Chhata basins, (iv) Eastern Lower plateau-Uraongarha, Raisa, Baru and Damra basins and (v) Northern Escarpment zone-Nalkari basin (incomplete), (Fig·2) for the study of relationships between certain morphometric variables by applying correlation analysis wherein mean values of the morphometric attributes (appendix A) have been taken into account.

Bifurcation Ratio Vs. Absolute and Relative Reliefs, Drainage Density, Stream Frequency and slope

No significant relationship is noted between the absolute reliefs and mean bifur-

cation ratios of the selected small drainage basins as is evident from the coefficient of correlation of + ·06 (totally insignificant). It is apparently observed that merely absolute relief is not a causative factor of the streams because a drainage basin may develop many streams in a region having high absolute height and also in a region of lower height alike. Dhopad basin having the highest mean absolute relief (Ar=925m) has the highest mean bifurcation ratio (Rb= 4·8) but Khakrajar basin with the mean absolute relief of only 546·07 m has also the mean Rb of 4·5 which is more than the basin of Saphi (Rb= 4·26) having the same height (Ar= 925m) as that of Dhopad basin. Similary Damra and Baru basins having much lower mean absolute reliefs (Ar= 282·75m and 318m respectively) than Sen basin (Ar= 919·74m) carry the same mean bifurcation ratio (Rb= 3·7) as that of Sen basin (Rb= 3·7).

Mean bifurcation ratio may be correlated with mean drainage density as the latter is related to stream length and hence positive correlation may be expected. Though the positive coefficient of correlation of 0.48 between mean drainage density (Dd) and mean bifurcation ratio (Rb) indicates direct relationship but it is significant at 5% probability level only. The hypothesis, that more branching generates higher drainage density, becomes partly true. The mean bifurcation ratio is positively correlated with mean stream frequency (r= 0.58) but such correlation is of no use as the bifurcation ratio is itself a ratio between the numbers of stream segments of two successive orders. The bifurcation ratio is not significantly correlated with average slope (r= + 0.39).

Thus it appears that the bifurcation ratio is more controlled by geological structure, lithological charateristics, climate and vegetal cover than the variables of drainage basin itself. The basins of the Central Ranchi Plateau having relatively hard rocks (granite-gneissic structure) have relatively lower values of Rb than the basins of the eastern margins of the Eastern lower plateau and the southernmost section of the southern lower plateau of this region where mica-schist structure in the case of the former (alongwith granite-gneisss) and the Dharwarian formations in the case of the latter accentuated by more jointings and Archaean lava intrusions have favoured relatively more branching of the drainage network. Slopes have played some role in giving relatively higher values of Rb in the western Highlands of this region.

Horton's observation regarding the relationship between bifurcation ratio and terrain characteristics wherein bifurcation ratio has been taken to vary from about 2·0 for flat or rolling basins to 3·0 to 4·0 for mountainous, highly dissected basin, does not hold good here as Birgora, Lohagra, Jumar and Chhats basins, draining over flat rolling plateau, have mean bifurcation rotios of 3·67, 4·2, 3·2 and 4·2 respectively. Chorley (1957) and Strahler (in Chow, V. T., 1964) have also contradicted above observation of Horton.

Basin Perimeter, Basin Area and Channel Length.

The basins of the different physiographic regions of the plateau register wide range of variations as regards basin areas, basin perimeters and main channel lengths (Appendix A); which are because of effects of slopes, absolute reliefs, scarps and some geological controls but the basin perimeter appears to be directly correlated with the square root of the basin area (r= + 0·85) and the channel length (r = 0.95). There are many complicated causative factors of basin area, basin shape and basin perimeter but rock types, relief, infiltration capacity, vegetation, climate and stage of basin development largely conrtol these variables. Raisa and Uraongarha basins of the Eastern Lower plateau register deviation from the aforesaid relationships as these two basins have comparatively longer

Table I : Correlation

Variables	Coefficient of determination R^2 (%)	Coefficient of Correlation (r)
1. Mean bifurcation ratio and basin area	0.16	+ 0.04
2. Mean bifurcation ratio and mean absolute relief (A_R)	0.36	+ 0.06
3. Mean bifurcation ratio and Mean relative relief (R_R)	18.5	+ 0.43*
4. Mean bifurcation ratio and Mean slope angle	15.2	+ 0.39
5. Mean bifurcation ratio and mean drainage density (D_d)	23.04	+ 0.48*
6. Mean bifurcation ratio and mean stream frequency	33.64	+ 0.58**

