SLOPE MORPHOLOGY

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SLOPE MORPHOLOGY

The morphological personality of the Chhatrapur Subdivision reflecting ubiquity of slope is manifested in the disjointed line of the massive Eastern Ghats, residual hills, dissected and subdued plateaus, relict weathered profiles, rugged slope faces, undulating plains, gullied surfaces, interfluvial ridges, talus and colluvial slopes and nearly level lands including a range of other minor tectonic forms and erosional, transportational and depositional land surface forms developed thereupon subsequently. All these slope forms and surfaces are the fundamental types of landscape feature (King, 1967, p.51) which have projected firstly the terrain character in terms of physical potentials and then have
determined the extension as well as intensity of agricultural landuse in the study area. They need, therefore, a careful study.

10.1. **SLOPE MECHANISM**

The term 'slope' is a common geomorphic expression referring to 'some small element or area of the land surface which is inclined from the horizontal (Strahler, 1968, p. 395). Thus, the slope may be designated as 'mountain slope', 'hill slope', 'valley side slope' besides all other inclined surfaces with reference to any plane, tangential to the surface base at any point. In fact the slopes are the 'upward or downward inclinations resulting from the form of the natural landscape' (Harry, 1969, p. 149) and the tangent of gradient is the first derivative of relative altitude, i.e., the rate of change of altitude with distance.

Slope thus defined is 'a function of structure, process, time and tectonics' (Ahmad, 1985, p. 41). The main features of slope are produced by tectonic activity and minor modifications are introduced by exogenic processes through the lapse of time. The surface material, surface elevation, relative heights, vegetation cover, magnitude of weathering and erosion and numerous other factors are involved in the mechanism of slope.
The Chhatrapur Subdivision experiences humid tropical climate (Ch. 4). Naturally fluvial processes are dominating. Therefore, the slope aspects of the Subdivision are an end product of geological and lithological textures of the terrain (Chs. 2 & 7), inequalities in elevation and forms (Ch. 3), varying textures of drainage (Ch. 8), extent of vegetation (Ch. 6) and uneven distribution of relief measures (Ch. 9). However, the most fundamental processes are the endogenic which have produced the initial slope and the processes involved in the development of subsequent slope with particular reference to 'the production of material by weathering of bedrock or the communication of already weathered material and the transport of such material downslope' (Clarke, 1970, p. 238).

10.2. **SIGNIFICANCE OF SLOPE IN THE CONTEXT**

Slope processes of all kinds and intensities are an integral part of dynamic and applied geomorphology. It is, therefore, essential that all informations of slope related to them need potentially systematic emphasis in analytical agricultural land use surveys. 'Other things like latitudinal location and technological and economic development being equal, slope is specifically most powerful physical determinant in agricultural land utilisation, affecting the existence, depth, structure, texture and stability of soil;
possibilities and pattern of irrigation, field pattern, distribution and size of holding; cropping pattern, agricultural output and efficiency, agricultural transport, etc.' (Ahmad, 1985, p.373). The significance of slope in the context of terrain evaluation and agricultural landuse may be discussed in detail as follows:

(1) The slope constitutes the most critical single factor affecting and modifying the consequential change in soil and erosion pattern, though the severity of soil erosion is not determined by the angle of slope alone. Further, the soils are not also an exclusive result of disintegration of rocks underlying them, but are rather that of a cumulative interaction of vegetation, slope, and topography on the weathered products. Owing to the steepness of slope and high elevation, soils do not get properly matured because of the moderate chemical weathering, mass-movement, strong fluvial erosion, together, they retard the mechanism of soil formation. Accelerated erosion owing to intermittent superficial slope angles is a serious and widespread threat in many agricultural land units. The removal of fertile soil may, in course of time, diminishes agricultural productivity and the yield per unit area. The gullies often reach considerably greater dimensions and not only cause damage in the form of regional truncation of soil profiles but also remove the underlying unconsolidated material and even soft and disintegrated bed
Sheet and rill erosions also cut through the entire soil profile and the resulting down slope transportation exposes the bare hard rock or unconsolidated over-burden. The thickness of soil depends upon the relative positions of highlands and lowlands. In higher areas due to steepness of slopes the weathered rock material is washed down over the lowlying areas where the thickness of soil cover increases progressively. On the other hand in the upland areas the soils are not thick. Further, the steepness of slopes leads to quicker runoff after rains. The velocity of water causes soil erosion making the slope areas unsuitable for cultivation. Where the erosion hazard is severe, terracing of agricultural field is essential after effective negotiation with the gradient of local slope unit in order to prevent soil erosion. 'Only very gentle slopes of less than 2° can be cultivated without the need of conservation measures. With increase in slope angle there is a more linear increase in liability to erosion' (Young, 1972, p.251). Soil sequences seem to be more often local than regional in their occurrences. There is possibility of relating their sequences with some local events through time element in dissection, ruggedness, erodibility, weatherability, tectonic disturbances and stability. In all these, a significant role of slope, though an end product of these elements, seems to be dominant at
direct glance and/or in disguise. Thus all these aspects of slope-soil relationship seemingly affect the extent of agricultural land utilisation in a given area.

