DOI: 10.21088/ijps.2348.9677.12125.4

Indian Journal of Plant and Soil
Volume 12 Number 1 January - June 2025

ORIGINAL ARTICLE

Soil Colour as Proxy to assess Drainage in Rice growing Alluvial Soils of Godavari Basin, Andhra Pradesh

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HOW TO CITE THIS ARTICLE:

B.P.Bhaskar. Soil colour as Proxy to assess Drainage in Rice growing Alluvial Soils of Godavari basin, Andhra Pradesh. Ind J Plant Soil. 2025;12(1): 37-47.

ABSTRACT

Alluvial soils in the Godavari basin's rice fields can be assessed for drainage using Munsell color. Munsell color gradations are converted to the CIELab system. Then, Mahalanobis distance is computed to create a drainage index. Soil samples from three landforms were analyzed: fluvial, fluvio-marine, and marine. The soil resource inventory was on 1:250000 scale. Fluvial plains had dark gray to very dark grayish-brown soil. The texture ranged from silty clay to clay. Fluvio-marine soils had intermittent sandy layers. Marine landforms showed varied colors in the C horizons' sandy layers. Fluvial plains' genetic horizons contained cambic (30.54±14.31cm) and slicken sided (104.5±15.57cm) features. Clay textured, very dark grayish brownish soils were most common (30%). Dark grayish-brown (12.8%) and silty clay dark brown (12.8%) soils followed Vertisols, except Fluventic Eutrudepts, had a mean L value of 32.2 ± 5.12 (CV of 15.91%). The mean "a" value was 3.26 ± 1.11. Variability was moderate (CV of 33.88%). An a*1 value less than 0.3 indicated low iron and poorly drained profiles. Fluvial soils had a mean drainage index (Di) of 2.96±0.35. Variability was low (CV of 11.73%), and drainage was imperfect. A strong positive relationship existed between the drainage index (DI) and CIE "L" values in fluvial soils (R^2=0.29). Fluviomarine soils had a mean Di of 2.98±0.39 at 40 to 100 cm. The CV was 18.48%. These imperfectly drained soils had high "b" values. Di correlated with "a" and "b" values: Di = 4.02 - 1.09(a)+0.23(b) with an R^2 of 0.98.The study shows that CIE-Lab values can define drainage class in alluvial soil profiles in the Godavari basin.

KEYWORDS

• CIE Lab • Drainage Index • Correlation • Mahanalobis Distance • Munsell Colour Charts • Similarity

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➤ **Received:** 18-04-2025 ➤ **Accepted:** 17-05-2025

INTRODUCTION

Soil colour is the first and foremost important soil morphological traits that can be easily recognized to differentiate genetic horizons as well as soil types during soil resource inventory programmes.[1] The soil colour can be used as an indicator of organic carbon content;[2,3] mineral composition,[4] Soil moisture regime and water content.[5,6] The soil color patterns can be related to a soils' capacity to drain water[7] such as and also to interpret oxidative and reductive processes caused by periodic or continuation of water saturation either due to landscape position[8] and/or the presence of a permanently or fluctuating water table near the soil surface.[9] The soil drainage classes in alluvial soils during field surveys is based on tacit knowledge of the soil surveyor as its physical measurements are too costly and time consuming. Hence soil colours and redoximorphic features are often used as indicator for making assessment of soil drainage including numeric index of Munsell notation[7] soil redness index[10] and soil hydromorphic index[8] based on the cumulative thickness of soil horizons with redoximorphic features.

The mental concept of soil drainage with empirical indices is particularly interested in understanding its spatial distribution across the landscape in relation to topography and soil wetness.[11,12] Numerous multivariate discriminant analysis using topographical and geological information were used to derive spatial inference models of soil drainage class[13,14] and landscape positions.[15] Like wise mapping of soil hydromorphic index using topographic indices were made[16] and less invasive techniques through use of remote sensing platforms have also been demonstrated.[17,18] Hence this study in Godavari basin, we hypothesized to explore relation between soil colour and Di (drainage index) with respect to landscape positions. The objective of this study is to convert the Munsell HVC to CIE Lab system and then compute Mahalanobis distance for making inference of soil drainage by working out similarity index from reference color in the basin.