* Significant at 5% probability level.
** Significant at 1% probability level.

channel lengths than many of the selected basins of the region although they have comparatively smaller basin areas. In the case of Uraongarha basin, parallel hill ranges from west to east and steep scarp faces have forced the river to adopt an elongated shape with longer channel length but lesser basin area. Many local hills have guided the longitudinal course of Raisa basin with the result it has become the most elongated basin with second longest channel length, but has small area as compared to other basins.

Length of Overland flow (Lg), Average slope, Dissection Index and Drainage Texture

Length of overland flow (Lg) is one of the most important morphometric variables which affects the hydrological and physiographic properties of the basins. It is generally argued that the early stage of the basin development is marked with maximum ' Lg ' and mature and senile stages register marked reduction in Lg. but the author disagrees with this corollary and the hypothesis of Coates (1958) to the effect that " other factors being constant, area more advanced into maturity appear to contain smaller overland flow-lengths than youthful areas". In the beginning of the stage of cycle of erosion, say in early youth, ' Lg ' may be relatively larger because of unconsumed divides but in the late youth and early mature stages the ' Lg ' tends to become smaller and there after it becomes larger. It may be postulated that the basins more advanced in stage, say beyond late maturity,

have larger 'Lg' than the basins in the stages of late youth and early maturity. The reason behind this hypothesis is apparent as the stage of basin development advances after youthful stage, there is marked reduction in relief, slope angle and gradient and hence many of the streams are integrated and thus the marked lengthening of main channel and its major tributaries at the cost of others result into low drainage density and hence longer 'Lg'.

The basins of the Western High lands (Sen, Ghaghra and Dhopad) and southern most section and s. w. section of the Southern Lower plateau (Ambajharia Jamjor, Dongajor, Banki II and Udiagara), which are in late youth to early mature stages, have much smaller 'Lg' than the basins of the Central Ranchi plateau (Jumar, Birgora, Sankh, Baki I, Saphi etc.-Appendix A) which are certainly in monadnock stage. It is important to note that the cyclic concept of the basin development should not be given much concession and latitude as 'Lg' is also affected by other factors viz rainfall intensity, infiltration rate, soils, vegetation etc. Vegetation is supposed to be most dominant controlling factor of overland flow as 'it increases the infiltration rate by promoting a thicker soil cover, a better soil texture and by breaking, the impact of rainrops on the surface, (Kirkby. 1969, p. 217) and thus a dense vegetation cover accelerates infiltration and discourages overland flow.' On the other hand a region devoid of vegetation or having thin vegetal cover maintains much overland flow because 'if rain drops strike the surface without being impeded by vegetation fine material is thrown into suspension by the impact and is redeposited as an almost impermeable surface skin, which can lower infiltration by as much as ten times' (Kirkby, 1969, p. 217). If the lengths of overland flow are viewed in the above perspective, the above observation of Kirkby becomes more realistic than the control of stages of cycle of erosion. The Western Highlands are most densely forested and hence shorter lengths of overland flow are well marked (Appendix A). On the other hand the central Ranchi plateau has only small patches of vegetation and thus relatively longer 'Lg' are noted.

The 'Lg' is negatively correlated with average slope angle of the basin ($r = 0.71$). i. e. steeper the slope angles, smaller the lengths of overland flow and gentler the slope angles longer the lengths of overland flow. The 'Lg' is again negatively correlated with dissection index ($r = 0.36$). Though the correlation is insignificant but it appears from the negative trend of 'r' that shorter the length of overland flow, the greater is degree of dissection and vice-versa. It is a known fact that a region or a basin has maximum relief during its late youth stage and hence maximum dissection is bound to exist in that stage and the maximum dissection is related to shorter 'Lg' indicating closer spacing of the steams Thus the hypothesis of the author, as given above, is further supported by this correlation.

