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Grain size characteristics of unconsolidated soil in the humid tropical region of Tripura

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ABSTRACT

Grain size characteristics form an important aspect of study in hydrological and soil sciences. Grain size refers to the single grain dimension of sediment or other grain particulate. The size of unconsolidated soil may range from boulders to gravel, as well as sand, silt and clay. Grain size analysis helps in determining the hydrodynamic state. It is also vital in determination of permeability of soil in an area. Therefore, grain size distribution is one of the textural properties of soil that affect the magnitude and direction of permeability. The present study intends to explore the characteristics of grain size and their distribution in different physiographic units of Tripura *viz.,* hills and piedmonts, intermontane synclinal troughs, terraces and tillas; and floodplains. Although the study area receives a good amount of rainfall, the study area suffers from low permeability and porosity. This paper attempts to analyse the statistical parameters of grain size distribution and the nature of grain size gradation in different physiographic units. The statistical analysis indicated poorly sorted soil with no variation in all the physiographic units. Further, it was observed that fine sand is the predominant grain observed in all the physiographic units, which is poorly graded.

1. INTRODUCTION

Grain size refers to the size of a single granular particle, such as sediment. This includes everything from boulders to gravel, as well as sand, silt and clay. Grain size scales such as the Wentworth and Krumbein phi (Φ) scales are widely used (Ubani *et al.,* 2018). Grain size characteristics are important in hydrological, geomorphological and sedimentological research (Friedman and Sanders, 1978; Goudie *et al.,* 1981; Balamurugan *et al.,* 2014) for conservation and management of natural resources (Nagaraju *et al.,* 2015; Singh and Su, 2021; Chandrakala *et al.,* 2022; Kumar *et al.,* 2023). Grain size analysis is one of the most significant and extensively used sedimentological tools for determining the hydrodynamic state (Balamurugan *et al.,* 2014). Therefore, grain size distribution is a fundamental soil property that has been studied extensively in numerous soil science researches (Hernádi *et al.,* 2009; Brzezińska *et al.,* 2011; Nosalewicz and Nosalewicz, 2011; Dobrowolski *et al.,* 2012; Bieganowski *et al.,* 2013).

Characterization of grain size distribution is an inevitable issue in environmental research (Deng *et al.,* 2018). The ease with which fluid passes through porous media is measured by permeability (Holtz *et al.,* 2011; Salarashayeri and Siosemarde, 2012; Ubani *et al.,* 2018). Permeability is a significant factor to consider when assessing the flow behaviour of groundwater sources (Ubani *et al.,* 2018). Grain size and other characteristics like porosity, density, grain shape, and sorting are vital in the determination of permeability. Permeability was found to be moderate to low in the present study area. The presence of fine sand in all the physiographic units indicates that the soil is poorly sorted, which has its influence on the porosity of the soil.

2. MATERIALS AND METHODS

Study Area

The study area is encompassed by geological strata that range in age from upper tertiary to recent, and it is situated between 22°56' and 24°32'N latitudes and 91°10' and 92°21'E longitudes. During the tertiary period, the sediments were deposited in the Surma basin under various environmental conditions that were governed by local tectonic activity. Tripura exhibits an uneven landscape that depicts the ridge and valley (structural) province of the tate tertiary fold mountain belt on the western border. The research region can be grouped physiographically into four main physical divisions: hills and piedmonts, intermontane synclinal troughs, terraces and tillas, and flood plains. Five parallel and sub-parallel hill ranges that run north-south split the state into wide parallel valleys with sporadic river and stream floodplains and are made up of undulating tillas (hillocks). Red loam and sandy loam soil make up 43.07% of the whole study area, followed by reddish-yellow brown sandy soils (33.16%), while older alluvial, newer alluvial and lateritic soil make up the remaining less than 10% of the total area. The state experiences three distinct seasons: summer, monsoon, and winter. It is well-known for its warm, humid tropical climate (Fig. 1).

