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Geoenvironmental Suitability Assessment of Three Agroecological Systems in India

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Abstract

The geo-environmental assessment is a prerequisite for adopting agro-ecological principles and achieving sustainable crop yields. We present three case studies from three agro-ecological regions. Pedological data sets were made and used to evaluate bio-physical parameters in Pulivendula tehsil in Kadapa, cotton producing Yavatmal district, and rice farming Majuli, Assam. According to the suitability assessment in pulivendula tehsil, 56091 ha are suitable for bananas under drip irrigation and 16364 ha are at high erosion risk. Cotton can be grown on 25 percent of total arable land in Yavatmal district, but 28.43 percent cannot be irrigated. Rice can be grown on 32% of Majuli island. However, there are limitations such as subsoil acidity, shallow ground water tables, poor organic carbon status, and low cation exchange capacity. Through land evaluation exercises, land resources can be harnessed using sustainable soil land management techniques. With the use of soil quality assessment and erosional status using USLE, the case studies shed light on region level biophysical constraints that affect productivity.

Keywords: Agroecology; Drip Irrigation; Geodiversity; Hydric Soils; Landforms; Shrink-S Well Soils; Semiarid Ecosystems; Soil-Site Suitability.

INTRODUCTION

Humans are especially conscious of the observable environment, such as the air, water, and landscape, when they are considering their surroundings. Most people have a negative perception of the subsurface as being dangerous, useless, and/or gloomy. The subsurface, however, plays a significantly larger role in society's ability to meet its demands than the majority of people realise. The effect and dependence on the subsurface are predicted to expand dramatically in the ensuing decades due to the world population's projected expansion to 9.7 billion people, the urbanisation rate reaching 66%, and the projected tripling of the size of the global economy (Crutzen and Stoermer, 2000; Andrews Speed, *et al.*, 2012). The conceptualization of (mostly) abiotic resources (including 3D-space) and their significance for human well being is necessary for the subsurface to be developed sustainably (Kennedy, *et al.*, 2015; Zhang, *et al.*, 2013). There are currently no reliable analyses of the subsurface's function and the

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associated environmental trade-offs. It takes more than adding up abiotic components to quantify geodiversity. Through procedures that represent the Earth's surface, it enables the investigation of the intricate interactions between various components. Spatial planning and geoconservation initiatives can benefit from this quantification (Gordon, *et al.* 2018). It may also provide the opportunity for an integrated investigation of abiotic factors and conservation strategies, reconsidering the order of importance for the preservation of the natural heritage, which includes both biotic and abiotic heritage (Bétard, *et al.* 2011).

Considering the geosystem as a geographical system, Sochava first used the term "Geosystems" in 1963 (Al'brut, 1977; Snytko and Semenov, 2008). He defined the geosystem as "a whole entity consisting of interrelated components of Nature that obey regularities operating in the geographical envelope or landscape sphere" (Sochava, 1974, quoted in Snytko and Semenov (2008) and Semenov and Snytko (2013). Since its introduction in 1990, the notion of geodiversity has received much attention from earth science experts (Zwolinski, *et al.,* 2018). Conservation, planning, and environmental mapping all depend on this idea, which has lately made it possible to identify geodiversity (Ozsahin, 2017). Geodiversity indices have been computed using geomorphological, geological, soil, and terrain maps for the Suriya region in Spain. The geodiversity of the Suriya region is divided into 5 classes, and the stiffness of the slope map is determined (Serrano*, et al.,* 2009). The Romanian Buzaului Geopark's geodiversity map was evaluated and provided using the same methodology (Comanescu and Nedelea, 2012) and in the Lar basin of Northern Iran (Ghahroudi Tali and Heidary, 2002). A variety of geomorphometric variables have been taken from the digital elevation model and compared to geological and climatic data using GIS software. The analysis produced by this data was utilised to create a geodiversity map (Argyriou, *et al.,* 2016). The Coromandel peninsula in New Zealand implemented a systematic approach for defining and quickly evaluating abiotic components. Using the most current data and records as a foundational database, this study is the first step in developing a universal system for evaluating the geodiversity of any region of our planet (Zakharovskyi, *et al.,*2022).