MATERIALS AND METHODS

Details of study area

East Godavari (Toposheet No-65) is situated between 17° 49 '59.99 "North latitude and 81° 49' 59.99" East longitude. The study encompassed eight villages: Sundarivari Markapalem, Appaniramuni, Visheweshwaraiah Puram, Keshavasadasu Palem, Pujaripalem, Appaniramuni Lanka, Anthareddi Palem, and Morri (Figure 1). The region is characterized by gently sloping alluvial plains, flatlands, and marine sedimentary areas, exhibiting minimal erosion and moderately well-drained soils. Marine plains experience rapid runoff, while flat or flat fluvial landforms exhibit very slow runoff. The flat fluvial areas are suitable for double cropping. The dominant natural vegetation includes the toddy palmyra tree (Borassus flabellifer), jillaedu (Calotropis gigantea and C. procera), nagajammudu (Opuntia ficus-indica), khadiramu (Acacia catechu), seemajalli (Prosopis juliflora), seethaphal (Annona squamosa), vaeepa (Azadirachta indica), and sarugudu (Casuarina equisetifolia). These research sites are located in proximity to the Bay of Bengal and are occasionally susceptible to moderate to severe flooding.

Figure 1: Location map of the East Godavari basin

EVALUATION SOIL COLOR FOR DERIVING SOIL DRAINAGE CLASS IN A PART OF EAST GODAVARI BASIN

In the Godavari basin, three sample strips were randomly chosen from each land unit, covering an area of approximately 7500 hectares. These stripes represent three different landform types: fluvial plains, fluvio-marine plains, and marine plains. The soil morphology was examined through twenty-two profiles as part of a soil resource inventory conducted at a 1:250,000 scale. This included ten profiles from fluvial landforms, four from fluvio-marine landforms, and eight from marine landforms. Additionally, this study aimed to convert Munsell color notation into the CIE Lab system and calculated the drainage index following the procedures outlined in Figure 2.

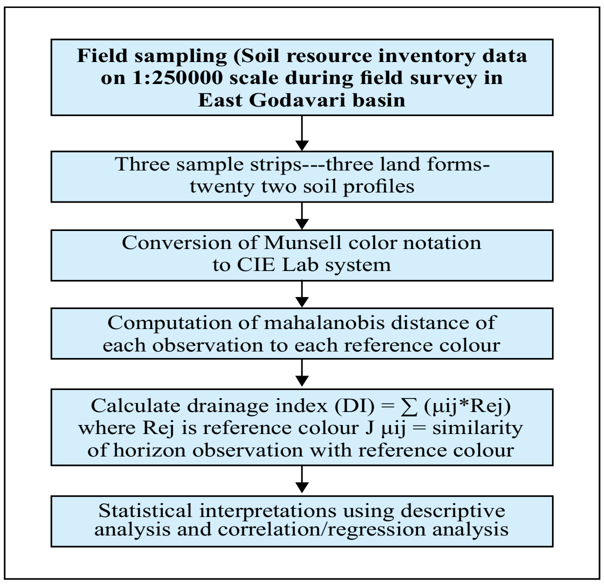

Figure 2: Flow chart of Methodology used to calculate Drainage index using soil color in alluvial soils of East Godavari basin

Conversion of Musell system to CIEL*a*b* system

Researchers utilize empirical coefficients derived from their own hypotheses.[19,20] The CIE-L*a*b* color space was established by the International Commission on Illumination in 1976. This system is based on Cartesian coordinates.[21,22,23] Since Munsell HVC soil color descriptions are not appropriate for quantitative analysis, they are transformed into the CIE-Lab color space.[24] In this model, L denotes the lightness of the color (with L=0 indicating black and L=100 indicating diffuse white), indicates the spectrum between red/magenta and green (where negative values signify green and positive values signify magenta), and b represents the range between yellow and blue (with negative values indicating blue and positive values indicating yellow). These parameters were employed to compute the Mahalanobis distance for each observation relative to each reference color.

$$di = \sqrt{(xi-cj)^{T} S^{-1} (xi-cj)}$$

The Mahalanobis distance, represented as "d," quantifies the similarity between a multivariate vector "x" (which includes observed L, a*, and b* values) and a reference color vector "c" (also composed of L, a*, and b* values). The similarity of each horizon observation to every reference color was calculated using the formula below:

$$\mu ij = \frac{1}{1+\sum_{l=1,l\neq j}^{c}\left(\frac{dil}{dij}\right)^{\frac{1}{m-1}}}$$

In this equation, "μij" denotes the similarity of horizon observation "i" to reference color "j," while "dil" indicates the Mahalanobis distance from observation "i" to other reference colors. Observations that are nearer to a reference color, as indicated by the Mahalanobis distance, exhibit greater similarity than those that are more distant. The drainage index, which ranges from 1 to 5, quantifies the level of soil drainage. Red soils possess the highest drainage index of 5, followed by brown soils at 4, yellow soils at 3, gray soils at 2, and black soils at 1. For each horizon, the drainage index was determined as a weighted average based on the similarity to each reference color.