(2) The pattern of agricultural land utilisation, in fact, begins with the morphology of the area. The slope is one of such specific aspects of terrain other than surface elevation, relative altitude, intensity of relief, ruggedness, dissection, drainage density and efficiency, which has the most potent influence on the agricultural landuse. Thus, the various forms of slope determine the soil use and agricultural landuse besides establishing a relationship between the slope and use of simple agricultural equipments. Moreover, analyses of terrain slopes have extended noticeable contribution to modern agro-geomorphological research. At a time when a theoretical geomorphologist explains the form of land through the identification of processes involved, and agro-geomorphologist estimates their quantitative influences on the quality and extent of agricultural landuse on a specified terrain under investigation and evaluation. Such terrain forms of varying orders express slopes of varying angles and dimensions.

(3) Dissected and/or mutilated slope surfaces give positive indication of the extent of land-levelling for
agricultural landuse. However, these seem to be the speculative elements in irrigation planning. The length and alignment of diversion channels are usually planned according to the frequency of breaks in a given slope unit of a unified area. It is difficult for irrigation channels to naturally negotiate even minor undulations in terms of slope. Therefore, owing to high degrees of slope, canals seem to be ordinarily absent in the hilly terrain units.

(4) Different degrees of slope extend their spheres of influence on the characteristically phenomenal runoff, infiltration and volume of underground water potential. 'Other things being equal, ground water varies inversely with slope. Low inclination guarantees slow runoff and ample soakage' (Ahmad, 1985, p.374). On steep slopes, the velocity of overland flow tends to be relatively high and infiltration rate lower than on gentler slopes of the same material. This increases erodibility.' Long slopes tend to build up large quantities of overland flow and consequently erosion, particularly near the foot of the slope, except when a high infiltration rate compensates for it' (Verstappen, 1983, p.371). On profile characteristics of slope also have to be considered, on convex slope erosion generally increases down-slope with increasing steepness, whereas on concave slopes the upper parts are usually susceptible to erosion. In the case of
straight slopes the distribution of erosion is more complex, it may occur particularly in the often slightly convex-top parts and/or in the lower parts where the factors, such as surface roughness, etc., may also be dominant governing factors. Break of slope are of particular importance in evaluating erosion susceptibility of a certain part of a slope (Verstappen, 1983, p.371).

In other words, when a slope has concave contours, a concentration of overland flow will occur which may easily lead to the formation of gully in the depressed central portion. Where a convex configuration occurs, there seems to be a tendency to a diffusion of the water which makes the erosion susceptibility less. Slopes with straight contours take an intermediate position in this respect, the length of slope in this case is often the leading factor in the distribution of gullies because of greater build-up of overland flow on long slopes. If a flat or gently sloping foreland of adequate dimensions occur in front of the eroding slope, the detached and subsequently down-slope transported material may be directly redeposited at its foot in the form of gently colluvial slopes (Verstappen, 1983, p.371).

(5) The agricultural field pattern, viz., layout, alignment, size and shape of fields, is a function of slope. Generally the pattern, distribution and size of holding change
according as the land gradient changes from the upslopes of the spurs and piedmont situations to the down-slopes of the valley sides and lowlands. Within an agriculturally potential limit of a given slope sequence, the higher values of land gradient are indicative of small and narrow elongated oblong field pattern whereas on the lesser slopes, wider and apparently large-sized rectangular field pattern seems to cluster owing to easy levelling and terracing. Any variation in the naturally set field-size in both these situations of land gradient may, however, be attributed to social phenomena of agricultural land subdivision and fragmentation. Ordinarily, certain amount of isolated residual forms and their gradients seem to have their potential reflections in the designing of shape of fields such as oblong, rectangular and variations of both in size and pattern. These lead to some irregularly designed sinuously terraced field curvatures which are interrupted occasionally by the rock exposures. In a perspective sky-line sketch, if observed upwards towards the upper reaches of a valley, especially the main valley from any observation point on a comparatively low gradient site or a fairly flat valley bottom point, the cumulative picture of these terraced agricultural fields appears to assume a semi-circular arch pattern along and across the upper three sides from the point of the observer's direct view. This parallactical
impression of a semi-circular field pattern may be attributed to the conspicuous change in the sequence of land gradient. Moreover, the absolute dimensions and relations of the fields seem to pattern in accordance with the conspicuous pattern of and change in the valley side upland gradient. The patterns of the terraced fields along the main valley in general, however, are mostly oblong or rectangular having length along and width across the valley particularly in its middle and lower reaches.

(6) The slope, apart from surface elevation is another example of geomorphic control of crops. The crops, notably paddy requiring inundation are confined to the low gradient nearly flat zones. Similarly the crops that require no waterlogging are generally situated on the comparatively upper slopes.

