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Biophysical land evaluation for Cavendish banana (*Musa* spp.) intensification in Pulivendula Tehsil, Kadapa District, Andhra Pradesh, India

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ICAR-National Bureau of Soil Survey and Land Use Planning. Regional Centre, Hebbal, Bangalore, Karnataka 560024, India. Tel.: +91-80-23412242, Fax.: +91-80-23510350, ♥email: bhaskaraphaneendra@gmail.com

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Abstract. *Bhaskar BP, Kumar SCR, Ramanappa RV. 2024. Biophysical land evaluation for Cavendish banana (*Musa spp.*) intensification in Pulivendula Tehsil, Kadapa District, Andhra Pradesh, India. Intl J Trop Drylands 8: 1-13.* The study is being conducted in Pulivendula, a drought-stricken area in the Kadapa District, Andhra Pradesh, India, to protect the agroecosystems from unpredictable seasonal rainfall and soil degradation. The study includes agro-climatic data, geopedological information, and a delineation of drip irrigation zones for bananas. Rainfall data from the past 21 years shows that the region receives an average rainfall of 650 mm per year, with seasonal droughts from June to September. The productivity statistics for bananas in the region show a compound growth rate of 3.8% per year, but it is considered a marginal zone due to the mean annual rainfall of 672.15±111.55 mm. The soil map was generated with 43 soil mapping units from twenty-five soil series classified under the subgroups of Entisols (4.1% of total area), Inceptisols (35.5%), Alfisols (4.8%), and Vertisols (23.3%). Overall, the mildly to strongly alkaline soils are grouped into five depths and eight textural groups, having high to very high cation exchange capacity, low organic carbon, and mean clay of 39.64±14.25%. The study found that 35% of the area had a high risk of soil erosion due to poor soil quality. Twenty soil mapping units in the interhill basin are evaluated as suitable for bananas, whereas they are moderately suitable for soils in colluvio-alluvial plains. Thirty-five thousand hectares of land are suitable for banana production under drip irrigation with biophysical limitations of rooting depth, topography, coarse fragments, alkalinity, and organic matter.

Keywords: Agroecology, geoenvironment, land evaluation, Pulivendula, semi-arid ecosystem

Abbreviations: AAFRD: Alberta Agriculture, Food and Rural Development, AAR: Average annual rainfall, AAT: average annual temperature, AEA: Agro Ecosystem Analysis, CEC: cation exchange capacity, Ci: Capability index, CV: Coefficient of variation, DTPA: Diethylene triamine penta acetic acid, ESP: Exchangeable sodium per cent, FAO: Food and Agriculture Organization of United Nations, FYM: Farm yard manure, GIS: Geographic information system, I_{dm}: Aridity index (De Martonne), IRS: Indian Remote sensing Satellite, K: Potassium, KML: Key hole markup language, LISS: Linear imaging self scanning sensor, OC: Organic carbon, SMU: Soil mapping unit, t/ha: tonnes per hectare

INTRODUCTION

The increasing population demands environmentally friendly land use to support food security. However, soil degradation can hinder food supply, especially in small-scale agricultural systems (Nziguheba et al. 2022). To address this, improved soil resource management and assessment of soil agricultural potential are necessary (Amara et al. 2021). Factors such as soil quality and climate are crucial in determining land suitability for agricultural use. Most land capability and soil suitability assessments fail to consider soil geographical variation and essential characteristics, despite this information being essential for resolving site or location-specific land use concerns. A comprehensive investigation of soil distribution provides precise classifications of land capacity and soil suitability (De Feudis et al. 2021). As an outcome, gaining comprehensive site-specific information on land and soil resources may assist in identifying the limitations and potentials of these scarce resources for sustainable banana production at Makuleke Farm (Swafo and Dlamini 2023). The significance of land qualities in land evaluation is underscored by their close association with topography, soil, and climate, which are crucial for meeting the specific requirements of banana cultivation (Ritung et al. 2007). When evaluating land, it is essential to consider land characteristics, including drainage, texture, soil depth, nutrient retention (such as pH and cation exchange capacity), alkalinity, erosion hazard, and flood/inundation. These factors are pivotal in determining banana growth and productivity potential (Zuazo 2008). To ensure optimal conditions for banana cultivation, the effective soil depth should exceed 125 cm and a suitable banana climate should have a mean temperature of 26.67°C and an average annual rainfall of 120 to 150 cm. It is crucial to avoid any dry months that could hinder the successful cultivation of bananas. When comparing different methods, it is imperative to establish a quantitative correlation with physical parameters that yield similar outcomes (Mueller et al. 2009).

Furthermore, it is advisable to consider locally proven and tested approaches and their respective indicator sets and thresholds (Kumar et al. 2017). These methods offer valuable insights and guidance for evaluating land quality and making informed choices about banana cultivation. Geographic Information Systems (GIS) can help identify the most suitable spatial arrangement for banana cultivation, considering specific requirements and preferences. GIS is highly appropriate for this purpose, as it provides attribute values for each location and offers a range of arithmetic and logical operators to combine these attributes. According to Samanta et al. (2011) and Nuarsa et al. (2018), GIS is vital in facilitating the multi-criteria evaluation function of suitability assessment.

Pulivendula Tehsil in Kadapa District of Andhra Pradesh is highly vulnerable to agricultural drought due to its rocky topography, high number of marginal farmers, and semi-agricultural nature (Bhaskar et al. 2019). Understanding the geo-environmental and agroecosystem relationships in different areas is crucial for promoting uniform soil-crop zones and integrating geo-environmental assessment. Gathering accurate site-specific information about land and soil resources is vital for identifying the limitations and potentials of these finite resources. The objectives of this study were twofold: firstly, to survey, classify, and characterize soils at Pulivendula division to derive and map land capability classes, and secondly, to quantify the physical and chemical properties of the soils to derive and map soil suitability classes for bananas.

MATERIALS AND METHODS

Description of the study site

The Pulivendula Tehsil in the Kadapa District, Andhra Pradesh, India has a total area of 1462.35 km^2 (146,235 ha). There are six Mandals within this tehsil's boundaries: Pulivendula, Vemula, Vempalli, Tondur, Simhadripuram, and Lingala (Figure 1). The research site is in a semi-arid region with 43 wet days and 564 mm of average annual rainfall. The Length of Growing Periods (LGP) for Pulivendula and Vemula, Lingala and Tondur, and Simhadripuram and Vempalli Mandals are from 90 to 105 days, 105 to 120 days, and 120 to 135 days, individually. Peanut production is only marginally feasible in this region under a hot, dry eco-subregion of the Rayalseema plateau's deep loamy and clayey red and black soils (Mandal et al. 1999). The research region comprises rocks from the Papaghni and Chitravati groups of the Cuddapah Super Group. The rock types found in the Papaghni group include conglomerates, quartzite, and arkose. The Chitravathi Group comprises intrusive rocks, dolomites, chert, mudstone, quartzite, and basic flows. Basu et al. (2009) state that the Tadipatri formations are made of quartzite and dolomite/quartzite.

Procedures

Agroecosystem analysis. The Agro Ecosystem Analysis (AEA) process was divided into three stages: I. agroclimatic analysis (rainfall and temperature), II. geo-pedological data sets, and III. suitability of soil units for bananas under drip irrigation. The data aggregation for the agroecosystem research is described as given below.