Lg has been accepted as an important morphometric indicator of the spacing of the streams in a given basin. In order to examine this observation, lengths of overland flow and mean values of drainage texture (Singh, 1978 B) of all the selected basins have been correlated and a positive coefficient of correlation of 0·93 has been noted. Such correlation is very significant and it suggests that the larger the Lg, the higher the values of drainage texture which means wider spacing of streams and hence coarse drainage texture.

Relief Ratio, Elongation Ratio, Average slope, drainage Density and sinuosity Index

Schumm has worked out a negative relationship between elongation ratio and relief ratio wherein elongation ratio of the drainage basin decreases with increasing

relief ratio and vice-versa. It is axiomatic to think that other factors being constant, a high relief ratio will correspond with an elongated shape (the smaller the elogation ratio, the more elongated shape) and low relief ratio may be associated with more circular shape of the basin. This observation is based on the connotation that there is gradual decrease in relief ratio with the advancement of the stage of basin development.

The above observation does not hold good in the present work. The basins of Lohagra, Birgora, Jumar (Central Ranchi Plateau), Chhata and Khakrajar (Southern Lower plateau) have higher elongation ratio (and hence comparatively less elongated shapes) with low relief ratios whereas only Ghaghra and Uraongarha basins have comparatively low elongation ratios with higher relief ratios. The remaining basins show opposite trends. The positive correlation co-efficient of 0·17 is opposite to the negative relationship as demonstrated by Schumm. On an average the values of relief ratios must produce negative correlation when related to elongation ratios but where absolute relief becomes passive in the basin development, this relationship may be reversed. The 'form factor' of Horton and relief ratio, when correlated, produce the same result of positive correlation ($r = +0{\cdot}25$).

Sankh rivar takes its source from the 'Pats' of the Western High lands at the height of above 1000 m but drains for major part of its course over Lohardaga peneplain at the average height of above 600 m and thus high relief ratio of 21.2 (m/km), which is second only to Ambajharia