(7) The difficulties and ease of agricultural transport vary directly with land gradient. The slope is also one of the main determinant causes of the cluster or scatter or dispersal of farm settlements in tune with the slope-regulated movement of agricultural implements, ploughing animals, seeds, fertilizer, harvested crops, vegetable and marketable commodities. The slope, therefore, determines the direction, quantity, speed and cost of transport in addition to an average
farmer's habitat and physical ability to negotiate the critical limits of a given grade of land gradient in terms of agricultural landuse.

Therefore, for determining an order of a terrain unit, the slope represents a significantly potential lobby of specifically basic and informative and interrelated physical components of a terrain. It is a categorical aid to visualise and evaluate a terrain unit and its objective comparison with other units of a terrain under study. In the fitness of the preceding truth, the author adheres to a morphometric identification of suitable slope categories and slope angles with an ultimate view to classify the terrain on the basis of several phenomenal slope units and to evaluate and determine the degree of agricultural landuse in a region of utmost physical inequalities as of the Chhatrapur Subdivision.

10.3. MEASUREMENT TECHNIQUES

The slope conditions over the study area have been shown by means of a slope category map (Fig.10.1) after Raisz and Henry's method (1937, pp.467-472) of slope determination. It shows categorical distribution of the degrees of formal land surface inclination. As the morphological character of the Chhatrapur Subdivision is illustrated by its appearance (Fig.3.1), a study of slope categories (Fig.10.1) provides not only the variety of terrain features, but makes available the relevant
interpretation of a complex form of its intra-regional agricultural landuse.

No doubt, the construction of a \underline{slope category map} (Fig.10.1) necessitates patience, practice, perfection, microscopic eye-estimation and identification of uniform segments of contour spacings and a certain degree of individual judgement. The technique as devised by \underline{Raisz and Henry} seems to be very much useful in making quantitative generalisation of phenomenal slope angles and land gradient zones of a given class of elevation (Table 3.1) above the sea-level.

The other contour-based popular \underline{method of average slope determination} by \underline{C.K. Wentworth (1930, pp.184-94)} has not been applied by the author for various reasons. The expected number of contour lines is not printed on the toposheets of a wide area around the coastal margins of the Chhatrapur Subdivision. Any theoretical interpolation of such contour lines in this part of the study area in keeping with the contour line bias-ness of the \underline{Wentworth's method} might distort and defeat the very purpose of the author's investigation. The Wentworth's slope devise is a 'general' and 'random' method of average slope determination from a contour map basing upon the formula:

\[
\text{Average slope} = \frac{\text{Average number of contour crossings per unit side of a square grid}}{\text{Length of one side of the grid in unit of contour interval}} \times \text{interval} \times 0.6366
\]
The most disadvantageous part of the method seems to have its exclusive dependence on contour interval. Thus, there is a positive chance of innumerable zero scores per unit uniform square grid in respect of average slope of a large area of coastal, alluvial and low surface elevation planation surfaces of the Chhatrapur Subdivision owing to the non-mention of contour lines in printed form in the corresponding topographical maps (1:63,360 & 1:50,000) at the obvious insistence of scale limitations. It is an undeniable fact that no area of the Chhatrapur terrain surface is without slope. It may be mentioned without ambiguity that most surfaces including practically level cultivated fields have imperceptible slopes. Thus, while giving weightage to the potentiality of slope studies in relation to the potential agricultural landuse evaluation, no element, perceptible or imperceptible, of slope is negligible in the Chhatrapur Subdivision. The features like knolls, hillocks, marine sand dunes, creeks and various other minor land projections fall victims to Wentworth's method which are not, however, overlooked in Raisz and Henery's method of slope determination. The Wentworth's method can be applied to some selected areas with evenly spaced contours only, while the method after Raisz and Henry seems applicable to each and every area. Moreover, the Raisz and Henery's method has provision to indicate direction of slope, so the amount of gradient in a
particular slope category can be mentioned along with the direction of slope which has much significance in agricultural landuse planning.

The author has, therefore, followed the method devised by Raisz and Henry. The topographical maps (1:50,000) of the Chhatrapur Subdivision have been taken and numerous small, irregular and unequal patches with more or less horizontal spacings of contour lines have been demarcated to denote the same number of contour lines per kilometre of horizontal distance. A horizontal scale of standard contour spacing has been drawn, so that the number of contours per kilometre on the map scale could be checked up with a pair of dividers. The slope category was then determined by careful inspection and individual judgement. The values in terms of the tangent of the average angle of slope have been converted into degrees (Table 10.1) with the help of tangent tables or scientific calculator. Finally a map (Fig.10.1) has been prepared.

10.4. SLOPE CHARACTERISTICS

Fig.10.1 and Table 10.1 reveal that the slope features in the Chhatrapur Subdivision display almost an identical pattern as those of dissection index, relative relief and drainage density (Figs.9.4, 9.2, 8.2). The slope categories of the terrain of the study area range from less than $0^\circ 30'$ to more than $40^\circ 0'$. Seven major slope categories have been
distinguished (Table 10.1) on the basis of their frequency of occurrence with a view to classify and evaluate the terrain for agricultural landuse in the Subdivision.