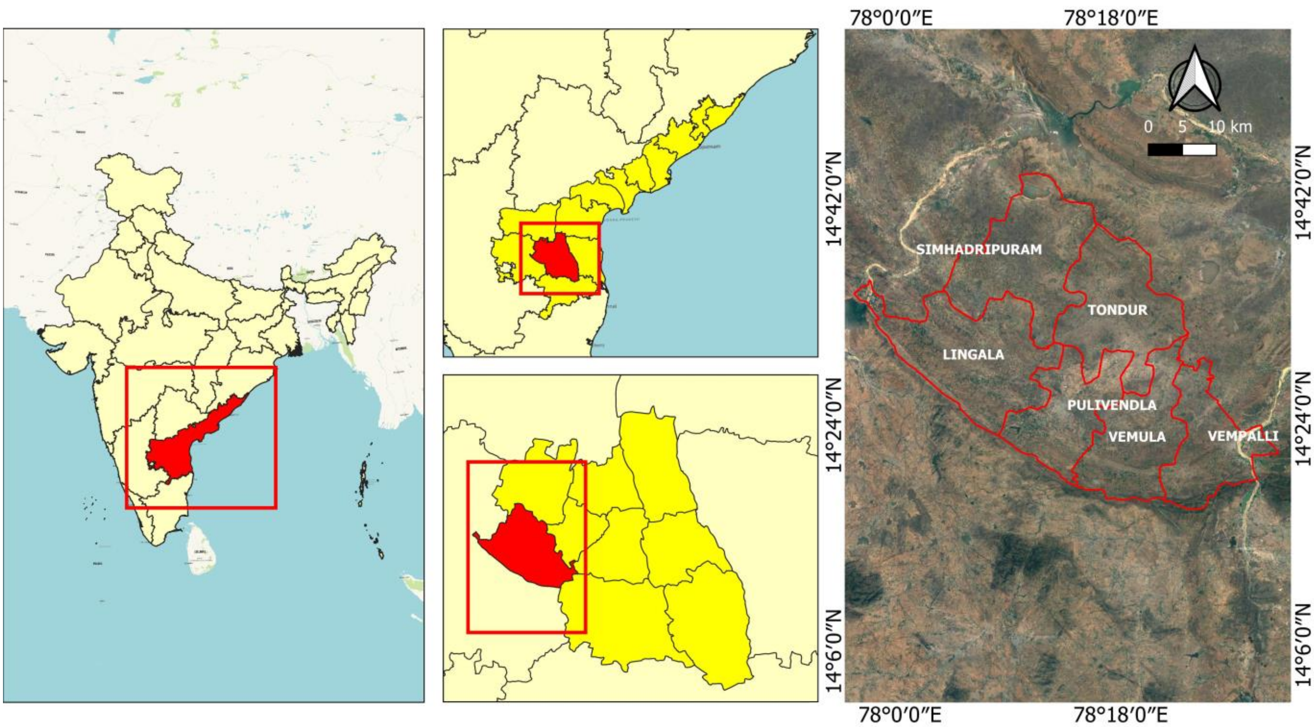

Figure 1. Location map of Pulivendula (between 14°16' and 14°44' N and 77°56' and 78°31' E), in Kadapa District, Andhra Pradesh, India

Agroclimatic analysis

The aridity index of De Martonne (1926) was calculated using data from the Indian Water Portal.org. from 1901 to 2002.

De Martonne's aridity index

The aridity index of De Martonne (Im) is defined as the ratio of the annual rainfall amount P in mm and the annual mean temperature in °C + 10.

I_{dm} = Aridity Index (De Martonne) = *AAR* /*AAT*+10

Where:

AAR: Annual Average Rainfall (mm)

AAT: Average Annual Temperature (°C)

The following equation determines the De Martonne Aridity Index's monthly value: I_{dm} = 12p'/t' + 10, where p' and t are the monthly mean values of precipitation and air temperature for the driest month (taken as January, February, March, April, and May for Kadapa District). Irrigating the land in this month is necessary when I_{dm} is less than 20 (Zambakas 1992). According to I_{dm} values, the climate is classified as follows: 0-10: Arid, 10-20: Semi-arid, 20-24: Mediterranean, 24-28: Semi-humid, 28-35: Humid, 35-55: Very humid, and >55: Extremely humid.

Geopedological data sets

The semi-detailed soil survey was completed following established standards. The base was created using topographical and geological maps of Pulivendula Tehsil in the Kadapa District at 1:50,000 and IRS-P6-LISS-IV at 1:25,000 scales. A geomorphological map was used to guide the selection of transects and random inspections (Soil Science Division Staff 2017; Shalaby et al. 2017). The soil data, including field and laboratory observations, represent the main soil series in the area (Dent and Young 1981; Grunwald 2009). A total of 330 profiles were studied in 66 transects, and each of them was examined (cut across as 3 to 4 landform units) in 128,609 ha of cultivated area, excluding the mining area of 17,626 ha in the region. The morphological characteristics of 25 soil series have been outlined by Schoeneberger et al. (2012). The samples were air-dried and set through a 2 mm sieve to estimate the fine earth component. The fine Earth fraction's physical (particle size distribution) and chemical characteristics were determined following established methods (Dewis and Freitas 1970).

Soil site suitability

The FAO framework for land evaluation and rainfed farming norms (FAO 1983) were used to evaluate the soil suitability at Pulivendula Tehsil, Kadapa District, Andhra Pradesh, India. The requirements indicated for banana suitability with degrees of limits were used and logically classified for highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and, currently (N1), based on soil site attributes as given in Table 1 (Djaenudin et al. 2003; Naidu et al. 2006; Mujiyo et al. 2021). Soils classified as S1 have no significant barriers to be used over time for a specific use. Soils in the S2 category have moderate to substantial constraints for long-term application of a particular use. In contrast, soils in the S3 category have serious constraints for sustained application of a specific use. The parametric technique was used to evaluate soil unit suitability for drip irrigation (Sys et al. 1991) by multiplying the soil series rating with its fraction of area (AAFRD 2004). The irrigation capacity index (Ci) for evaluating the capability of irrigation was determined using the following formulas:

Ci = A * B/100 C/100 D/100 E/100 F/100.

Where:

Ci: Irrigation capacity index

A: Soil texture rating

B: Soil depth rating

C: $CaCO_3$ concentration rating

D: Salinity/alkalinity rating,

E: Drainage rating

F: Slope rating.

The five capability groups for Ci were categorized as follows: Excellent (CI >80 with symbol, S1), Suitable (S2-CI ranging from 80-60), Slightly suitable (S3-CI ranging from 45-60), Almost unsuitable (N1-CI ranging from 30-45), and Unsuitable (N2-CI less than 30).

Data analysis

GIS analysis

The maps of soil units (also known as soil series association) and soil suitability were generated with IRS-P6 plus 1:25000 scale topo base and Arc GIS 10.8.1 software. Therefore, to begin, the coordinates of the 23 soil series were used to mark the site of each profile pit. Each placemark was designated with the name of the soil series association in the land unit. After inserting and labeling all 43 soil mapping unit placemarks, the "add path" option was used. The mapping units were established utilizing the soil attributes derived from the profile pits. The "add polygon" tool made a polygon from land, forming placemarks. The polygon was then digitized to generate the shape of each soil form. The polygon was given a name based on the soil type and saved as a KML layer. Second, in Arc Map, a conversion tool called "From KML" (Keyhole markup language, file format used for displaying geographic data) was used to convert the KML layers of the polygons stored as a shape file. After generating all of the soil-landform shape files, a spatial distribution map was generated by "checking" all of the shape files on the same reference frame. The Pulivendula Tehsil base map was added using the "add data" function. Soil suitability maps have been renamed based on suitability class. They were subsequently mapped using the same process to map the soil forms.