Reference colour	Munsell colour			CIE Lab system		
	Hue	Value	Chroma	L	a	b
Gray 1	10YR	4	2	41.03	6.91	9.15
Gray-2	7.5YR	4	2	41.16	8.31	8.33
Gray-3	10YR	6	2	61.67	4.84	9.73
Black-1	10YR	2	2	19.07	15.73	8.13
Black-2	7.5YR	3	2	30.70	10.91	7.82
Black-2	10YR	3	2	30.56	9.69	8.52

Note: reference soil colours to above Munsell notations be considered for alluvial soils of Godavari basin[25]

The drainage index was calculated using the formula Di = Σ (μij * RCj), where DII represents the drainage index and RCj denotes the reference color J being analyzed. Mottles present in the profiles were not documented and, therefore, were excluded from this study. The drainage index for each horizon within the profile was computed, and a weighted average was applied to ascertain the overall drainage for the complete profile.

STATISTICAL ANALYSIS

Descriptive statistics were employed to analyze the soil color, allowing for an understanding of their variability across profiles. The differences in mean were evaluated using an F test, followed by a post-hoc Fisher test at a significance level of $p < 0.05$. To explore the relationships between various soil properties, correlation coefficients were determined using the Pearson method. All calculations were performed using the SPSS software package.

RESULTS AND DISCUSSION

Soil morphology

The soils of the Godavari basin primarily display a dominant hue 10YR, categorized into subgroups of Vertisols, Inceptisols, and Entisols. These soils are characterized by an endo-saturated condition, featuring a dark gray to very dark grayish-brown matrix with textures ranging from silty clay to clay, typically found in fluvial landforms. Additionally, fluviomarine soils contain intermittent sandy layers, while the C horizons of soils in marine landforms exhibit a variety of sandy layer colors. The descriptions of the horizons are detailed as follows:

A horizon

A horizon in fluvial plains consists of 24 layers with a mean thickness of 16.45 ± 3.95 cm and moderate coefficient of variation (23.96%). Three matrix colors are observed -dark brown, very dark grayish brown, and very dark gray, with mostly silty clay texture. Six Ap horizons were studied, with a mean thickness of 15.5 ± 2.66 cm and low variability (CV of 17.19%). Fluvio-marine soils display a dark brown to very dark grayish brown matrix with four textural groups-silty clay loam, silt loam, clay loam, and silty clay. The A horizon is absent in soils of marine landforms.

Subsoil Genetic Horizons

The fluvial plains contain different types of horizons, such as cambic, slicken sided, and gleyed B horizons. The cambic B horizons have an average thickness of 30.54 ± 14.31cm with moderate variability (CV of 46.9%), while the gleyed slicken sided B horizons have an average thickness of 104.5 ± 15.57cm with the least variability (CV of 14.9%). There are a total of 28 cambic B horizons and 26 gleyed B horizons among the 148 B horizons. Six matrix colors were recorded, including very dark grayish brown, dark brown, very dark gray, dark gray, dark grayish brown, and black. The dominant color is clay textured very dark grayish brown, accounting for 30.4% of the total, followed by dark grayish brown (12.8%) and silty clay dark brown (12.8%) (Figure 3).

The Bw horizons have darker and/or stronger colors compared to the underlying layers. They also tend to have blocky subangular fine-to-medium structures, while the BC horizons have blocky angular medium-to-coarse structures. Fine-to-medium roots were found in all B and BC strata. In fluvio-marine landforms, the B horizons exhibit eight patterns and seven textural groups (Fig 3). The average thickness of the B horizon is 105cm with a standard deviation of 37.24 and a moderate coefficient of variation (CV) of 35.36 percent. Dark brown is the dominant, occurring 10 out of 25 times, and clay texture. The diagnostic cambic horizons were identified in all specified subsurface B layers based on thickness, texture, color, structure development, and biological activity, according to Soil Survey Staff.[26] These soil profiles were found in fluvio-marine plains, where groundwater significantly affects soil attributes. However, Gleyic qualities have also been identified according to WRB. The complementary oximorphic rusty-brown colors (10YR 4-5/3-4) were concentrated around coarse-textured lenses, root channels, and fine-textured interbeddings. Sands, loams, and silty clay loams all exhibited gleyic characteristics, regardless of their texture class. However, the presence of stagnic qualities was much more common in the soils under study, especially in fine-textured soils. Interestingly, these stagnic characteristics were not limited to a specific area within the soil profile but were found at various depths. In fine-textured soils, the stagnic qualities often started just below the A horizon, even as deep as 15-18 cm, and extended into the underlying Bw layers. On the other hand, the expression of stagnic qualities in the Bw layers was relatively weak, with "clear" or "strong" expression typically occurring around 40-50 cm below the soil surface. In these fine-textured soils, the stagnic qualities could be observed down to a depth of 150 cm (the bottom limit of the soil profile) or until they reached the underlying sand. It is worth noting that even in sandy layers, certain profiles exhibited distinct and pronounced stagnic features. These findings align with similar observations made in agricultural soils of Japan.[27]