10.4.1. Areas of very steep slope (>90°):

Covering 18.44% of the total area, the region of very steep slopes projects a good deal of variation ranging from more than 90° to above 60°. It presents a typical example of a distinctly hilly nature of the terrain characterizing convex-rectilinear-concave and rectilinear-concave slope profiles clad with dense natural vegetation and/or absolute bare rocky surfaces. This zone of the Chhatrapur Subdivision, most prominently in its north displays almost an identical trend as those of surface elevation, relative relief, dissection index, intensity of relief and drainage texture besides ruggedness and absolute relief. In this zone, an apparent discontinuity in the oscillation of the crestline and its composite slope facies refers to the outstandingly disjointed ridges of the northeast-southwest trending Eastern Ghats and their far and near offshoots forming more or less stable unconsumed remnants of prolonged denudation since the earliest movements of the Archaean times. Their current form seems mainly to be due to differential weathering and erosion.

The solid Khondalitic geology of this distinct zone of a discontinuous line of hills in the Subdivision appears to
find its sharp surface expressions in the north, northeast, east and southwest and in many other scattered hilly terrain units in isolation. Such expressions include the steep cliffs, elongated ridges, spurs, narrow valley-side slopes, escarpments, innumerable high altitude surfaces and undulating rocky and debris slopes. Considering the topographical irregularities with reference to their corresponding variation in respect of the regional slope magnitudes, this very steep slope zone of the study area may be sub-categorized into three:

1. Slope above 30°,
2. Slope between 15°1' & 30° and
3. Slope between 9°1' & 15°

10.4.1.1. **Slope above 30°** - This slope sub-unit appears in different parts of the Chhatrapur Sub-division with its maximum areal concentration in the northern and northeastern hill tracts of Polosara, Kodola and Khallikote blocks. The local relief of these outstandingly precipitous slope units varies between 300 to 500 metres or more while the texture of drainage is uniformly fine. Similarly the indices of dissection and ruggedness are apparently pronounced in their expressions in the form of very steep bare Khondalitic cliffs veneered rarely by very thin film of virgin soil wooded with thorny vegetation. As such, this hilly unit of extra-ordinary
relief sharpness, high surface elevation and very steep rectilinear-concave slope is seemingly susceptible to extensive fluvial erosion. Thus, the usability status of the available surface water for an effective agricultural land-use seems to be in the neighbourhood of zero. Further, in this unit, access to land seems to be ordinarily restricted. All these negative aspects, therefore, set very severe limitations on any form of potential agricultural land utilisation in this slope unit of above 30° in the Chhatrapur Subdivision.

10.4.1.2. Slope between 15°1' & 30° - The unit of very steep slope with a hilly land gradient between 15°1' to 30° seems to form a major orographical enclave of the skeletal Ghat segments and dissected plateaus over most of the Chhatrapur Subdivision. It accounts for its large concentration in the northern hilly terrain anomalously eccentuating and eccentri-cally associating with the characteristics of high relief and moderately high surface elevation between 150 and 300 metres above the sea-level. In a similar manner, the amplitude of available relief varies between 100 and 200 metres with a well-drained phenomena of fine drainage texture. This is an area of high dissection which seems to have been tightly packed with NE-SW aligned narrow rugged and discontinuous line of hills of steep concave and rectilinear upslopes and midslopes forming the water divides of the prominent south
flowing stream channels of the Rushikulya system. The geolithological sequence of this sub-slope unit includes a range of garnetiferous rocks of Khondalitic and granite gneiss suit.

The monumental discontinuity in the elongation of these steep disjointed residual hill segments in the south of the northern hilly terrain seems to be more or less uniformly distributed and stood as outstandingly contrasting topographical elements over the vast level, nearly level lands and the rugged uplands of Polosara, Kavisuryanagar, Purusottampur and non-littoral Chatrapur and Ganjam blocks.

These sub-units of very steep slope between 15°1' & 30° have been remarkably overburdened with parallel gullies and laterites which seem to present a sequence of conspicuously sterile soils and more or less barren subterranean moisture chambers besides untillability and inaccessibility. Consequently in such units of the Chhatrapur Subdivision, any planned effort for agricultural land utilisation seems to be non-remunerative and uneconomic.

10.4.1.3. **Slope between 9°1' & 15°** - The general topographic imprints of this unit of very steep slope category have been identified as dissected hilly rugged terrain with flat-topped low hills and narrow valleys of the Chhatrapur Subdivision.
This unit presents a characteristically rectilinear midslopes of strongly sloping undulating upslopes and downslope exposures of hard granite gneiss and Khondalitic rocks. The dominant surface expression denotes a lateritic and/or ferruginous landscape.

These strongly sloping low altitude hills represent the disjointed Eastern Ghat offshoots and residual segments of dissected plateaus comprising the Chandikho ranges of the northeastern Khallikote; Pandiripada mal ranges of the northern Polosara; Athgarpatna hills of Kavisuryanagar, Karakhol ranges of the western Chilka high lands; Jharan and Mangaldhimiri hills of western Purusottampur and Bhalupahar hills of northern Kodola block. These strongly sloping low hill segments mostly constitute the precipitous free-face rectilinear slopes and basal concavity of the subdued plateau fringes.