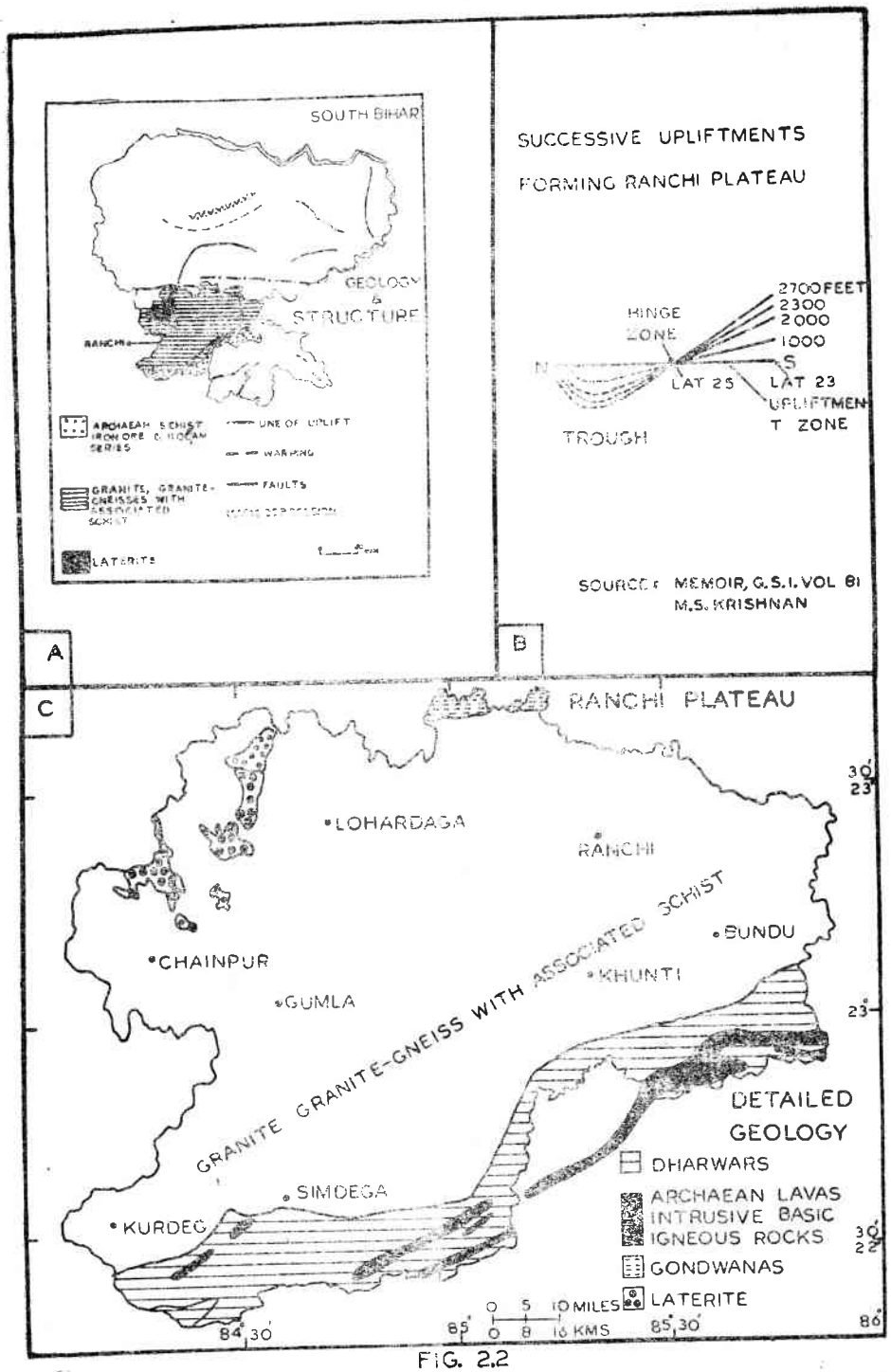
Table II : Correlations

Variables	Coefficient of determinations R^2 (%)	Coefficient of correlation (r)
1. Basin area and perimeter (perimeter as a function of square roots of basin areas)	72.25	+0.85**
2. Channel length and basin perimeter	90.25	+0.95**
3. Lg and average slope	50.41	+0.71**
4. Lg and drainage texture	86.49	+0.93**
5. Relief ratio and elongation ratio	2.89	+0.17
6. Relief ratio and slope	34.81	+0.59**
7. Lg and dissection index	12.96	−0.36
8. Relief ratio and drainage density	21.16	+0.46*
9. Relief ratio and Horton's form factor (F)	6.25	+0.25
10. Relief ratio and standard sinuosity index (SSI)	26.01	−0.51*

N = 23

* Significant at 5% of probability level.

** Significant at 1% of probability level.



Ftg 1 : Geological map of the Ranchi Plateau

basin (22.29), does not render elongated shape as elongation ratio (Schumm's 'R') and circularity index (Miller's 'C') stand at 0.76 and 0.85 respectively. Dongajor basin presents a similar trend as it has circularity index of 0.83, elongation ratio of 0.87 and Horton's form factor of 0.63, but its relief ratio (17.65) is much higher than Khakrajar basin (relief ratio =5.87) of which circularity index and elongation ratio are only 0.4 & 0.57 respectively, which are much lower than the values of Dongajor basin. Thus it may be concluded that relief ratio becomes a poor morphometric determinant (at least in the cases of the selected basins of the Ranchi plareau) of the basin shapes.

Melton (1957) correlated drainage density with relief ratios of 31 basins of the East Devon plateau and obtained a coefficient of correlation of +0.69. The relief ratios and drainage density values of the selected 23 small basins, when correlated, render a coefficient of correlation of + 0·46. The relief ratios may also be correlated with average slopes (r = + 0·59).

Relief ratio may be correlated with standard sinuosity index (SSI). It is axiomatic to deduce that more sinuous river may have lower relief ratio and less sinuons river may be associated with higher relief ratio. Thus it appears from the above hypothesis that SSI is negatively related with relief ratio. This hypothesis becomes partly true when the relief ratios and sinuosity indices of the 23 selected small basins are correlated and the correlation yields a negative coefficient of correlation of 0·51.

Absolute Relief, Relative Relief, Slope Dissection Index, Drainage Density, Stream Frequency and Drainage Texture

Mean absolute reliefs and relative reliefs are positively correlated (r = 0·43) but it should not be inferred that high absolute relief will always produce high relative relief as the coefficient of determination being only 18·49% (R^2) represents only low percentage of the total observation but within the basin this relationship is certainly more pronounced. It is pertinent to point out that absolute relief is neither a causative nor determinant factor of relief. The coefficient of correlation between absolute relief and average slope standing at +0·57 indicates a positive relationship between these two variables but again abolute relief should not be taken as causative factor of average slope.