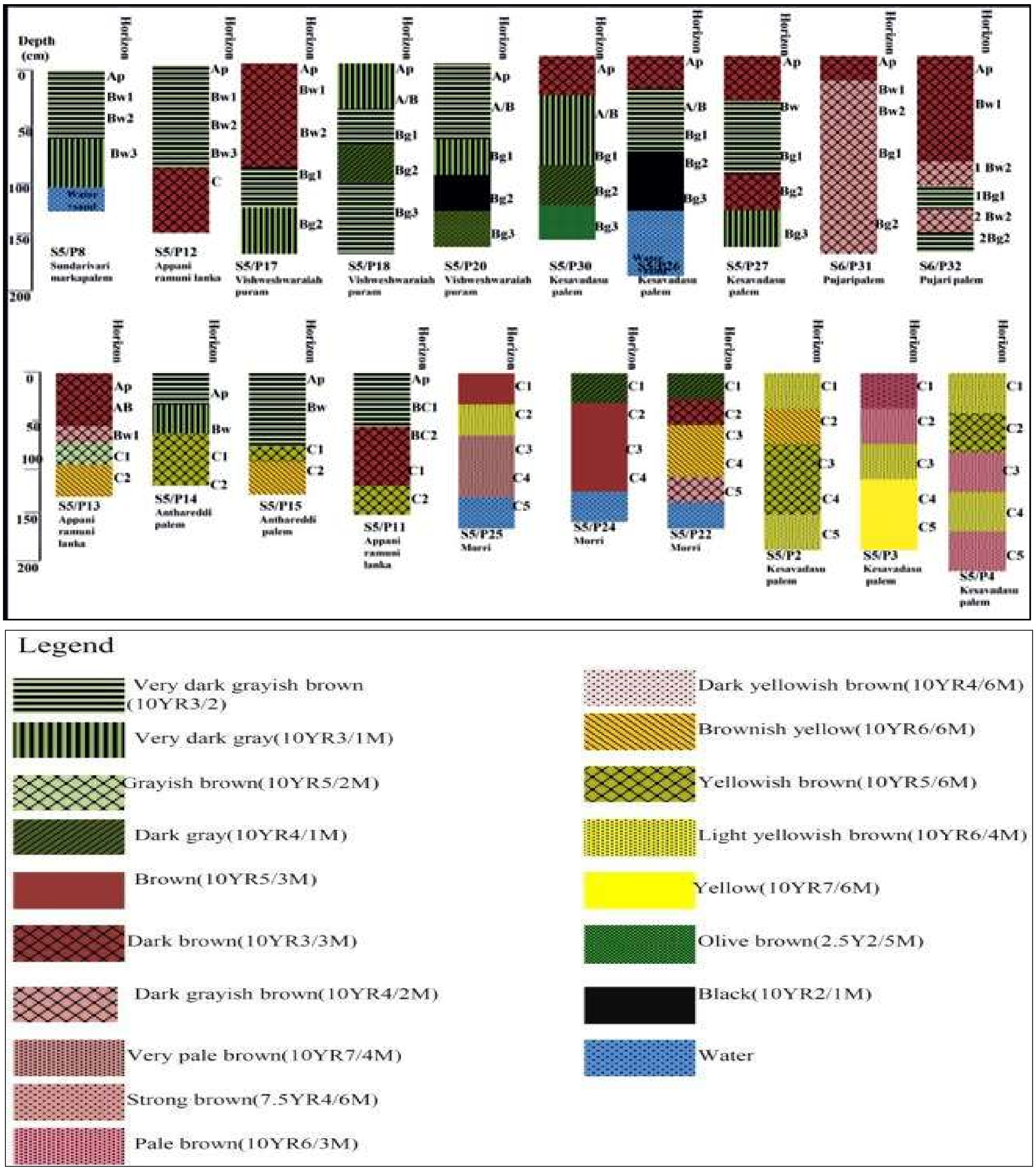

Figure 3: Depth function of soil matrix colour in Godavari basin

Coastal marine sediments are formed from fluvio-marine deposits exposed to a peraquic moisture regime where gleization is the main pedogenic process.[28] The marine landscapes have 51 C horizons with variegated colors, with brown being the dominant color at 21.57 percent. Other colors include yellowish brown, brownish yellow, dark brown, pale brown, and very pale brown. The C horizon is more than 150cm deep with a sandy texture. Soil color varies with depth and size, likely due to differences in organic matter and iron oxides. Wet soil profiles have darker colors in subsurface horizons compared to dry ones.[29] These soils have fibric or sapric organic components and are found on flat terrain. Both marine and marine-alluvial sediments are the parent materials of the Godavri basin, influenced by lithogenic processes that alter nutrient distributions. These soils are primarily loose quartz sands and are classified under the subgroups of Entisols.[30]

CIE L*a*b* system

The very dark grayish brown soils have L value of 30.8, a* of 3.5 and b* of 12.2 for 10 YR 3/2 but reduced to 1.9 for a* and 6 for b* for very dark gray horizons (10 YR 3/1). The dark brown horizons have 30.8 value for L, 5.1 for a* and 17.9 for b*. The CIE Lab values show gradational increase of L values (41.2 to 61.7) and drastic rise in brownish yellow layers (b* to 38.4). Similar trend observed in yellowish brown C horizons of S5/P14 with value of 51.6 for L, 8.8 for a* and 38.9 for b*. The erratic patterns of CIE-Lab values in C horizons of marine soils relatively high b* values and low a* values as compared to fluvio-marine and fluvial soils (Table 1). The Fluvial soils have a dominant hue 10YR CV of 37.21% hue with value of 3 to 6 and chroma of 1 to 3 in subsoils. As these soils are mostly subgroups of Vertisols except Fluventic Eutrudepts (S6/P5 and P4). The mean L value is 32.2 ± 5.12 and CV of 15.91 percent. The mean "a"value is 3.26 ± 1.11 and moderate variability (CV of 33.88%) with a*1 value less than 0.3. The high variability of b value (CV 0.35%) is recorded with a mean of 11.65 ± 4.33. The indices a*1 and b*1 point to another dynamic of soil reaction indicating redness (a*) and yellowness (b*). The relatively low values of a * <5 and yellowness (b*) <20 and a*1 <0.35 in these soils indicate poorly formed and low in iron compounds in the profiles. These findings are in conformity with the findings of Vodyanitskii and Kirillova.