Sample Collection and Analysis

The soil samples were obtained from four physiographic units- hills and piedmonts, intermontane synclinal troughs, terraces and tillas, and flood plains. A total of 40 soil samples were collected and air-dried prior to sieving. Soil samples were collected using core cutter from a depth of 12 cm in a plastic bag, labelled and then brought to the laboratory for analysis. About 100 g of each sample was passed through a series of finer sieves arranged in decreasing order. The sieving was performed with a sieve shaker, and the time per sample ranged from 15 to 20 mins. The statistical moments were computed by measuring the weight retained within each sieve to a precision of 0.01 g. Gradistat Version 8.0 software was used to process the grain-size data received after sieving. The grain-size data obtained after sieving was processed using the Folk and Ward (1957) moment method. This software was used to calculate all the statistical metrics, such as mean size, sorting (standard deviation), skewness and kurtosis. Further, soil gradation of each physiographic unit was determined through grain size distribution curve.

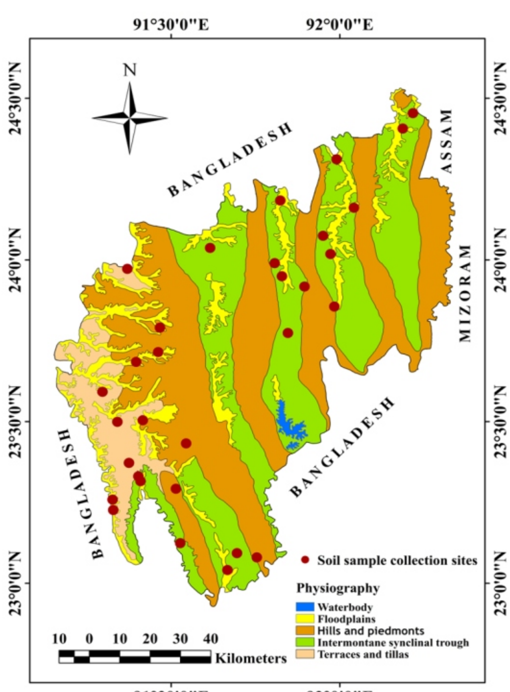


Fig. 1. Location of study area

Mechanical soil analysis method also known as sieve method was applied by allowing 50 g of air dried soil sample to pass through sieves ranging from 4.75 to 2 mm sieve size. Gravel was obtained from soil that remained in sieve size of 4.75 mm. Thereafter, soil that passed through 2 mm sieve was used to calculate the fractions of sand, silt and clay by sedimentation process using hydrometer method in the laboratory (Adebayo *et al.,* 2021). Grain type was assessed using the United States Department of Agriculture (USDA) and Unified Soil Classification System (USCS) scheme of textural classification of soil size fraction. According to USDA, the grain size fraction classification boundaries for gravel, sand, silt and clay percentage were >2, 2-0.05, 0.05-0.002 and <0.002 mm, respectively, were used. Similarly, according to USCS, the categorization boundaries for the determination of gravel, sand, silt and clay fractions were 76.2-4.75, 4.75-0.075 and <0.075 mm.

3. RESULTS AND DISCUSSION

Textural Classification of Soil

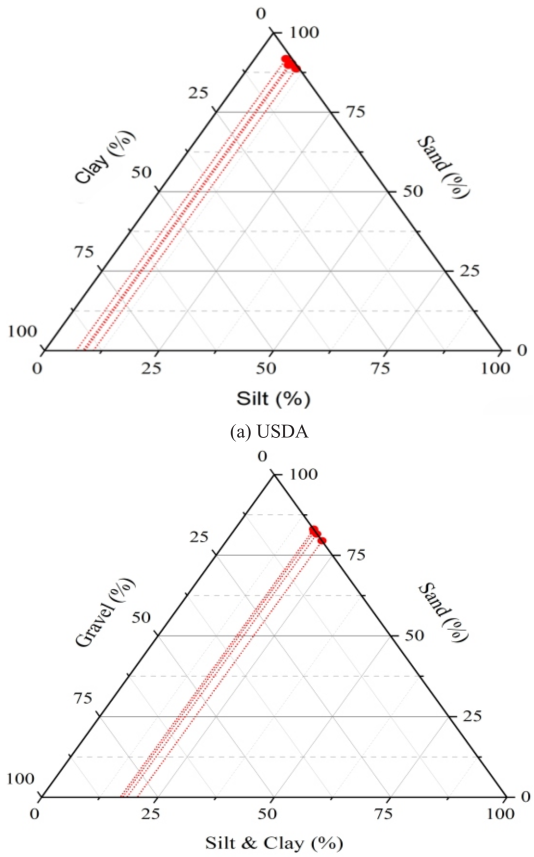
Soil texture refers to the fractional amount of sand, silt and clay fractions. Grain size refers to how grains are arranged in the rock unit, and their form and size. The size and connectivity of the pores are governed by grain size. As a result, grain size distribution is one of the textural features of soil that affects the magnitude and direction of permeability. The information obtained from grain size analysis can be helpful in understanding the hydraulic properties of the soil and the sedimentary environment and geological history. According to USDA and USCS, the dominant soil found in all the physiographic units of Tripura was sand (Table 1).