Table 1. Soil site suitability rating for banana

Land–climate suitability	Suitable class of banana (Mujiyo et al. 2021)			
	S1	**S2**	**S3**	**N1**
Climatic parameters				
Altitude(meters)	<1,200	1,200-1,500	1,500-2,000	>2,000
Rainfall(mm/year)	1,500-2,500	1,250-1,500	1,000-1,250	<1,000
Temperature (^{0}C)	22-33	34-36/24-25	37-38	>38
Soil physical characteristics				
Soil depth(cm)	>125	125-75	50-75	<50
Soil textural class	L, Cl, SCl, SiL	SiCL, SC, C (<45%)	C (>45%), Sl	LS, S
Period of dry month	0-3	3-4	4-6	>6
Topography				
Slope (%)	<8	8-16	16-40	>40
Drainage class	Good to well-drained	Moderately drained	Poorly drained	Very poorly drained
Soil chemical parameters				
Total N (%)	>0.4	0.1-0.4	0.05-0.1	<0.05
Olsen's P(mg/kg)	>20	15-20	8-15	<8
Exchangeable K (cmol/kg)	>0.8	0.4-0.8	0.1-0.4	<0.1
pH	6.0-7.5	5.5-6.0&7.5-8.0	5.0-5.5&8.0-8.5	<5.0 &>8.5
OC(g/kg)	24 to 15	15 to 8	<8	
Base saturation(%)	50-35	35 to 20	<20	
Depth to mottling (cm)	>110	85-110	60-85	<60
Ground water table (cm)	>150	125-150	100-125	<100
Bulk density (Mgm^3)	<1.31	1.31-1.47	>1.47	
Permeability (cm/h)	>7.9	7.9 - 5.00	<5.0	
Clay CEC	>12.4	8.9-12.4	<8.93	

Profile weighted mean

the depth-weighted approach was utilized To depict the overall pattern of soil properties for each soil profile. This involved integrating the measured value of each soil property for genetic horizons with respect to depth, as per the formulae proposed by Clark and Roush (1984). The formula is as follows:

$$\hat{w} = \frac{\sum_{i-1}^{n}(measured\ soil\ property\ XD)n}{\sum_{i-1}^{n} D}$$

Where:
ŵ: Weighted mean
'n': Number of horizons
'D': Thickness of each horizon,
∑: Total thickness of the soil profile

Soil erosion estimation

The soil erosion for each soil mapping unit was calculated using the USLE (Universal Soil Loss Equation) developed by Wischmeier and Smith (1978). The general USLE equation is as follows:

A = R x K x LS x C x P

Where:
A: Computed spatial average soil loss and temporal average soil loss per unit area (ton ha^{-1} yr^{-1})
R: Rainfall erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1})
K: Soil erodibility factor (Mg h MJ^{-1} mm^{-1})
LS: Slope length and steepness factor
C: Cover management factor
P: Conservation practice factor

Based on the calculated values, the mapping units were categorized into 8 classes: Very low: soil loss ≤0.5 t/ha/yr, Low: 0.5-1 t/ha/yr, Low-medium: 1-2 t/ha/yr, Medium: 2-5 t/ha/yr, High-medium: 5-10 t/ha/yr, High: 10-20 t/ha/yr, Very high: 20-50 t/ha/yr, Extremely high: > 50 t/ha/yr (Uddin et al. 2016).

Compound growth rate

To determine the compound growth rate for the area and productivity of bananas over the years, a calculation was performed using time as the independent variable and the area and productivity of bananas as the dependent variable. The exponential growth function used for this calculation is as follows:

$Y = a.b^x$

Where:
Y: Dependent variable for which the growth rate is estimated
a: Intercept or constant
b: Regression/trend coefficient
x: Period in years
b = (1+r) and r = is the compound growth rate.

RESULTS AND DISCUSSION

Climate and soils

Monthly rainfall and temperature (1901 to 2002)

The average annual precipitation was 672.17±111.55 mm, and the Coefficient of Variation (CV) was 16.59. Monthly precipitation data shows that September and

October receives over 100 mm of precipitation with a CV of less than 55 percent. The percent coefficient of variation was greater than 100 for January, February, March, April, and December. The skewness coefficients are positive, indicating that light precipitation is regular while heavy precipitation is very common. A skewness coefficient close to zero for August, September, and October suggests that the data follow a normal distribution. The average air temperature is 26.23±0.38°C, and the CV is 1.43%. While the average monthly air temperature in April and May was above 30.0°C, the average air temperature in other months was 22.01±0.61°C in December and 28.40±0.70°C in June. The skewness coefficient of air temperature for May (-0.09), June and August (-0.02), December (-.024) and January (-0.4) was negative, showing that the data are normal. This result showed that rainfall is unpredictable and erratic, with large seasonal variations (Table 2).

Aridity analysis

The De Martonne Aridity Index (I'_{dm}) of less than 15 is given for monthly decadal data sets from January to August to designate climate as semi-arid, and I'_{dm} less than 20 indicates that the land in this month requires irrigation (Zambakas 1992). Similar observations have been recorded, warranting the identification of substitute remunerative crops in Alfisols (Kumari et al. 2016). This crop requires an annual rainfall of 1,200 mm to 2,690 mm (Carr 2009). However, the banana production area in the Kadapa basin falls in marginal zones, receiving mean annual rainfall of 672.17±111.55 mm. The percent coefficient of variation (CV) was 16.59 (Table 2), where bananas experience seasonal droughts (Aridity index less than 15 from June to August, Table 3), resulting in considerable yield losses (Bhaskar et al. 2023). The results from Pulivendula are in agreement with the findings of Van Asten et al. (2011), who reported that in areas with rainfall less than 1,100 mm per year, yield losses in banana can range from 20 to 65% and 8 to 10% loss of bunch weight for every 100 mm decline in rainfall. The mean monthly aridity (De Martonne Aridity Index) from 1901 to 2002 is shown as 18.43, signifying semi-arid conditions, with a mean annual rainfall of 679.59±237.52 mm, of which Kharif rainfall contributes 340.69 mm (50.28% of total rainfall) and a mean air temperature ranging from 30.70°C to 36.90°C.

Area and productivity of bananas concerning rainfall

Table 4 presents fourteen years of data on the banana area and productivity in the Kadapa District from 2007-2008 to 2020-2021. The banana area expanded steadily from 4,282 ha (2007-2008) to 42,533 ha (2020-2021), with a mean productivity of 51,508.8±11,420.6 kg ha^{-1} and moderate variation (CV of 22.17%). The average annual rainfall in the region is 733.9±259.7 mm/year, with moderate variability (CV of 35.38%). The Dwarf Cavendish banana, a semi-perennial crop with a long cycle (approximately 12 to 14 months), is grown in the Kadapa District from June to July. The area statistics under banana show a substantial increase from 4,282 ha (2007-2008) to 42,533 ha with a compound annual growth rate of 25.82%. The productivity statistics of bananas show a gradual increase from 35 t ha^{-1} (2007-2008) to 59.9 t/ha (2020-2021) with a 12.2% compound annual growth rate (Table 4). The area under banana relation to rainfall can be explained with a regression equation:

Area (ha) = 71.9749 + 0.1442 (Rainfall, mm) with a correlation coefficient of 0.39, indicating a weak direct relationship and p-value of 0.167 and F value of 2.16. For every increase of 1 mm rainfall, the increase in area is 0.1442 ha.