The amplitude of available relief in these units is fairly high over 100 metres because of an apparently hilly nature of the terrain. Owing to an internal variation in the intensity of slope and structural mineralogy, the drainage density per unit area seems to vary accordingly. But the texture of drainage is noticeably fine. Further, the degrees of dissection and ruggedness maintain an apparent parallelism with the magnitudes of relative relief and stream frequency per unit slope-length.
<table>
<thead>
<tr>
<th>Categories</th>
<th>Slope categories in degrees &amp; minutes</th>
<th>Frequency in km²</th>
<th>In percent to total area</th>
<th>Cumulative frequency</th>
<th>Major categories</th>
<th>Percentage of major categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$0^\circ 30' , \text{f} , \text{below}$</td>
<td>892.95</td>
<td>41.69</td>
<td>892.95</td>
<td>Very gentle (892.95 km²)</td>
<td>41.69</td>
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<td>2</td>
<td>$0^\circ 31' - 1^\circ 0'$</td>
<td>419.19</td>
<td>19.57</td>
<td>1312.14</td>
<td>Gentle (419.19 km²)</td>
<td>19.57</td>
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<tr>
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<td>$1^\circ 01' - 1^\circ 30'$</td>
<td>243.86</td>
<td>11.38</td>
<td>1556.00</td>
<td>Moderately gentle (243.86 km²) (1^\circ 01' - 1^\circ 30')</td>
<td>11.38</td>
</tr>
<tr>
<td>4</td>
<td>$1^\circ 31' - 2^\circ 0'$</td>
<td>27.44</td>
<td>1.28</td>
<td>1643.33</td>
<td>Moderate (98.25 km²) (1^\circ 31' - 2^\circ 0')</td>
<td>4.59</td>
</tr>
<tr>
<td>5</td>
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<td>27.44</td>
<td>1.28</td>
<td>1643.33</td>
<td>Moderate (98.25 km²) (1^\circ 31' - 2^\circ 0')</td>
<td>4.59</td>
</tr>
<tr>
<td>6</td>
<td>$2^\circ 31' - 3^\circ 0'$</td>
<td>10.92</td>
<td>0.51</td>
<td>1654.25</td>
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<td>0.51</td>
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<td>7</td>
<td>$3^\circ 01' - 6^\circ 0'$</td>
<td>77.45</td>
<td>3.62</td>
<td>1731.70</td>
<td>Moderately steep (77.45 km²) (3^\circ 01' - 6^\circ 0')</td>
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</tr>
<tr>
<td>8</td>
<td>$6^\circ 01' - 9^\circ 0'$</td>
<td>15.19</td>
<td>0.71</td>
<td>1746.89</td>
<td>Steep (15.19 km²) (6^\circ 01' - 9^\circ 0')</td>
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</tr>
<tr>
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<td>94.20</td>
<td>4.40</td>
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<td></td>
<td>4.40</td>
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<tr>
<td>10</td>
<td>$12^\circ 01' - 15^\circ 0'$</td>
<td>40.20</td>
<td>1.88</td>
<td>1881.29</td>
<td></td>
<td>1.88</td>
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<tr>
<td>11</td>
<td>$15^\circ 01' - 20^\circ 0'$</td>
<td>76.88</td>
<td>3.59</td>
<td>1958.17</td>
<td></td>
<td>3.59</td>
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<tr>
<td>12</td>
<td>$20^\circ 01' - 25^\circ 0'$</td>
<td>51.72</td>
<td>2.41</td>
<td>2009.89</td>
<td>Very steep (305.11 km²) (&gt; 9^\circ 0')</td>
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<tr>
<td>13</td>
<td>$25^\circ 01' - 30^\circ 0'$</td>
<td>27.31</td>
<td>1.27</td>
<td>2037.20</td>
<td></td>
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</tr>
<tr>
<td>14</td>
<td>$30^\circ 01' - 35^\circ 0'$</td>
<td>63.67</td>
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<td>2100.87</td>
<td></td>
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<tr>
<td>15</td>
<td>$35^\circ 01' - 40^\circ 0'$</td>
<td>22.13</td>
<td>1.03</td>
<td>2123.00</td>
<td></td>
<td>1.03</td>
</tr>
<tr>
<td>16</td>
<td>Above $40^\circ 0'$</td>
<td>19.00</td>
<td>0.89</td>
<td>2142.00</td>
<td></td>
<td>0.89</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>2142 km²</td>
<td>100.00</td>
<td>2142 km²</td>
<td></td>
<td>100.00</td>
</tr>
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</table>
These slope units have been eroded into well-separated parallel ridges and spurs indicating the effects of differential weathering and erosion. The scarps of these strongly sloping low hills seem to register intermittent breaks in slope giving a natural scope to mechanical disintegration of the slope surfaces into huge tors (Plate 1.2). Owing to the conspicuous steepness of slope, rapid runoff and hard substratum, the potential reserve of underground water is very poor. The excessively drained nature of the terrain results in extensive rainwash and soil-creep. These have given way to the formation of innumerable parallel gullies the sides of which are covered with coarse angular debris of talus and the bases with colluvial surface materials.