According to USDA, the classification boundaries for the determination of gravel, sand, silt, and clay fraction was >2, 2-0.05, 0.05-0.002, and <0.002 mm, respectively. As per USDA classification, the highest percentage of sand was observed in intermontane synclinal troughs and the lowest in the flood plains. Gravel was found to be highest in the hills and piedmonts and lowest in the flood plains. Flood plains were found to be occupied with the highest percentage of silt, whereas intermontane synclinal troughs have the lowest percentage of silt. Clay was not observed in any of the physiographic units. The textural triangle shows sand in all the physiographic units (Fig. 2a).

The USCS classification system uses boundaries of 76.2-4.75, 4.75-0.075 and <0.075 mm for gravel, sand, silt and clay, respectively. According to USCS classification, the highest percentage of sand was observed in the hills and piedmonts and the lowest in the flood plains. Gravel was found to be highest in intermontane synclinal troughs and lowest in the flood plains, and hills and piedmonts. Silt and clay percentage was dominant in the flood plains and lowest in the hills and piedmonts. The textural triangle shows the presence of sand in all the physiographic units (Fig. 2b).

Table: 1
Physiography-wise soil texture of the study area

Physiographic units	USDA classification of soil texture (%)				USCS classification of soil texture (%)		
	Gravel >2mm	Sand 2-0.05 mm	Silt 0.05-0.002 mm	Clay < 0.002 mm	Gravel 76.2-4.75 mm	Sand 4.75-0.075 mm	Silt & Clay < 0.075 mm
Hills and piedmonts	1.77	89.87	8.36	0	0	83.09	16.91
Intermontane synclinal troughs	1.35	91.8	6.85	0	0.24	82.32	17.44
Terraces and tillas	0.86	90.36	8.78	0	0.09	81.57	18.34
Flood plains	0.69	88.68	10.63	0	0	79.46	20.54



(a) USDA

(b) USCS

Fig. 2a-b. Ternary diagram showing fractions of gravel, sand, silt and clay

Physiography-wise Statistical Analysis of Grain Size Parameters

Fine sand is the predominant material found in all the physiographic regions (Table 2a), according to a statistical analysis of grain size performed using Gradistat version 8. The parameters used to describe the grain size distribution is given below:-

Mean

The average grain size of the soil samples that were collected from the different physiographic units ranged from 192.6-222.3 μm in all the physiographic units, indicating the dominance of fine sand (Table 2a).

Standard deviation (σ_1)

The standard deviation, often known as grain size sorting, measures the spread or the scatter of grain sizes about the average or mean sizes. Sorting is a technique for determining the grain size variation and distribution of sediments in unconsolidated deposits or sedimentary rocks using a cumulative curve. This equation has numerical values ranging from zero for exceptionally well-sorted distributions to four for extremely poorly sorted distributions. The standard deviation for all the physiographic units was found to be poorly sorted (2.557-2.672 μm) *i.e.,* the sediments usually have lower pore spaces because of the fine grain fragments that tend to fill in the open spaces (Table 2b).