Productivity(t ha^{-1}) = 50.4893 + 0.001389 (rainfall, mm) with R^2 of 0.001 and F value of 0.0119, p= 0.91

The linear regression studies concerning rainfall and yield data have Inherent uncertainty to match yield data and need refinement in mapping cropland areas, specifically banana-growing regions in Kadapa. The annual rainfall is below 1,500 mm (Calberto et al. 2015), which is inadequate for a good harvest, and 6 to 7 dry months receiving below 60 mm rainfall (From December to June). The poor correlation between annual precipitation and banana production is positive but insignificant, which means that production increases with rainfall. This observation confirms with the findings of Sabiiti et al. (2016).

Table 2. Month-wise descriptive statistics for rainfall and air temperature (1901 to 2002)

Month	Rainfall (mm)			Air Temperature (°C)		
	Mean ±SD	**CV (%)**	**Skewness coefficient**	**Mean ±SD**	**CV (%)**	**Skewness coefficient**
January	0.72±1.0	139.0	1.42	22.57±0.67	2.98	-0.04
February	3.06±6.09	198.5	1.48	24.69±0.76	3.11	0.07
March	6.67±10.28	154.1	1.56	27.70±0.77	2.78	0.22
April	21.97±23.71	107.9	0.99	30.24±0.62	2.07	0.35
May	58.1±44.31	76.3	0.85	30.63±0.81	2.66	-0.09
June	50.1±28.27	56.3	0.48	28.40±0.70	2.46	-0.02
July	70.9±32.73	46.1	0.57	26.99±0.54	2.00	0.14
August	92.2±50.08	54.2	0.053	26.55±0.46	1.76	-0.002
September	154.4±69.82	45.2	0.20	26.30±0.57	2.17	0.30
October	123.9±66.35	53.5	0.31	25.38±0.46	1.84	0.08
November	72.37±53.76	74.2	0.68	23.33±0.66	2.82	0.06
December	17.25±18.97	109.9	1.19	22.01±0.61	2.79	-0.24
Total	672.2±58.66	16.59		26.23±0.38	1.43	

Table 3. Monthly decadal data on the aridity index

Climatic variables	January	February	March	April	May	June	July	August	September	October	November	December
De Martonne Aridity Index												
1901-1910	10.06±0.04	10.07±0.18	10.13±0.25	10.52±0.71	11.22±1.11	11.29±0.58	12.03±0.93	13.37±1.99	15.79±2.75	13.49±1.68	12.34±2.66	10.75±0.79
1911-1920	10.03±0.03	10.05±0.09	10.25±0.46	10.29±0.43	11.54±0.66	11.09±0.51	12.13±1.39	12.56±1.42	15.52±1.62	13.88±2.47	13.45±2.09	10.46±0.54
1921-1930	10.04±0.02	10.11±0.18	10.19±0.27	10.75±0.75	11.58±2.01	11.35±0.53	12.08±1.07	12.10±0.99	15.05±2.25	14.03±2.26	12.97±2.28	10.54±0.86
1931-1940	10.02±0.03	10.18±0.30	10.17±0.18	10.81±0.85	11.20±0.85	11.47±0.67	11.98±0.63	12.66±2.09	14.57±2.47	13.66±1.57	12.75±1.61	10.44±0.61
1941-1950	10.02±0.03	10.09±0.13	10.15±0.34	10.48±0.37	11.65±1.25	11.41±0.63	12.15±1.17	13.13±1.14	15.46±1.62	13.40±2.10	12.62±1.95	10.68±0.87
1951-1960	10.01±0.02	10.03±0.07	10.17±0.22	10.82±0.75	12.06±1.61	11.55±1.14	12.60±1.06	12.71±1.70	14.68±3.55	14.47±2.60	11.78±1.92	10.67±0.89
1961-1970	10.03±0.05	10.06±0.10	10.16±0.29	10.72±0.90	11.58±1.17	11.67±0.62	12.52±0.97	13.52±1.81	15.29±2.43	13.98±2.30	12.06±1.87	10.91±0.66
1971-1980	10.02±0.03	10.12±0.19	10.09±0.16	10.57±0.85	11.94±1.49	11.40±0.48	12.27±1.00	12.85±1.51	14.44±2.35	15.08±3.00	12.91±1.60	10.51±0.67
1981-1990	10.02±0.05	10.14±0.26	10.37±0.29	10.56±0.45	11.40±1.34	11.39±0.60	12.54±1.21	12.76±1.87	16.02±2.75	13.82±1.30	12.03±0.83	10.67±0.42
1991-2002	10.02±0.04	10.07±0.13	10.11±0.16	10.64±0.47	11.67±0.69	11.90±0.92	12.05±0.68	13.84±1.32	13.96±1.32	15.46±1.41	12.07±1.24	10.60±0.71

Table 4. Area, the productivity of bananas concerning rainfall

Year	Area (ha)	Productivity (kg ha^{-1})	Rainfall (mm)
2007-2008	4,282	35,000.00	910.80
2008-2009	5,329	34,343.22	648.70
2009-2010	14,752	35,000.00	591.60
2010-2011	13,129	35,000.76	899.70
2011-2012	16,504	52,200.01	664.30
2012-2013	15,914	54,900.03	548.20
2013-2014	15,665	56,700.03	689.20
2014-2015	15,888	60,000.00	432.60
2015-2016	12,800	65,000.00	1,012.80
2016-2017	16,371	53,000.00	590.70
2017-2018	26,212	59,980.12	854.20
2018-2019	23,685	60,000.00	376.70
2019-2020	25,887	60,000.00	678.20
2020-2021	42,533	59,999.72	1,378.10
Mean±SD	17,782.2±9,577.1	51,508.8±11,420.6	733.9±259.7
CV(%)	53.85	22.17	35.38

Table 5. Physical and chemical characteristics of soil series in Pulivendula Tehsil, Kadapa District, Andhra Pradesh, India