[24] In case of stratic fluvio-marine soils, the mean for L is 39.12 ± 6.74 with CV of 17.24. The low variability is recorded for a*1 (12.4%) and for b*1 (10.8%).

Table 1: Statistical summary of CIE-Lab values with reference to fluvial landforms of Godavari basin

Statistics	Fluvial soils					Fluvio-marine soils					Marine soils				
	L	a*	b*	a*1	b*1	L	a*	b*	a*1	b*1	L	a*	b*	a*1	b*1
Mean	32.2	3.26	11.65	0.29	3.24	39.12	4.68	17.7	0.27	3.78	53.36	5.21	24.26	0.22	4.71
Sd (±)	5.12	1.11	4.33	0.07	3.98	6.74	2.21	7.76	0.03	0.41	10.69	2.17	10.57	0.04	1.29
CV(%)	15.91	33.88	37.21	23.29	122.97	17.24	47.2	43.8	12.4	10.8	20.04	41.56	43.55	16.4	27.29
Skewness	0.71	-0.36	3.11	0.22	-10.28	-0.59	7.07	1.03	5.33	1.16	-0.33	0.44	0.39	-0.65	5.01
Kurtosis	1.97	1.61	23.83	6.65	113.08	0.21	2.08	0.78	1.79	-0.77	-0.2	-0.26	-0.48	4.15	28.05
(KS test)	0.42	0.29	0.28	0.29	0.39	0.29	0.25	0.24	0.31	0.25	0.21	0.18	0.18	0.21	0.27
ρvalue	< .00	< .00	< .00	< .00	< .00	0	0 .01	0.02	0	0.01	0.01	0.04	0.05	0.02	0

Drainage index

The Di index for fluvial soils has a mean of 2.96 and a standard deviation of 0.35, with a low variability (CV of 11.73%). These values suggest that the drainage as imperfectly drained. However, when considering drainage at 40 to 100 cm, the index values indicate poor drainage, supporting the classification of soil moisture as endo aquic conditions (Table 2). A correlation analysis between the Drainage Index (Di) and CIE "L" values reveals a strong and statistically significant positive relationship. The R-squared value is 0.29, indicating the strength of the relationship. The regression equation for this relationship is Di = 1.6492 + 0.03967 (L). Additionally, the F-test yielded a value of 9.43 at 1,23 degrees of freedom, with a corresponding p-value of 0.0054. The CIE Lab and Di weighted means were computed for fluviomarine soils. Di has a mean of 2.98±0.39 with a CV of 13.24%, and at 40 to 100cm, it is 1.66±0.31 with a CV of 18.48%.