Most of these slope units in the Chhatrapur Subdivision are too steep and/or too rugged to allow ploughing. Further, the strongly sloping surface configuration of these units seems to hinder the growth of human settlement ultimately resulting in discontinuous patches of agricultural landuse.

Thus, the category of very steep slope surfaces as a whole, owing to the rocky and hilly nature of the terrain, severe soil erosion, rapid runoff, shallow and moderately deep soils and poor surface and underground water potential, act as strongly negative phenomenon against any form of agricultural landuse operation in the Chhatrapur Subdivision.
10.4.2. Areas of Steep Slope (6°1' - 9°):

The areas of steep slope cover only 0.71% of the total geographical area of the Chhatrapur Subdivision. It comprises the moderately high altitude hilly and undulating high upland segments of eastern Kavisuryanagar, northwestern Purusottampur, northeastern and north-central Khallikote, central Hinjili and Chatrapur blocks. The characteristic topographical expressions of this category include highly rugged residual steep hills and rugged upland plateau fringes which are moderately dissected into vertically parallel concave gullies. The surface covering is characterised by the residual overburden of tropical weathering of the hard garnetiferous gneiss and granite gneiss. The sharpness of relief is between 80 metres to more than 100 metres with a moderately fine drainage density and high ruggedness.

Therefore, the area-slope relationship of this category of steep slope shows a characteristically rolling and conspicuously rugged upland terrain segments incised deeply by the active fluvial erosion. A fairly well-drained nature of the terrain overwhelmingly gets the better of the rate of infiltration. Thus, the status of ground-water holds no potential promise for the agricultural landuse development in these tracts.

Owing to the undulating nature of the rectilinear upslopes and gullied concavity along this region's midslopes and
down-slopes, there are fairly large terraced oblong cultivated fields. These plots seem to concentrate on the stepped upland benches, upland valley bottoms and foot slopes of hills. These fields consist of thick mantle of dry ferruginous stony and lateritic soils denoting poor land potential. In few of these tracts, the nodes of transport and settlement are confined to an intermediate position between the steep uplands and steep valley bottoms.

10.4.3. Areas of Moderately Steep Slope (3°1' - 6°) :

Covering 3.62% of the total area of the Chhatrapur Subdivision, the areas of moderately steep slope are scattered more or less in all surface elevation zones. The significant topographical expressions of this slope unit consist of dissected scarps, rugged undulating moderately high uplands, dissected plateaus and their fringes, isolated upland and hill segments of prolonged incision and the rugged offshoots of the tail-end hill segments of the Eastern Ghats.

These astoundingly conspicuous slope units generally constitute the lowlying fluvial ridge and valley landscape units of the study area. The occasional high values in respect of moderately steep slope class appear to evolve where a moderate to high relative relief has been traced out to be a direct product of fluvial erosion. It denotes moderate dissection and high and moderate ruggedness.
Despite the comparatively ameliorative surfaces in terms of slope, the moderately steep slope regions of the Chhatrapur Subdivision impede agricultural landuse operation by presenting innumerable surface obstacles of high grade surface irregularities exposing bare outcrops of very hard pyroxenated granulites, ferruginous quartzites and basic granulites. Therefore, even under active fluvial action the drainage density is not potentially aggregated on these slope facies.

Outside the northern hill zones, some of these slope unit of moderate steepness have been, however, brought under cultivation by adopting the techniques of land levelling. These tracts now thrive upon tank irrigation in some favoured low dissected and marginally rugged uplands of Khallikote, Kodola, Polosara and Ganjam blocks of the Chhatrapur Subdivision.

10.4.4. Area of Moderate Slope (1°31' - 3°):

Covering 4.59% of the total area, the category of moderate slope is distributed quite widely into irregular patches almost all over the study area. This unit includes undulating rugged plateaus, rugged inherited upland surfaces, channel side terraces, inter-fluvial ridges, low angled minor local watersheds, dissected residual low hills and their colluvial rolling and convex slopes. The conspicuous
topographical sharpness is moderate in keeping with the variation in the structural response of the hard Kondalites and granitic gneiss to differential weathering.

These moderately sloping uplands of the northern and northeastern hill regions of Polosara, Kodola and Khallikote blocks have low convexity crest slopes with low concavity down-slope. A considerable gravity of ruggedness, frequency of ephemeral streamlets and the incised lateritic capping of the gully heads over very hard Khondalitic basement are indicative of poor ground water reserve. These negative phenomena set severe terranean limitations upon the site and situation with regard to human settlement and agricultural land utilisation. However, many areas of such slope zones have been brought under cultivation through great human efforts.

The moderately deep red ferruginous and detrital soils along the upland valley side terraces, comprising parts of Kavisuryanagar, Kodola, Ganjam, Khallikote and Chatrapur blocks, seem to be held by potential soil moisture in near-surface saturated conditions. The soils along the upslopes of these valley terraces are, however, mostly dry owing to the rapidity of runoff. Despite moderate ruggedness, these upland tracts have been made suitable for both dry and wet
crops with the help of water-logging the agricultural plots of the valley side terraces by means of gradient regulated irrigation channels of the upland reservoirs.