Soil series	Particle size distribution (%)			pH	EC (dS m^{-1})	Organic carbon	$CaCO_3$	CEC cmol kg^{-1}	PBS	ESP
	Sand	silt	clay			g kg^{-1}				
1. Kanampalli (Kpl)	72.1	4.3	23.6	8.3	0.14	16.3	10	12.9	71	0.16
2. Ganganapalle (Ggp)	32.1	20.5	47.4	7.1	0.23	17.7	30	30.5	100	0.39
3. Lingala (Lgl)	44.4	23.8	31.8	8.1	0.22	11.9	20	26.6	100	0.15
4. Rachanakuntapalle (Rkp)	57.3	18.3	24.4	7.2	0.16	8.4	-	25.7	46	0.16
5. Mupendranapalle (Mpl)	29.5	29.0	41.5	8.4	0.38	10.7	40	29.1	100	0.76
6. Tallapalle (TlP)	40.9	19.6	39.5	7.9	0.19	9.7	70	28.3	100	1.13
7. Santhakovur (Skv)	48.8	18.7	32.5	7.9	0.29	9.2	150	21.7	100	2.76
8. Tatireddipalle (Trp)	14.9	27.8	57.3	7.7	0.22	11.2	40	54.5	100	0.26
9. Cherlapalle (Cpl)	32.5	21.2	46.3	8.1	0.34	6.2	110	33.2	100	23.64
10. Kottalu (Ktl)	74.9	10.3	14.8	7.9	0.16	3.6	20	7.6	100	1.97
11. Murarichintala (Mct)	71.1	14.2	14.7	8.0	0.25	4.7	10	7.2	100	0.14
12. Vemula (Vml)	32.8	24.9	42.3	8.0	0.20	7.0	160	30.1	100	1.79
13. Sunkesula (Skl)	50.1	15.4	34.5	8.0	0.30	11.1	40	28.0	100	1.61
14. Simhadripuram (Spm)	23.2	21.5	55.3	8.0	0.25	8.4	140	42.7	100	6.46
15. Velpula (Vpl)	60.7	13.5	25.8	7.9	0.14	3.3	50	13.0	100	2.31
16. Agraharam (Ahm)	23.6	18.2	58.2	8.3	0.21	9.3	110	44.2	100	2.22
17. Balapanur (Bpr)	23.0	24.0	53.0	8.0	0.41	5.7	100	37.4	100	11.04
18. Parnapalle (Prp)	78.4	8.9	12.7	7.8	0.31	5.0	20	10.3	100	4.95
19. Gondipalle (Gpl)	29.5	19.4	51.1	7.9	0.21	14.7	150	35.8	100	0.87
20. Goturu (Gtr)	42.0	13.9	40.0	8.2	0.47	8.4	90	36.9	100	15.77
21. Pulivendula (Pvd)	38.6	1.2	60.2	8.5	1.47	2.6	110	24.2	100	67.89
22. Pernapadu (Ppd)	33.4	19.3	47.3	8.0	0.19	6.3	130	45.0	100	0.33
23. Agadur (Agd)	32.6	19.8	47.6	7.8	0.19	5.4	100	42.6	100	0.45
24. Tondur (Tdr)	29.8	22.3	47.9	8.1	0.25	5.8	100	41.9	100	4.6
25. Bhadrampalle (Bpl)	45.0	5.9	49.1	7.9	0.33	4.1	100	27.3	100	8.78

Textural characteristics of soil series

Table 5 shows each soil series's profile weighted mean of sand, silt, and clay. Among the 25 soil series analyzed, the sand content shows significant variation. In Paranapalle (P18), the weighted mean for sand content is 78.4%, while it ranges from 74.9% in Kottalu (P10) to 72.1% in Kanampall (P1) and 71.1% in Murrarichintala (P11). The lowest recorded weighted mean for sand content is 14.9% in Tatireddipalle (P8), but it varies from 23% in P1 to 60.7% in P15. For the silt content, the profile weighted mean is 1.2% in P1, but it varies from 27.8% in P8 to 5.9% in P25. As for clay, soils with a weighted mean of more than 60% in P21 are classified as very fine at the family level, while soils with clay content ranging from 30% to 60% are considered fine. In specific soil series, P18 (12.7%), P10 (14.8%), and P11 (14.7%) are classified as coarse loamy due to their weighted mean clay content. On the other hand, Rachanakuntapalle (P4) and Velpula (P15) have loamy soils with a weighted mean clay content of 24.4% and 25.8%, respectively. The Kanampalli (P1) and Ganganapalli (P5) have lithic contact within 50cm but differ in particle size class, with P1 being loamy skeletal (clay of 23.6%) and Ganganapalli (P2) being clayey (clay of 47.4%). The weighted mean clay percentage of the Rachanakuntapalle series (P4) is 24.4%, whereas Mupendranapalle (P5) and Tallapalle (P6) are 41.5% and 39.5%, respectively. Particle size is considered fine for 13 soil series (P6, P8, P9, P12, P14, P16, P17, P19, P20, P22, P23, P24 and P25) where clay content exceeds 35% in the control section (25 to 100cm, (Soil Survey Staff 2014). The weighted mean for clay is 12.7% for P18 and 14.8% for P10/P11 when the sand content exceeds 70%.

Chemical characteristics of soil series

The mean pH value of the soils in Pulivendula (P21) is 7.68±0.68 with a coefficient of variation of 7.99% in soils on quartzite (P1 to P5) and 8.01±0.2 with a coefficient of variation of 2.47 % in other soils over shale. These soils are mild to moderately alkaline with a pH of up to 8.0, which aids in nitrogen fixation (Varaprasad et al. 2000). These soils had exceptionally low organic carbon (2.6 g kg^{-1}) in Pulivendula soil (P21) but more than 10 g kg^{-1} in P8, P13, and P19 in shale soils with a mean of 7.26±3.13 g kg^{-1} (Table 5). The mean organic carbon in soils over quartzite is 13.58±4.24 g kg^{-1} to be classified as medium to high status (Hazelton and Murphy 2007), which promotes good structural condition and stability. Only 28% of soils have more than 10 g kg^{-1} organic carbon and may be used for sustainable banana production. The remaining soils have low to extremely low organic carbon status, limiting the capacity to improve banana yields and necessitating organic carbon build-up. The Cation Exchange Capacity (CEC) of Pulivendula Tehsil soils varies from 7.2 cmol (+) kg^{-1} in P11 to 54.5 cmol (+) kg^{-1} in P8. Soils on quartzite have a mean CEC of 23.93±7.64 cmol (+) kg^{-1}, whereas soils on shales have a mean CEC of 30.52±13.12 cmol (+) kg^{-1}. It was shown that 72% of soils have high (24%) to very high (48%) CEC, while the remaining 28% had low (12%) to moderate (16%) CEC. Notably, low CEC might be attributable to soils' high sand and low organic matter content. The calcium carbonate ($CaCO_3$) level varies from 10g/kg in P1 to 160 g kg^{-1} in P12 for classification as Calcic Haplustalfs. Soils on shale contain higher $CaCO_3$ with a mean of 87.62 46.57g/kg than soils on quartzite with a mean of 20±10 g kg^{-1}. During soil studies in the region, it was observed that greater $CaCO_3$ levels in the interhill basin and colluvial alluvial complex soils are caused by limited drainage, as evidenced by the emergence of calcic layers in P12. This conclusion is consistent with the findings of Bhaskar et al. (2015) in the Seoni area of Madhya Pradesh. Except for P9, P20, and P21, these soils have a percent base saturation of more than 100 and an ESP (exchangeable sodium percent) of less than 15%. The mean ESP of shale soils is 7.61±15.03 (Sd), although less than one in other soil series.

Soil map

Twenty-five soil series were identified, and a soil map with 43 mapping units was developed (Figure 2). Soils on quartzitic hills and ridges include eight mapping units, typically interconnected with rock outcrops, are extremely shallow, somewhat excessively drained, moderately alkaline, sandy loam to clay loam textured, and cover 54,812 hectare (37.48% of total area). Shale landforms cover 73,797 ha (50.46% of total area). The interhill basin soil mapping units consist of seven mapping units with six soil consociations and one soil association (4.79% of the total area). These soils are shallow and well-drained, with highly alkaline gravelly clay subsoil layers of loam to gravely clay. The gently sloping lands cover 39,092 hectares (30.4% of the total area) and have been separated into 12 soil mapping units.