These soils are described as imperfectly drained with high "b" values. Notably, Di is correlated with both "a" and "b" values, expressed in the regression equation Di = 4.02 - 1.09(a) + 0.23(b) with an R^2 of 0.977. The F value is 127.308, significant at a p-value of 0.001. Table 2 displays the weighted mean values of CIE Lab and Di for marine soils at the study site. The L value averages at 49.62±11.39, while the "b" value is 21.89±8.50. These values are notably higher compared to fluvial and fluviomarine soils. However, the Di index suggests poor to imperfect drainage, with values ranging from 0.60 to 2.09 at a depth of 0.4 to 1m. The mean Di index is 2.09±0.73, and the Di index at 0.4 to 1m is 1.12±0.61. The coefficient of variation (CV) is high for the "b" value (38.82%) and Di at 0.4 to 1m depth (54.54%). Additionally, there is a significant correlation between the Di index and the a/b values at 1% level of significance, with an R^2 value of 0.84**. The regression equation representing this relationship is Di = 3.14 + 0.59(a) - 0.18(b). The F-value is 24.44 with 2,9 degrees of freedom, and the p-value is 0.00023.

Table 2: Weighted mean for CIELab system and drainage index

Profile	Weighted mean					Di	Drainage class	Di (at 40 to 120cm)
	L	a	b	a*1	b*1			
Fluvial soils								
S5/P12	33.8	3.07	10.94	0.29	3.42	3.12	Imperfectly drained	1.95
S5/P13	50.91	4.92	22.36	0.23	4.45	2.06	Poorly drained	0.98
S5/P14	46.49	7.24	31.33	0.25	4.14	1.3	Very poorly drained	0.46
S5/P15	51.11	6.12	27.64	0.23	4.38	2.25	Poorly drained	1.12
S5/P17	30.8	2.94	10.01	0.3	3.35	3.12	Imperfectly drained	1.85
S5/P18	33.29	2.93	10.33	0.28	3.55	2.96	Imperfectly drained	1.35
S5/P19	30.8	2.32	7.63	0.31	3.24	3.08	Imperfectly drained	1.42
S5/P16	38.39	2.47	9.38	0.26	3.83	2.66	Imperfectly drained	1.06
S5/P20	34.19	1.46	17.74	0.23	-8.76	2.99	Imperfectly drained	1.32
S5/P11	40.7	5.04	19.92	0.26	3.91	3.04	Imperfectly drained	1.48
S5/P30	29.98	3.28	12.67	0.27	3.72	2.14	Poorly drained	0.96
S5/P29	30.8	1.89	8.61	0.25	4.99	2.5	Imperfectly drained	1.47
S5/P26	24.86	2.21	8.47	0.25	4.52	2.34	Poorly drained	1.23
S5/P27	30.8	2.87	11.56	0.22	5.65	2.65	Imperfectly drained	1.55
S5/P28	27.77	1.98	7.35	0.26	4.2	2.95	Imperfectly drained	1.94
S5/P25	64.9	4.6	24.57	0.19	5.35	1.27	Very poorly drained	0.39
S5/P24	50.37	4.08	17.53	0.23	4.27	2.71	Imperfectly drained	1.58
S5/P23	48.41	4.51	18.83	0.24	4.19	2.79	Imperfectly drained	1.79
S5/P22	51.22	5.19	26.28	0.19	6.51	1.55	Poorly drained	0.58
S5/P21	50.11	4.01	17.23	0.24	4.26	2.69	Imperfectly drained	1.64
NR/S1	45.29	8.21	30.72	0.26	3.94	2.09	Poorly drained	1.09
S5/P2	57.62	6.76	32.09	0.21	4.77	1.54	Very poorly drained	0.6
S5/P3	65.99	5.6	30.14	0.19	5.28	0.99	Very poorly drained	0.51
S5/P4	27.49	2.26	7.07	0.33	3.08	2.86	Imperfectly drained	1.65
S5/P5	30.8	2.32	7.62	0.31	3.24	3.07	Imperfectly drained	2.09
S5/P10	35.7	3.99	13.85	0.29	3.56	3	Imperfectly drained	1.87
S5/P7	35.61	3.57	12.6	0.29	3.65	3.04	Imperfectly drained	1.74
S5/P9	35.24	3.69	12.54	0.3	3.52	2.98	Imperfectly drained	1.49
S6/P27	30.8	4.19	11.86	0.36	2.99	2.59	Imperfectly drained	1.59
S6/P28	39.74	3.52	13.01	0.28	3.86	2.97	Imperfectly drained	1.65
S6/P29	34.07	3.66	12.42	0.3	3.51	2.99	Imperfectly drained	1.73
S6/P30	32.88	3.5	12.06	0.31	3.64	3.41	Imperfectly drained	2.26
S6/P31	30.8	3.5	12.2	0.29	3.49	3.23	Imperfectly drained	1.87
S6/P32	30.8	3.5	12.2	0.29	3.49	3.23	Imperfectly drained	1.99
S6/P20	36.6	3.57	13.29	0.28	3.94	3.4	Imperfectly drained	1.72
S6/P21	30.8	3.3	11.42	0.29	3.44	3.24	Imperfectly drained	1.73
S6/P22	34.39	3.4	12.58	0.27	3.72	3.23	Imperfectly drained	1.72
S6/P23	28.15	2.99	10.73	0.24	3.11	2.8	Imperfectly drained	1.56