As regards dissection index, drainage density, stream frequency and drainage texture, absolute relief becomes passive factor because no significant relationship is observed as is apparent from the correlation matrix (Table III). The correlation cofficient between absolute relief and dissection index (–0·13) indicates that absolute relief alone does not affect dissection of a region, for example, a region having lower average height but pronounced relative relief and much gradient may have higher dissection index than a region having higher mean height but level surface. This fact is fully observed in the basins of the Central Ranchi plateau and southern lower plateau.

Relative Relief, Slope, Drainage Density, Stream Frequency, Dissection Index and Drainage Texture

It is apparent from the correlation Matrix (Table III) that relative relief is a significant morphometric variable as it is directly related to a number of geomorphic attributes. Relative relief is highly correlated with average slope (r = + 0.87). Such a high correlation, which is significant at 1 per cent. probablility level, clearly demonstrates the fact that if the relative relief increases, slope also increases and vice-versa. The coefficient of determination (R^2) covers more than 75 per cent. of the total observations and thus the relationship is well marked within the basins and among the basins. In fact relative relief and slope are cause and effect of each other i. e. high relative relief is responsible for higher slope

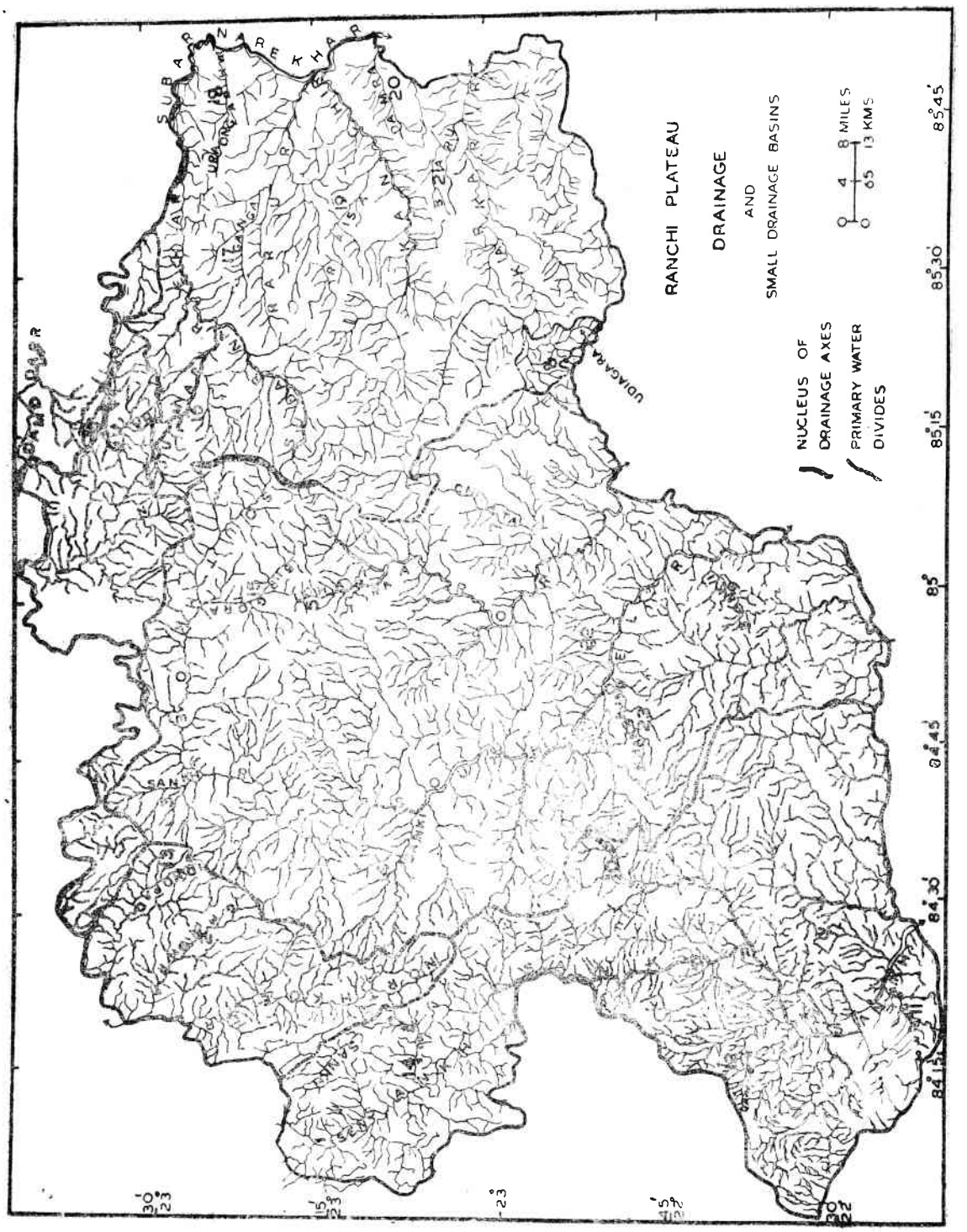


Fig 2 : Drainage and Small Drainage Basins of the Ranchi Plateau

Table III : Correlation Matrix

Variables	A_R	R_R	S	D	D_d	S_F	D_T
A_R	X	+0.43*	+0.57**	−0.13	−0.09	+0.07	−0.06
R_R		X	+0.87**	+0.80**	+0.49*	+0.59**	−0.54**
S			X	+0.79**	+0.70**	+0.71**	−0.68**
D				X	+0.55*	+ 0.50*	−0.54**
D_d					X	+0.89**	−0.93**
S_F						X	−0.98**
D_T							X

N = 23

A_R = Mean absolute relief
R_R = Mean relative relief
S = Mean slope angles
D = Mean dissection index
D_d = Mean drainage density
S_F = Mean stream frequency
D_T = Mean drainage Texture
Note = Negative correlation of D_T with other six variables has been explained in the text.
* Significant at 5% probability level
** Significant at 1% probability level

and steep slopes generate high relative relief and vice-versa. The coefficient of correlation between relative relief and dissection index standing at +0.80 indicates a significant positive reletionship between these two variables. Like slope, dissection index also affects relative relief. The more the dissection of a region, the higher the relative relief and vice-versa. Thus relative relief and dissection index are cause and effect of each other.