Skewness

Skewness is a metric for determining the normalcy or symmetry of a real value in relation to the mean. The

Table: 2
Physiography-wise grain size parameters

(a) Mean	Folk and ward method		
	Geometric (μm)	Logarithmic (Φ)	Description
Hills and piedmonts	219.3	2.189	Fine sand
Intermontane synclinal troughs	222.3	2.170	Fine sand
Terraces and tillas	196.3	2.349	Fine sand
Flood plains	192.6	2.376	Fine sand
(b) Sorting (σ)			
Hills and piedmonts	2.660	1.412	Poorly sorted
Intermontane synclinal troughs	2.564	1.358	Poorly sorted
Terraces and tillas	2.557	1.354	Poorly sorted
Flood plains	2.672	1.418	Poorly sorted
(c) Skewness (*Sk*)			
Hills and piedmonts	0.000	0.000	Symmetrical
Intermontane synclinal troughs	0.000	0.000	Symmetrical
Terraces and tillas	-0.054	0.054	Symmetrical
Flood plains	0.027	-0.027	Symmetrical
(d) Kurtosis (*K*)			
Hills and piedmonts	1.052	1.052	Mesokurtic
Intermontane synclinal troughs	0.891	0.891	Platykurtic
Terraces and tillas	1.274	1.274	Mesokurtic
Flood plains	1.099	1.099	Leptokurtic

numerical values of this equation can be zero, positive or negative and range from +1 to -1 when the distribution shifts from very fine to very coarse skewed. Skewness values depict symmetrical ranging from -0.054-0.027 µm in all the physiographic units (Table 2c).

Kurtosis

Graphic kurtosis (K_0) or Peakedness describes the peakedness for a given distribution around the mean. This expression's numerical value ranges from zero for extremely platykurtic distributions, in which the extremes are more sorted than the centre, to around 4.5 for very leptokurtic distributions, in which the centre is better sorted than the extremes. Hills and piedmonts, and flood plains have the same characteristics of mesokurtic (1.052 and 1.099 µm) that has the same extreme value as a normal distribution. Whereas, Kurtosis for intermontane synclinal troughs indicate platykurtic (0.891 µm), referring to the relative flatness of a probability distribution (Table 2d). Terraces and tillas depict leptokurtic (1.274 µm).

The dimension of permeability and the cross-sectional area of the pore throat have a direct relationship. As particle size grows, so does the pore throat size, resulting in an increase in permeability. Sorting has a lesser impact on permeability than grain size, but an increase in sorting, *i.e.,* better or well sorted grains, improves permeability. Table 2 shows the physiography-wise grain size parameters. The statistical analysis indicates poorly sorted soil with no variation in all the physiographic units. Skewness and Kurtosis show the dispersion of grain size. Since the Skewness value is zero, it indicates symmetrical, *i.e.,* uniform distribution. Kurtosis shows the dominance of Mesokurtic type of dispersion in the hills and piedmonts, and flood plains, whereas it is platykurtic and leptokurtic dispersion in the intermontane synclinal troughs, terraces and tillas.

Physiography-wise Grain Size Distribution

The grain size of the soil varies because of the nature, texture and the condition of the soil. In the present study, sieve analysis was performed for four physiographic units: hills and piedmonts, intermontane synclinal troughs, terraces and tillas, and flood plains to check the particle finer passing in each sieve, given in different value (mm) in percentage. Particle sizes were determined for the four physiographic units based on soil samples collected from different areas (Table 3 to 6).

Hills and piedmonts

The soil samples of 10 areas, namely Uttar Longtrai, Kathalbari, Belbari, Senapara, Uttar Baramura, Raiobari, Gorjee, Purba Sabroom, Mungiakami and Balidhum were collected for the grain size analysis.

The particle size distribution in each sieve passes more than 90% up to the sieve opening 1 mm, which means the particle size is not much finer in between the sieve opening 4.75 to 1 mm, as the passing grain amount is more. As the particles passing through the sieve of 0.125 to 0.031 mm became low from 27.29 to 3.1%, the size of the soil became finer. The highest percentage of soil was retained in the sieve opening 0.125 mm with 42.56% while none was retained in the sieve opening 4.75 mm.

Intermontane synclinal trough

A total of 13 soil samples from various places of valley area like Kamalpur, Dolucherra, Kathalcherra, Rajkandi, Dharmanagar, Madhya Padmabil, Kalyanpur, Hrishyamukh, Ganganagar, Satnala, Joymani Para, Kadamtala, and Kumarghat were collected.

The average percentage of finer passing shows that the maximum sieve opening ranges from 4.75 mm to a minimum sieve opening of 0. 015 mm. It was found that more than 90% of the soil passes through the sieve size 4.75 to 1 mm, and it declines from the sieve opening of 0.71 to 0.015 mm. The mass of soil retained was highest in the sieve opening 0.125 mm with 38.96%, indicating the presence of finer particles.