Table cont...

Profile	Weighted mean					Di	Drainage class	Di (at 40 to 120cm)
	L	a	b	a*1	b*1			
Fluvial soils								
S6/P24	48.45	5.41	21.6	0.29	4.55	3.64	Moderately well drained	1.67
S6/P25	34.39	3.4	12.58	0.27	3.72	3.23	Imperfectly drained	1.78
S6/P26	28.15	2.99	10.73	0.24	3.11	2.8	Imperfectly drained	1.51
S6/P4	39.47	4.1	15.78	0.26	3.85	3.11	Imperfectly drained	1.87
S6/P5	38.35	4.28	16.47	0.26	3.83	3.18	Imperfectly drained	1.56
S6/P6	38.35	4.28	16.47	0.26	3.83	3.18	Imperfectly drained	1.85
S5/P18	33.29	2.93	10.33	0.28	3.55	2.96	Imperfectly drained	1.35
S5/P19	30.8	2.32	7.63	0.31	3.24	3.08	Imperfectly drained	1.42
S5/P16	38.39	2.47	9.38	0.26	3.83	2.66	Imperfectly drained	1.06
S5/P20	34.19	1.46	17.74	0.23	-8.76	2.99	Imperfectly drained	1.32
S5/P30	29.98	3.28	12.67	0.27	3.72	2.14	Poorly drained	0.96
S5/P29	30.8	1.89	8.61	0.25	4.99	2.5	Imperfectly drained	1.47
S5/P26	24.86	2.21	8.47	0.25	4.52	2.34	Poorly drained	1.23
S5/P27	30.8	2.87	11.56	0.22	5.65	2.65	Imperfectly drained	1.55
S5/P28	27.77	1.98	7.35	0.26	4.2	2.95	Imperfectly drained	1.94
S5/P10	35.7	3.99	13.85	0.29	3.56	3	Imperfectly drained	1.87
S5/P7	35.61	3.57	12.6	0.29	3.65	3.04	Imperfectly drained	1.74
S5/P9	35.24	3.69	12.54	0.3	3.52	2.98	Imperfectly drained	1.49
S6/P27	30.8	4.19	11.86	0.36	2.99	2.59	Imperfectly drained	1.59
S6/P28	39.74	3.52	13.01	0.28	3.86	2.97	Imperfectly drained	1.65
S6/P29	34.07	3.66	12.42	0.3	3.51	2.99	Imperfectly drained	1.73
S6/P30	32.88	3.5	12.06	0.31	3.64	3.41	Imperfectly drained	2.26
S6/P31	30.8	3.5	12.2	0.29	3.49	3.23	Imperfectly drained	1.87
S6/P32	30.8	3.5	12.2	0.29	3.49	3.23	Imperfectly drained	1.99
S6/P20	36.6	3.57	13.29	0.28	3.94	3.4	Imperfectly drained	1.72
S6/P21	30.8	3.3	11.42	0.29	3.44	3.24	Imperfectly drained	1.73
S6/P22	34.39	3.4	12.58	0.27	3.72	3.23	Imperfectly drained	1.72
S6/P23	28.15	2.99	10.73	0.24	3.11	2.8	Imperfectly drained	1.56
S6/P24	48.45	5.41	21.6	0.29	4.55	3.64	Moderately well drained	1.67
S6/P25	34.39	3.4	12.58	0.27	3.72	3.23	Imperfectly drained	1.78
S6/P26	28.15	2.99	10.73	0.24	3.11	2.8	Imperfectly drained	1.51
mean	33.1	3.18	11.98	0.28	3.29	2.96		1.61
sd	4.72	0.83	2.97	0.03	2.58	0.35		0.29
CV	14.27	26.02	24.78	10.82	78.47	11.73		18.06
Fluviomarine								
S5/P12	33.8	3.07	10.94	0.29	3.42	3.12	Imperfectly drained	1.95
S5/P11	40.7	5.04	19.92	0.26	3.91	3.04	Imperfectly drained	1.48
NR/S1	45.29	8.21	30.72	0.26	3.94	2.09	Poorly drained	1.09
S6/P4	39.47	4.1	15.78	0.26	3.85	3.11	Imperfectly drained	1.87
S6/P5	38.35	4.28	16.47	0.26	3.83	3.18	Imperfectly drained	1.56
S6/P6	38.35	4.28	16.47	0.26	3.83	3.18	Imperfectly drained	1.85
S5/P17	30.8	2.94	10.01	0.3	3.35	3.12	Imperfectly drained	1.85
mean	38.11	4.56	17.19	0.27	3.73	2.98		1.66
sd	4.69	1.77	6.88	0.02	0.24	0.39		0.31
CV(%)	12.32	38.78	40.04	6.42	6.48	13.24		18.48
Marine soils								
S5/P13	50.91	4.92	22.36	0.23	4.45	2.06	Poorly drained	0.98
S5/P14	46.49	7.24	31.33	0.25	4.14	1.3	Very poorly drained	0.46
S5/P15	51.11	6.12	27.64	0.23	4.38	2.25	Poorly drained	1.12
S5/P25	64.9	4.6	24.57	0.19	5.35	1.27	Very poorly drained	0.39
S5/P24	50.37	4.08	17.53	0.23	4.27	2.71	Imperfectly drained	1.58
S5/P23	48.41	4.51	18.83	0.24	4.19	2.79	Imperfectly drained	1.79
S5/P22	51.22	5.19	26.28	0.19	6.51	1.55	Poorly drained	0.58
S5/P21	50.11	4.01	17.23	0.24	4.26	2.69	Imperfectly drained	1.64