The control of relative relief decreases over drainage density, stream frequency and drainage texture as compared to slopes and dissection indices. Drainage density is directly related to relative relief as is indicated by the positive coefficient of correlation of 0.49 between the mean values of these two variables. In fact, drainage density should not be taken as a function of relative relief rather relative relief should be taken as the product of the drainage density as it is the streams which dissect the terrain and thus produce vertical irregularities of reliefs. But vertical irregularities may not always be due to vertical erosion but they may also be due to tectonic factors.

The positive correlation ($r = +0.59$) between relative relief and stream frequency should not be used in favour of relative relief as a causative factor of stream frequency rather streams are responsible for shaping relative relief of a region. The negative correlation ($r = -0.54$) between relative relief and drainage texture is interesting and needs further clarification. This negative correlation is in fact a direct relationship as regards the classes of these two variables because the values of stream spacing in terms of fraction of mile have been correlated with relative reliefs. This correlation reveals the fact that drainage texture decreases with increasing relative

relief which means that the spacing between two streams decreases with increasing relative relief and hence the higher the relative relief, the finer the drainage texture (due to closer spacing of streams) and the lower the relative relief, the coarser the drainage texture.

Slope, Dissection Index, Drainage Density, Drainage Texture and Stream Frequency

Slope is an omnipresent morphometric variable because it is related to almost all the morphometric variables, acting some times as an independent and some times as a dependent variable. Dissection index, drainage density, drainage texture and stream frequency are highly related to slopes. It appears from the correlation matrix (Table III) that slope is one of the most important causative factors of the above variables. The coefficient of +0·79 between mean slope angles and mean dissection indices of the 23 small basins indicates a direct relationship between these two variables, i.e. the steeper the slope angle, the more the dissection index and vice-versa. This relationship is well marked in nearly all of the 23 small basins with slight departures. Since drainage densiy is dependent on the lengths of streams which are dependent on numbers of streams, hence slope affects both (drainage density and streams frequency) with the same magnitude as is apparent from the correlation, matrix (Table III), wherein coefficients of correlation between mean slopes and mean stream frequency and mean slopes and mean drainage density stand at +0·71 and 0·70 respectively. Thus it appears from the correlation coefficient that the number of streams of a given basin increases with increasing slope angles and vice-versa. It may be further clarified that steeper slopes generate and maintain larger number of streams than the gentler slopes if other factors remain constant and thus it may be pointed out that high drainage density corresponds to steeper slopes and low drainage density is associated with gentler slopes.