10.4.5. Areas of Moderately Gentle Slope (0°1' - 1°30'):

Covering 11.38% of the total area, the areas of moderately gentle slope in the Chhatrapur Subdivision hold the formal slope and altitudinal expressions of low undulating, moderately low rugged and rolling uplands presenting the significant breaks in the gradient especially in their downslope rectilinear basal concavity expressing the subdued nature of an old plateau or hill. Such areas generally coincide with moderate and low relative relief, moderately low dissection, moderate drainage texture and density over and above the phenomenal ruggedness over the basements of variable grades of Khondalites and granite gneiss. The soil texture includes a range of sandy and clay in addition to other ferruginous red soils and lateritic surface materials. The quality of available ground water is brackish in many parts of Polosara and Khallikote blocks owing to an extensive clay pan conditions. These hard pans have frequent surface exposures in well-eroded and truncated granulitic basement situations. But the low ruggedness and availability of surface water through canal irrigation schemes of Bhaguva, Dhanei and Kharkhari rivers especially during kharif months help
the potential conduct of agricultural landuse operation in these parts of the Chhatrapur Subdivision.

There seems a positive relationship between the intensity and potentiality of agricultural landuse and the category of moderately gentle slope in the northern hilly terrain and its scattered hill units in the rest of the study area. In these hilly terrain segments, ploughing operations are difficult and, therefore, uneconomic. The agriculture in these parts is at lowest subsistence level only.

But outside the hill tracts, these slope units have relatively favourable conditions for agricultural operation. The irrigation networks in most of these moderately gentle low uplands seem to compensate the potential deficit of underground water.

10.4.6. Areas of Gentle Slope (0°31' - 1°):

The areas of gentle slope account for 19.57% of the total area. It covers almost all surface elevation zones comprising more or less all administrative blocks of the Chhatrapur Subdivision. The conspicuous slope features of this category show almost similar pattern as those of moderately low and low relative relief, dissection index and drainage texture. This gently sloping unit of the study area is characterised by gentle surface undulations constituting the incipient
gullies of the non-hilly nearly level lands and gentle rectilinear bases in the hill tracts. It has large area under the nearly level plains constituting concavo-convex upper terraces and confluence points, convexo-concave and rectilinear-concave sand dunes, mud-flats and other uniformly undulating surfaces with broad and shallow depressions. This gently sloping unit generally registers moderate erosion, low dissection, moderate and low drainage density and low ruggedness. Therefore, it is suitable for terraced cropping and potential grazing barring some of the environmental restrictions of the littoral tracts.

In the lower margins of the high scarp lands of the north and northeastern hill tracts of Polosara, Kodola and Khallikote blocks a maximum amount of debris accumulation has formed very low oscillating colluvial surfaces. But owing to the hard rock basement, the condition of ground water is poor. The soils are red ferruginous and soft lateritic. These are often stony and form a moderately shallow and readily erodible mantly of considerable sterility. Therefore, this unit, though gentle sloping, inherits the regional constraints of a hilly terrain with regard to accessibility and agricultural landuse development.

In the middle and lower reaches of the riverine tracts especially along the south flowing rivers of Rushikulya
system, this category of gentle slope expresses itself in the relatively level plains with the slopes grading towards the rivers. In the riverine tracts of Polosara, Kavisurryanagar and Khallikote blocks, the slope facets are characterised by the concavo-convex upper terraces especially in the lower-middle and lower reaches. The litho-structural identity of these gently sloping riverine tracts include varieties of comparatively less-resistant Khondalites and granite gneiss. The texture of soil varies from moderately deep to deep sandy loam, clay and sandy clay with streaks of ferruginous red loamy and sandy soils. Owing to the availability of potential surface and ground water most of these tracts are extensively utilized for kitchen gardening.

The gently sloping littoral tract of the southern Chatrapur block presents a series of broad convexo-rectilinear-concave sand-dunes and depressions of swamp and mud. The landscape is dotted occasionally with irregular rocky knolls of granulites and quartzites. These littoral segments present a vast stretch of dune and beach sand besides deep saline marine clay. The terrain segment registers a virtual absence of surface drainage owing to a high superficial permeability of sand. Because of severe beach erosion, presence of swamps and mudflats, subterranean water of marine incursion and surface salinity, this gently sloping nearly level littoral landscape of the Chhatrapur Subdivision sets severe limitations upon any form of a planned effort with regard to agricultural land utilisation.
Summing up, these gently sloping units in the non-hilly areas of the study area seem to be very much similar to flat lands in many respects including in extensive agricultural landuse operations because these nearly level slope units present no serious problems to cultivation. The minor surface irregularities can be removed in most cases by levelling. These densely settled, potentially irrigated and readily accessible slope units are, however, prone to extensive floods in some years of heavy rain fall, like one of the severe Rushikulya floods in 1990 which naturally demand controlling measures.