Table cont...

Profile	Weighted mean					Di	Drainage class	Di (at 40 to 120cm)
	L	a	b	a*1	b*1			
					Fluvial soils			
S5/P2	57.62	6.76	32.09	0.21	4.77	1.54	Very poorly drained	0.6
S5/P3	65.99	5.6	30.14	0.19	5.28	0.99	Very poorly drained	0.51
S5/P4	27.49	2.26	7.07	0.33	3.08	2.86	Imperfectly drained	1.65
S5/P5	30.8	2.32	7.62	0.31	3.24	3.07	Imperfectly drained	2.09
mean	49.62	4.8	21.89	0.24	4.49	2.09		1.12
sd	11.39	1.54	8.5	0.04	0.92	0.73		0.61
CV(%)	22.96	32.15	38.82	18.75	20.57	35.09		54.54
S5/P3	65.99	5.6	30.14	0.19	5.28	0.99	Very poorly drained	0.51
S5/P4	27.49	2.26	7.07	0.33	3.08	2.86	Imperfectly drained	1.65
S5/P5	30.8	2.32	7.62	0.31	3.24	3.07	Imperfectly drained	2.09
mean	49.62	4.8	21.89	0.24	4.49	2.09		1.12
sd	11.39	1.54	8.5	0.04	0.92	0.73		0.61
CV(%)	22.96	32.15	38.82	18.75	20.57	35.09		54.54

CONCLUSION

A total of twenty-two soil profiles from the Godavari basin, representing three distinct fluvial landforms, were selected to determine the drainage index by converting Munsell notation into the CIE-Lab system. The Mahalanobis distance was calculated for each horizon, and weighted averages were then computed for depths ranging from 40 to 100 cm to assess internal drainage. The findings indicate that fluvial and fluviomarine soils exhibit imperfect drainage, while marine soils range from imperfectly to very poorly drained. This research highlights the effectiveness of CIE-Lab values in characterizing the drainage properties of fluvial soils in the Godavari basin and suggests their applicability in similar rice growing ecosystems elsewhere in the region.

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