It is important to point out that slope is not the only factor which has an upper hand in determining density but other factors like rainfall intensity, infiltration, overland flow, through flow, geological structure and vegetation cover also play their roles in controlling the drainage density. For example, Dongajor basin has the largest value of mean drainge density (Dd = 5.6) but its mean slope (S = 6°30′) falls in the category of moderate slope. Thus in the case of Dongajor basin it is not the slope which is more responsible for the highest value of mean drainage density but it is comparatively weak Dharwarian formation and the joints of the rocks which have favoured more branching of streams.

Similarly slope also directly affects the drainage texture. The negative correlation coefficient (r = -0.68) between these two variables indicates that the values of drainage texture increase with decrease in slope angle and vice versa. This means that when the slope angle increases, the drainage texture becomes finer (since the spacing between the streams decreases with increase in slope angles and hence the texture becomes finer.)

Drainage Density, Stream Frequency and Drainage Texture

It is axiomatic to think that drainage density, stream frequency and drainage texture should be higely correlated among themselves as all of them are equally affected by common factors like geological structure, climate, vegetation and slopes. Drainage density is highly positively correlated with stream frequency(r = +0·89)which shows that drainage density increases with increase in the number of streams of the basin and vice-versa. The result of correlation between these two variables of 23 small drainage basins of the Ranchi plateau very much resembles the result drawn by Melton (1957), who derived a coefficient of

correlation + 0·97 between drainage density and stream frequency of 156 sample basins.

Drainage texture is negatively correlated with drainage density(r = −0·93)which means drainage texture decreases with increase in drainage density and vice-versa, meaning thereby that higher the drainage density, finer the drainage texture and lower the drainage density, coarser the drainage texture (high texture value = wider spacing = coarse texture and low texture value = close spacing = fine texture). Strahler (1957) also derived a high correlation between texture ratio (which is a ratio of the total number of contour crenulations of the most crenulated contour of the basin to the length of the perimeter of the same basin (Smith, 1950) and drainage density.

Stream frequency and drainage texture, when correlated, render most significant negative coefficient of correlation of − 0·98, which shows almost linear relationship between these two variables which is indicated by the scatter diagram of these two variables. Negative correlation between these two variables shows that fine drainage texture (low texture value) is associated with high stream frequency and coarse drainage texture (high texture value-wider spacing of streams) corresponds to poor stream frequency.

Conclusion

The correlation analysis of certain morphometric attributes has revealed several significant relationships. Basin perimeters and channel lengths and basin perimeters and the square roots of basin area are strongly positively correlated (r = 0·95 and r = 0·85 respectively). Absolute reliefs have proved to be very poor morphometric determinants of several geomorphological variables such as average slopes, relative reliefs, dissection index, drainage density, drainage texture, stream frequency etc. Average slopes and relative reliefs have emerged as very significant morphometric attributes which affect many of the geomorphological variables. Slope, therefore, may be termed as 'devil's own variable' as it is related to nearly all of the morphometric variables. Slopes are highly negatively correlated with length of overland flow(r = −0·71 positively correlated with reliefs (r = + 0·59), dissection indices (r = + 0·79), stream frequency (r = + 0·71). drainage density (r = + 0·70) and are negatively correlated with drainage texture (r = —0·68). Relative reliefs are positively correlated with bifurcation ratio (r = + 0·43), slopes (r = + ·87), dissection indices (r = + 0·80), drainage density (r = + 0.49), stream frequency (r = + 0·59) and are negatively correlated with drainage texture (r = − 0·54). Drainage density is highly positively correlated with stream frequency (r = + 0·89) and is very highly negatively correlated with drainage texture (r = − 0·93). Stream frequency and drainage texture are most highly negatively correlated (r = − 0 98).

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