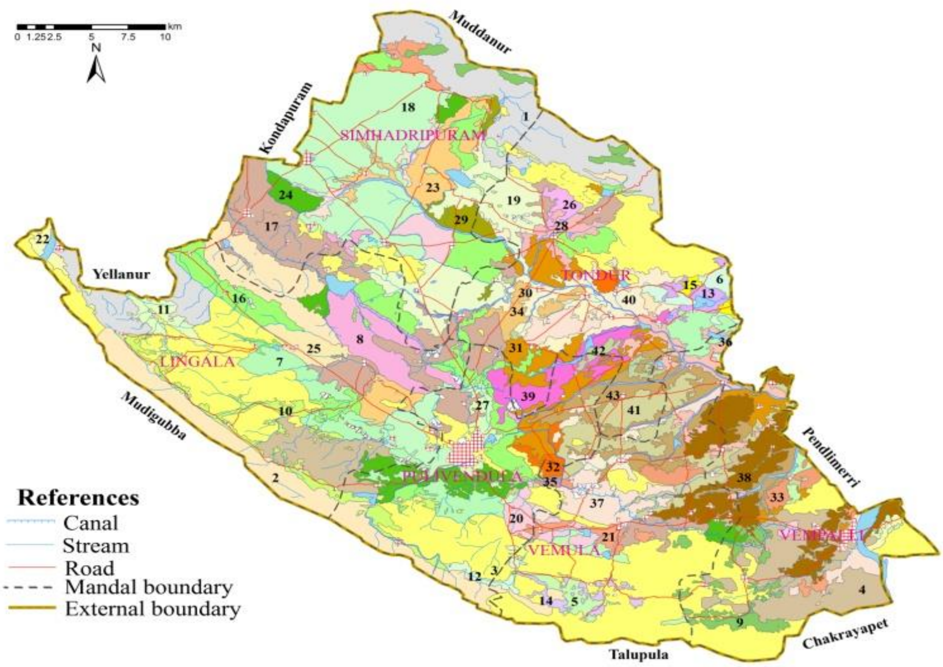

Figure 2. Soil map of Pulivendula Tehsil, Kadapa District, Andhra Pradesh, India

Vemula soils (20-1,667 ha, 1.2%) are shallow, well-drained calcareous red soils with strongly alkaline clay surface soils and argillic horizon. The 11 SMUs are linked with very deep, moderately well-drained calcareous, strongly to moderately alkaline black soils with shrink-swell potential. Colluvic and alluvial plains soils cover 28,542 ha (22.19% of total land area) with Tondur-Pernapadu series (30), Pernapadu-Gondipalle association (33), Goturu-Gondipalle association (36), and Agadur-Pernapadu association (41). Furthermore, 25 soil series were classified in four orders viz., Alfisols (6 367 ha, 4.8%), Entisols (5 477 ha, 4.1%) Inceptisols (47,342 ha, 35.5%) and Vertisols (31,118 ha, 23.3%), five suborders (Ustalfs, Orthents, Aquepts, Ustepts, and Usterts), seven Great groups (Paleustalfs, Rhodustalfs, Haplustalfs, Ustorthents, Halaquepts, Haplustepts and Haplusterts. Six soil series, Murarichintala, Kottalu, Vemula, Rachakuntapalle, Lingala, and Velupula, are classed as Alfisols because they have distinct wet and dry seasons (ustic moisture regime), and the clay ratio in B layers is 1.2 times higher than in eluvial A horizons. The particle size of these soils differs from fine loamy (P10, P11), clayey skeletal (Vemula, P12, Lingala, P3), loamy skeletal (P4), and fine (Velupula, P15). These series are classed at the great group level as Paleustalfs, Rhodustalfs, and Haplustalfs, with lithic contact within 50 cm (P3/P4), calcic (P12), and Typic in others. The seven series of Vertisols in colluvio-alluvial sectors have high sodium-loaded slickensided horizons and are classified as Sodic Haplusterts. At the broadest level, nine soil series are categorized as Haplustepts. However, they are subdivided into three subgroups: Lithic, Typic, and Vertic. In addition, three soil series on hills/ridges are grouped into two subgroups: Lithic/Typic Ustorthents.

Suitability for banana under drip irrigation

Sys et al. (1993) parameters were used to assess the suitability of 43 soil mapping units for bananas. As shown in Table 6, SMU 1 to 8 in hills and ridges (54,812 ha, 37.48% of total area) are unsuitable for banana growing due to their proximity to rock outcrops. This unit comprises shallow, gravelly soils (Kanampalle, Ganganapalle, Rachanakuntapalle, Mupendranapalle, and Lingala series) with low water holding capacity, low organic carbon, root limiting layers below 50 cm, and low readily available K/Zn. These units are potentially unsuitable but respond well to input use and conservation strategies to upgrade to S3. The interhill basin has 20 SMUs and encompasses 45,255 hectares (30.94% of the total area). The soil depth of over 100 cm is excellent for banana production, although feeder roots are limited to 45 cm (Shanmugavelu et al. 1992). In addition, 15 soil mapping units (SMU 29 to 43) in colluvio-alluvial plains (28,542 ha, 19.52%) contain very deep, fairly well-drained, calcareous, strongly to moderately alkaline black soils with significant shrink-swell potentials. Only five SMUs (32, 38, 40, 41, and 43) are moderately suitable for bananas due to the coarse texture, coarse fragments, calcium carbonate, exchangeable Na/K, and drainage constraints (Table 6). The data indicates that an estimated 56,091 hectares, comprising 38.353 percent of the land, are considered suitable for growing bananas. These suitable areas are geographically dispersed along the canal network, extending from the northwest to the southeast.

The optimal soil conditions for bananas is 30 to 50% clay, pH of 5.5 to 7, 0.5% organic carbon, 50 cm, and a slope of 0-3% (FAO 2018). The land evaluations for bananas using 43 soil mapping units were made and delineated 8 soil mapping units (12, 21, 23, 24, 25, 26) covering 8,337 ha (5.70% of total area) in interhill basins with medium soil erosion risk and needs organic carbon management for enhancing productivity (50 t/ha of FYM). The seven marginally suitable SMUs (22,688 ha,15.51% of area), viz., 11, 13, 14, 17, 19, 20 and 27) have soil constraints of high calcium carbonate, low organic carbon, strong alkalinity, coarse fragments, and low available K and DTPA-Zn. The strongly alkaline shrink-swell soils in colluvial-alluvial sectors are evaluated as marginally suitable for bananas (Figure 3).

These soils have more than 45% clay with high soil water holding capacity, and experiencing seasonal drought in the region led to poor crop growth and subsequent yield loss. Shrink-swell soils and off clay-rich Alfisols subsoils acquire significant structures in the B horizon (Pedocutanic B). Root development and water transport are frequently hampered by the hard, compact, and thick B horizons (Fey 2010). Banana growth on these soils will be limited to a tiny volume of soil that cannot supply appropriate anchoring, water, and nutrients (Fullen and Catt 2014). The bananas on shallow Lithocutanic and Pedocutanic B horizons have root-limiting soil depth, causing waterlogging during periods of heavy rain, and are susceptible to falling below the permanent wilting percentage during drought events (Jackson 2008). Waterlogging promotes Panama disease in bananas by increasing the solubility and bioavailability of redox-sensitive micronutrients, including iron and manganese, and inhibiting nitrification (Orr and Nelson 2018). Under reduced conditions, the banana plants will exhibit reduced water intake and stomatal conductance, delayed development, withering, and lower yields (Maestre-Velero and Martínez-Alvarez 2010).