Terraces and tillas

The terraces are landforms consisting of a flat or slightly inclined geomorphic surface. The soil samples were collected from seven areas, namely Mohanpur, Purba Chandigarh, Rangmala, Rangamura, Peporiokhola, Gardang and Trishna R.F.

More than 90% of the soil passes through the sieve opening between 4.75 to 0.71 mm, and the percentage of finer passing sharply decreases from 26.97 to 4.46% in the sieve opening between 0.125 to 0.031 mm.

Flood plains

Tripura's flood plains are covered with alluvial soil, and those in the west and south account for most of the State's agricultural area. Eight soil samples of flood plains were collected from Kulai, Srirampur, Sonatala, Madhya Ghaniamara, Kusamara, Harina, South Dumacherra, Pecharthal.

More than 90% of the soil passes through the sieve opening of 4.75 to 0.71 mm, sharply decreasing from 75.69

Table: 3
Grain size analysis of soil in hills and piedmonts

Sieve size (mm)	Percentage of soil retained in each sieve	Percentage of finer passing
4.75	0	100
2	1.77	98.23
1.41	2.38	95.85
1	1.14	94.71
0.71	4.62	90.09
0.35	20.24	69.85
0.125	42.56	27.29
0.088	10.38	16.91
0.0625	8.55	8.36
0.031	5.26	3.1
0.015	3.1	0

Table: 4
Grain size analysis of soil in intermontane synclinal troughs

Sieve size (mm)	Percentage of soil retained in each sieve	Percentage of finer passing
4.75	0.24	99.76
2	1.35	98.41
1.41	1.58	96.83
1	1.39	95.44
0.71	5.63	89.81
0.35	22.37	67.44
0.125	38.96	28.48
0.088	11.04	17.44
0.0625	10.83	6.61
0.031	4.38	2.23
0.015	2.23	0

to 3.8% in sieve size of 0.35 to 0.031 mm. The highest percentage of soil was retained in the sieve opening of 0.125 mm at 41.92%, and no soil was retained in the sieve opening of 4.75 mm.

Physiography-wise Soil Gradation

Grain size is an important aspect of soil mechanics and indicator of hydraulic conductivity. The grain size distribution curve depicts not only the range of particle sizes found in a soil, but also the type of particle size distribution. The particle size significantly impact on the distribution and transportation of soil water (Zhao *et al.,* 2011). From the result of sieve analysis, physiography-wise gradation of soil was determined based on the calculation of parameters, such as coefficient of uniformity and coefficient of curvature. Poorly graded soils were observed in all the physiographic units (Table 7).

Effective size (D_{10})

D_{10} is the diameter in the grain size distribution curve corresponding to 10% finer or passing particle. The hydraulic conductivity and drainage through soil can be estimated using the effective size of granular soil. The effective grain size in all the physiographic units reveals more or less the same value. The D_{10} value ranges from 0.060 to 0.070 mm.

Uniformity coefficient (C_u) and Coefficient of curvature (C_u)

Uniformity coefficient is defined as the ratio of D_{60} to D_{10} where D_{60} is the diameter that corresponds to 60% finer, and D_{10} represents 10% finer. The values of the uniformity coefficient range from 4.14 to 4.45 mm. The ratio of the square of D_{30} to the product of D_{10} and D_{60} values of coefficient of curvature is known as the coefficient of curvature. The values of the coefficient of curvature range from 0.75 to 1.11 mm.

It is evident from Fig. 3 that a decrease in the gradation curve is observed from grain size of 1mm onwards in all the physiographic units. The maximum composition of soil as determined from the curve is sand. The coefficient of uniformity and coefficient of curvature as derived from gradation curve was <6 and in the range of 1-3 in the hills and piedmonts, terraces and Tillas. Also, the coefficient of uniformity for the intermontane synclinal troughs and flood Plains do not meet the criteria of <6. Therefore, poorly graded soil may be deciphered from the gradation curve.