10.4.7. Areas of Very Gentle Slope (\(< 30^\circ\)) :

The very gently sloping and monotonously flat region of the Chhatrapur Subdivision covers the largest percentage (41.69%) of the total study area. The region coincides with low relative relief, low dissection and low to moderate and occasionally high drainage density, very low surface elevation and low ruggedness. Owing to its monotonously flat nature of the terrain, these very gentle slope units of the Chhatrapur Subdivision ensure adequate drainage and ideal condition for any type of farming and free use of any farm machinery. The other geo-ecological and agronomic conditions are also equally favourable. Almost all potential arable land segments of the Chhatrapur Subdivision fall in this category.
of slope, because this is the most productive slope unit exemplifying minimum limitations in the form of water-logging and erosion. Moreover, irrigation facilities have been developed well to compensate the fluctuating trend of rainfall and unreliable ground water level in some parts.

It is noted that the areas of the very gentle slope cover extensive fluvial and coastal alluvial tracts, planation surfaces of very low surface elevation, flood plains, flat-topped plateaus, piedmont benches, rectilinear foot slopes and valley flats. The maximum frequency of these lands lie in Hinjili, Purusottampur, Chatrapur, Ganjam and Kodola blocks. A broad belt of very gentle slope stretches along the course of the lower Rushikulya on its both sides (Fig.10.1). Other significant patches in isolation are found in the northeast central Khallikote, west central Chilka borderland, northeastern hill tracts of Polosara and western and southwestern low altitude non-hilly subdued planation surfaces of Chatrapur block.

On the basis of the intensive field study, the author has divided the areas of very gentle slope into two micro-units:

1. **The Northern Plain** and its northeastern elongation and patches in isolation, and

2. **The Southern Plain** and its southeastern elongation and patches in isolation.
The Northern Plain of Very Gentle Slope - It covers a major part of Kodola and some portions of northeastern Kavisuryanagar, northeastern Polosara, northeast central Khallikote and western borderlands of the Chilka lake. The Kodola and Kavisuryanagar units are characterised by absolute flatness of the surface except where they are cut across by streams. The stream incision seems to work deeply but the rate of infiltration is low owing to hard rock basement and conspicuous subsurface clay pan. The textural complexities of soil comprising sandy loam, clay and alluvial red soils are in situ and detrital derivatives of the granulites, leptinytes and ferruginous quartzites. This level terrain segment over the comparatively weaker Khondalitic basement in the centre as well as in the west provides favourable geo-lithological response to Bhaguva, Dhanei and Jagati rivers and many other ephemeral channels to accomplish their functions of erosion and to subsequently deposit silt, sand, clay and gravels. These well-drained parts constitute flat river terraces and rectilinear flood plains of medium and fine textured alluvial material which are potential in terms of soil and water for agricultural land utilisation.

The northeastern elongation of the northern plain (Fig.10.1) seems to be an aggradational unit of persistent detrital surfaces constituting unconsolidated colluvo-fluvial material
brought down from the nearby hills. Owing to the dissected margins and surface ruggedness, the land available for cultivation is marginally low and, therefore, put to intensive agriculture. As the underground water potential is moderately poor, the irrigation is by and large confined to tanks. The low-efficiency segment canals of Salia river irrigation system operate especially in the favoured tracts. The conspicuous agricultural landuse details, therefore, forcefully present a vast area under the cultivable waste-lands in spite of a very gentle nature of the terrain in these parts.

The lateritic soil surfaces of these very gently sloping lands of Khallikote and Polosara blocks and western borderland of the Chilka lake are of widely diffused unconsolidated transported detrital materials. These laterites correspond to the down-slope rectilinear surfaces of low dissection and low amplitude of available relief. Owing to an active process of leaching, these apparently dry unconsolidated surfaces are often devoted to dry corps and rainfed transplanted paddy or, left as simple barren lands.

The Southern Plain of Very Gentle Slope - This constitutes subdued rectilinear plateau tops, piedmost plains, fluvial and coastal plains comprising the level lands of Hinjili, Purusottampur, southeastern Kavisuryanagar, northeastern and southwestern Chatrapur, southeast and central Ganjam coastal,
inland and lacustrine plains. The region presents a strong element of linearity in the function of erosion and consequen-
tial deposition besides presenting the phenomenal weathering.
A monotonously flat nature of the southern level terrain seg-
ment of very gentle slope follows almost an identical trend as those of low dissection and relative relief zones.

This lowlying rectilinear erosion surface owes its plana-
tion to the comparatively less resistant Khondalitic and granite-gneiss basements, fluvial action, and notable chemical weathering. Here the deep soils of medium fine texture owe their bilateral origin to a highly weathered pulverisation retaining no original rock texture and to extensive deposition of eroded alluvial soils rich in organic matter. The region is characterised by favourable underground, surface and irriga-
tion water potentials. Therefore, this very gently sloping southern plain, excepting the unproductive littoral margins, is the most productive and highly potential agricultural region of the Chhatrapur Subdivision both in terms of inten-
sity and extent of agricultural land utilisation.