The suitability of 43 soil mapping units for bananas is evaluated using the criteria of Sys et al. (1993). The SMUs from 1 to 8 in hills and ridges (54,812 ha, 37.48% of total area) are unsuitable for banana cultivation but respond well to inputs and conservation measures. Furthermore, the interhill basin comprises twenty soil mapping units, which collectively span an area of 45,255 hectares, accounting for 30.94% of the total area. Out of these twenty units, only eight (namely, 12, 18, 21, 23, 24, 25, 26, and 28) are moderately suitable, requiring careful organic carbon management. These eight units cover 12.42% of the interhill basin, equivalent to 18,174 hectares. Conversely, seven soil mapping units (covering 22,688 hectares, or 15.51% of the area) are marginally suitable. These units, namely 11, 13, 14, 17, 19, 20, and 27, face limitations such as calcium carbonate enrichment, low organic carbon content, strong alkalinity, coarse fragments, and low availability of potassium and DTPA-Zinc. Fifteen soil mapping units (SMU 29 to 43) on colluvial-alluvial plains (28,542 ha, 22.19%) have very deep, moderately well-drained, calcareous, and strongly to moderately alkaline black soils with high shrink-swell potentials. Only 5 SMUs (32, 38, 40, 41, and 43) are marginally suitable for bananas (Table 6). The results from land evaluation for drip irrigation show that 13 units were evaluated as marginally suitable for bananas. In addition, 9 SMUs are highly suitable (34,502 ha) since 8 SMUs (13,882 ha) are moderately suitable (Figure 4).

Table 6. An assessment of soil mapping units for suitability of bananas using drip irrigation and their erosion status

Land Form	Soil Mapping Unit	Area		Banana		Drip		Soil Loss (t/ha/year)
		ha	Percent (%)	Rating	Suitability Class	Rating	Suitability Class	Soil Erosion Risk
Hills and ridges	1. Rockoutcrops®-Kanampalli (Kpl)	7,953	6.18	3.34	N2	17.96	N2	25.11/high
	2. Rockoutcrops®-Ganganapalle (Ggp)	7,464	5.80	9.65	N2	21.60	N2	57.94/high
	3. Rockoutcrops®-Rachanakuntapalle(Rkp)	24,939	19.4	3.72	N2	24.30	N2	9.91/high-medium
	4. Rockoutcrops®-Lingala (Lgl)	6,410	4.98	4.26	N2	25.52	N2	102.8/extremely high
	5. Rachanakuntapalle (Rkp)-rockoutcrops®	1,333	1.04	4.12	N2	53.20	N2	8.93/high-medium
	6. Ganganapalle (Ggp)-Rockoutcrops®	677	0.53	16.40	N2	33.25	N2	57.94/extremely high
	7. Rockoutcrops®-Mupendranpalle (Mpl)	3,572	2.78	15.60	N2	29.93	N2	8.6/high-medium
	8. Mupendranpalle (Mpl)-Rockoutcrops®	2,464	1.92	11.32	N2	76.95	S1	8.56/high medium
Interhill basin	9. Tallalapalle (Tlp)	1,829	1.42	14.21	N2	90.25	S1	8.97/high- medium
	10. Murarichintla (Mct)	1,934	1.50	15.83	N2	85.50	S1	8.90/high -medium
	11. Tatireddipalle (Trp)	788	0.61	49.42	S3	95.00	S2	1.33/low-medium
	12. Kottalu (Ktl)	372	0.29	69.04	S2	68.40	S1	3.46/medium
	13. Santhakovur (Skv)	548	0.43	41.42	S3	72.20	S1	11.84/high
	14. Murarichintala (Mct)-Tallapalle (TlP)	508	0.39	43.73	S3	95.00	S3	8.92/high -medium
	15. Cherlapalle (Cpl)	184	0.14	19.81	N1	85.50	S1	5.27/high- medium
	16. Balapanur (Bpr)	6,559	5.10	41.18	S3	95.00	S1	24.23/very high
	17. Simhadripuram (Spm)	7,583	5.90	43.73	S3	90.25	S1	1.82/low -medium
	18. Simhadripuram (Spm)-Agraharam (Ahm)	9,125	7.10	61.29	S3	67.50	S1	2.68/medium
	19. Balapanur (Bpr)-Sunkesula (Skl)	4,294	3.34	52.89	S3	56.53	S1	3.65/medium
	20. Vemula (Vml)	1,667	1.30	40.00	S3	85.50	S2	7.65/high-medium
	21. Velpula (Vpl)	1,326	1.03	68.64	S2	85.74	S1	4.12/medium
	22. Parnapalle (Prp)	446	0.35	30.78	N1	90.25	S2	1.36/low-medium
	23. Agraharam (Ahm)	2,690	2.09	76.71	S2	90.25	S1	3.59/medium
	24. Sunkesula (Skl)	2,778	2.16	64.60	S2	90.25	S2	2.97/medium
	25. Agraharam (Ahm)-Sunkesula (Skl)	802	0.62	71.87	S2	80.75	S2	3.61/medium
	26. Agraharam (Ahm)-Simhadripuram(Spm)	369	0.29	66.82	S2	17.96	s1	2.78/medium
	27. Sunkesula(Skl)-Simhadripuram (Spm)	741	0.58	58.34	S3	21.60	S2	2.65/medium
	28. Velpula (Vpl)-. Vemula (Vml)	712	0.55	61.16	S2	24.30	S2	5.36/high-medium
Colluvial-alluvial pediplains	29. Bhadrampalle (Bpl)-Agadur (Agd)	788	0.61	29.84	N1	25.52	S2	19.34/high
	30. Tondut (Tdr)-Pernapadu (Ppd)	1,351	1.05	31.12	N1	53.20	S1	85.36/extremely high
	31. Tondur (Tdr)	3,568	2.77	29.07	N1	33.25	S1	102.80/extremely high
	32. Agadur (Agd)	633	0.49	48.45	S3	29.93	S1	1.86/low-medium
	33. Pernapadu (Ppd)-Gondipalle (Gpl)	853	0.66	29.17	N1	76.95	S2	5.68/high-medium
	34. Tondur (Tdr) – Agadur (Agd)	709	0.55	34.88	N1	90.25	S1	90.56/extremely high
	35. Pulivendula (Pvd)-Pernapadu (Ppd)	101	0.08	23.27	N2	85.50	S1	15.32/high
	36. Goturu (Gtr)-Gondipalle (Gpl)	1,501	1.17	33.80	N1	95.00	S1	2.75/low-medium
	37. Pernapadu (Ppd)	3,689	2.87	34.20	N1	68.40	S1	17.31/high
	38. Pernapadu (Ppd)-Tondur (Tdr)	4,358	3.39	32.15	N1	72.20	S1	85.36/extremely high
	39. Gondipalle (Gpl)	1,683	1.31	22.72	N1	95.00	S3	3.10/medium
	40. Goturu (Gtr)	1,707	1.33	41.18	S3	85.50	S1	1.33/low-medium
	41. Agadur (Agd) – Pernapadu (Ppd)	3,613	2.81	42.75	S3	95.00	S1	15.36/high
	42. Bhadrampalle (Bpl)	448	0.35	17.44	N2	90.25	S1	24.23/very high
	43. Pulivendula (Pvd)	3,540	2.75	15.99	N2	67.50	S1	17.31/high
	Total	128,609	100			56.53		