Table: 5
Grain size analysis of soil in terraces and tillas

Sieve size (mm)	Percentage of soil retained in each sieve	Percentage of finer passing
4.75	0.09	99.91
2	0.86	99.05
1.41	3.22	95.83
1	0.64	95.19
0.71	0.95	94.24
0.35	17.12	77.12
0.125	50.15	26.97
0.088	8.63	18.34
0.0625	9.65	8.69
0.031	4.23	4.46
0.015	4.46	0

Table: 6
Grain size analysis of soil in flood plains

Sieve size (mm)	Percentage of soil retained in each sieve	Percentage of finer passing
4.75	0	100
2	0.69	99.31
1.41	2.61	96.67
1	1.61	95.09
0.71	3.62	91.47
0.35	15.78	75.69
0.125	41.92	33.77
0.088	13.23	20.54
0.0625	9.91	10.63
0.031	6.83	3.8
0.015	3.8	0

4. CONCLUSIONS

Grain-size characteristics are important in hydrological and environmental research because they reveal important information about the nature of the soil, including its texture, size, etc. Sand is found in all of the study area's physiographic units, including hills and piedmonts, intermontane synclinal troughs, terraces and tillas and flood plains, according to a textural examination of the soil samples. Additionally, a grain-size examination reveals that fine sand predominates throughout all physiographic units. The soil was discovered to be poorly sorted in all of the physiographic units, which suggests low porosity and, thus, limited permeability of soil.

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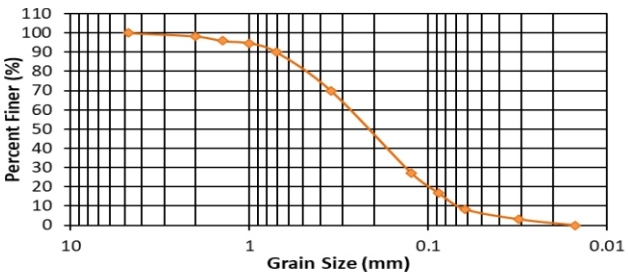
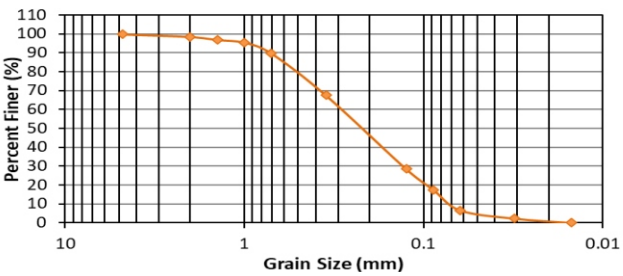
Table: 7
Physiography-wise soil gradation

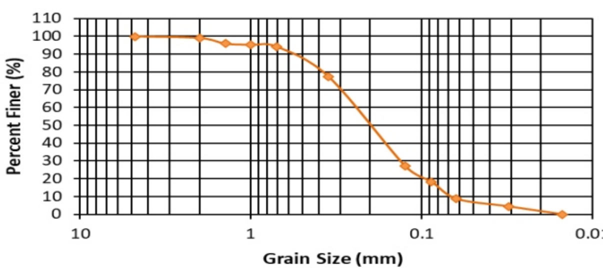
Physiographic units	D_{10}	D_{30}	D_{50}	D_{60}	Uniformity coefficient (C_u)	Coefficient of curvature (C_c)	Soil gradation
Hills and piedmonts	0.067	0.14	0.245	0.298	4.45	1	Poorly graded
Intermontane synclinal troughs	0.070	0.13	0.249	0.307	4.39	0.81	Poorly graded
Terraces and tillas	0.066	0.14	0.228	0.273	4.14	1.11	Poorly graded
Flood plains	0.060	0.11	0.212	0.266	4.43	0.75	Poorly graded



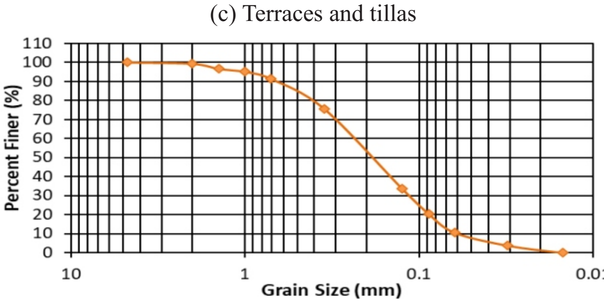
(a) Hills and piedmont



(b) Intermontane synclinal troughs



(c) Terraces and tillas



(d) Flood plains

Fig. 3a-d. Physiography-wise soil gradation

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