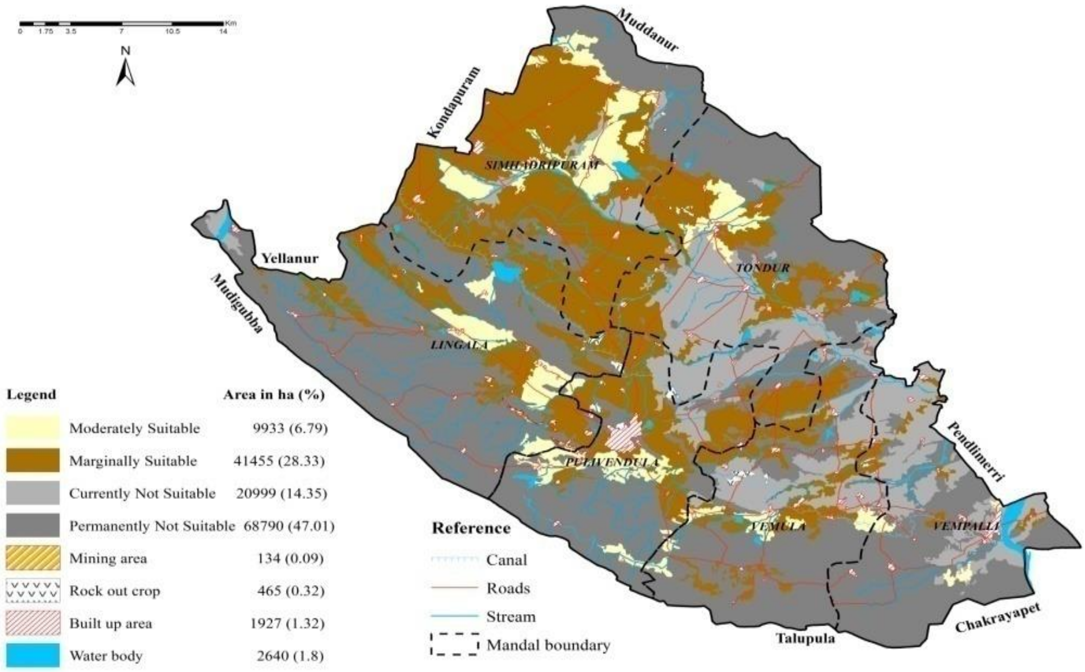

Figure 3. Soil–site suitability map for banana in Pulivendula Tehsil, Kadapa District, Andhra Pradesh, India

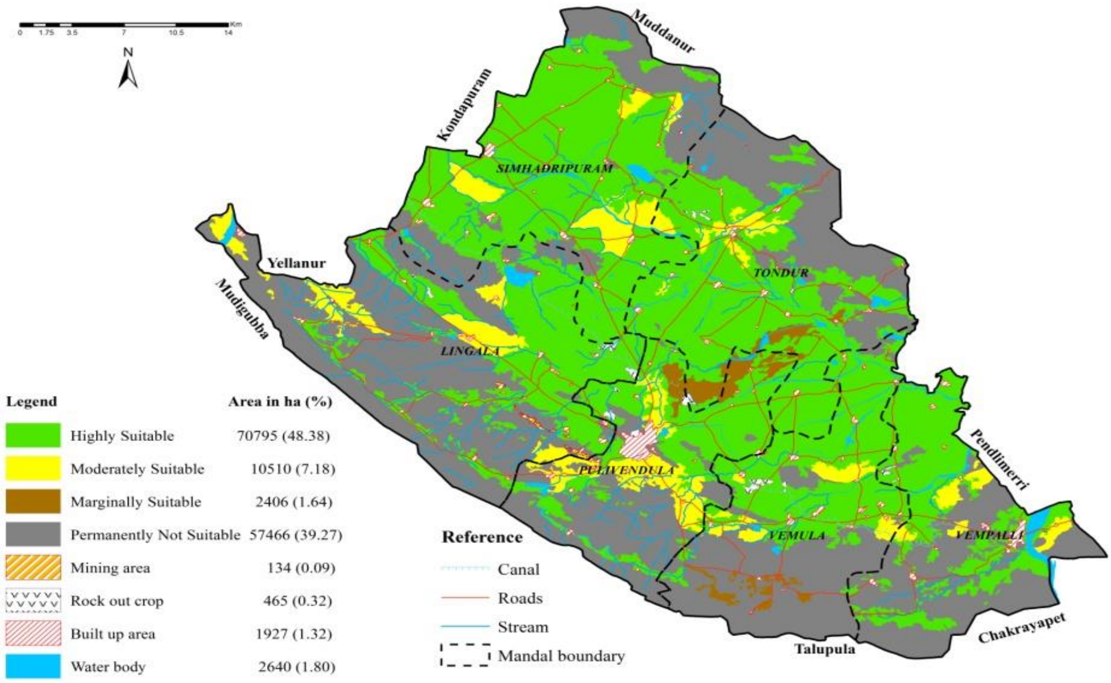

Figure 4. Suitability map for drip irrigation in Pulivendula Tehsil, Kadapa District, Andhra Pradesh, India

The interhill basin includes 20 soil mapping units covering 30.95% of the total area (45,255 ha), with a mean soil loss of 5.76±5.25 t/ha/yr. The mean soil loss with high medium erosion risk. Seven suitable SMUs for bananas (SMU12, 21,23,24,25,26 and 28) are classified as medium erosion risk zones, with mean soil loss of 3.25±0.55 t/ha/yr except in SMU 28 with high-medium risk (5.36t/ha/year, Table 6). This landscape unit is generally employed in the region for banana-based cropping systems, where crop management and soil erodibility determine adoption strategies for climate variability, input management, and moisture conservation. The 15 colluvial-alluvial pediplain SMUs encompass 28,542 ha (19.52%), with a mean of 32.51±37.39 t/ha/yr. The five SMUs with high erosion risk encompass 11,731 ha (8.02%), with a mean of 16.92±1.66 t/ha/yr. The four SMUs in colluvial-alluvial pediplains are designated as extremely eroded zones and include 9,986 ha (6.82%) with mean soil loss of 91.02±8.23 t/ha/yr. Pernapadu-Gondipalle (33) unit has an area of 853 ha (0.58%) under the low-medium erosion class and 1.46% (2,134 ha) under the high-medium erosion class (Table 6). The focus is on soil conservation practices in highly degraded regions. Sustainable land management options must be prioritized in light of terrain characteristics, land use cover status, and local community interests. Agroforestry, terracing, and a cut-and-carry technique can mitigate erosion in the steep slopes of the Palakonda range.

In conclusion, the climatic study of Pulivendula Tehsil is critically analyzed for banana production at a suitable scale for regional planning. The findings of a banana suitability analysis under drip irrigation reveal that 56,091 ha of land in winter hill basins and colluvial-alluvial deposits are appropriate (S2 and S3) for banana agriculture, compared to the present area of 22,000 ha. Furthermore, the analysis showed that 34,502 ha of feasible banana land is considered highly suitable for drip irrigation systems, with an extremely high erosion risk area of 16,364 ha. This study provides a baseline for agricultural land appraisal; it will assist farmers and decision-makers in various agroecological zones in determining how to undertake land evaluations to boost agricultural production and prevent unsuitable agricultural practices that may contribute to land degradation.

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