The geosystem can be identified by certain geological formations, landscapes, and rock, mineral, and fossil compositions. Additional distinguishing characteristics used to describe geosystems include the risk of certain natural disasters (such as earthquakes, landslides, liquefaction, and subsidence) as well as unique anthropogenic stresses (e.g. subsurface construction, mineral extraction, contamination). The subsurface is referred to as the region below the earth's surface, including both subterranean and submarine regions. On the one hand, we identify ecological systems, such as biomes at the surface of the terrestrial environment and marine ecosystems, which are tied to biotic communities and activities influenced, for example, by the availability of light, water, and oxygen. In contrast, the lack of light and frequently anaerobic conditions in the lithosphere and its geosystems are linked to low biological activity. Land inside the Central Framework (SEEA) is segregated from natural resources in recognition of its unique function in the supply of space (UN, 2014 a,b). De Groot (2006) recognised the carrier role as the fifth service category when evaluating sustainable landscapes, which includes mining and habitation among other things. But Common International Classification of Ecosystem Services CICES does not currently contain this. As a result, the key question is whether the subsurface can or should be fully incorporated into the ecosystem services concept or if the issues that need to be solved are too dissimilar and call for a different strategy. Mineral resource extraction is a relevant setting for exhibiting trade-offs in the subsurface. The policy focus on subsurface resources is currently on high-value minerals (such rare earth metals) and energy resources as a trade component and in relation to climate change. Given the increasing population and ongoing urbanisation process, the scarcity and accessibility of locally supplied large volume materials like aggregates (such as gravel, sand, and clay) may be just as significant but attract less attention.

The geosystems research is inadequate, and the watershed was employed as a management unit to define a study region with comparable features (UN, United Nations Statistics Division, 2014 a and b). Using the guidelines for land management and various land uses that will help to establish a greater possibility of agricultural development in a region. Based on these considerations, the objective of this research is to develop criteria to be used for the selection of potential sites for the identifying as agroecosystems in relation to geodiversity and to apply them to three semi-arid agroecological conditions in India. The overall goal of the agri environmental assessment was to design effective implementation of measures for conservation of biodiversity through sustainable local agricultural practises. To monitor and assess the effectiveness and efficiency of agri-environmental measures, the proposed approach would focus on the state of each agro-ecosystem and its ability to perform selected environmental functions, local agricultural land use and practises; and the impacts of agri-environmental measures on agro-ecosystems' ability to deliver ecological services.

MATERIALS AND METHODS

Study Area

Three case studies in three agroecological regions were chosen for geoenvironmental assessment: banana growing Pulivendula tehsil in Kadapa district, cotton growing Yavatmal district in Maharashtra, and rice growing Majuli island in Assam. The study areas are detailed below.

Case Study 1: Pulivendula Tehsil, Cuddapah District

Pulivendula covers 127463.0 hectares (ha) and is located between 14°16' and 14°44' N and 77°56' to 78°31'E (Fig. 1). Pulivendula's agroclimate is semiarid, with a mean annual rainfall of 564mm and 43 wet days. The LGP ranged from 90-105 days for Pulivendula and Vemula, 105-120 days for Lingala and Tondur, and 120-135 days for Simhadri puram and Vempalli mandals, according to land appraisal norms. The study are comes under a hot dry ecosubregion (K6E2) with deep loamy and clayey mixed red and black soils, low to medium available water holding capacity (AWC), and 60-90 day growing period (LGP) (Mandal, *et al.*,1999).

Fig. 1: Location map of Pulivendula tehsil, Kadapa district, Andhra Pradesh

The geology is granites, granite gneisses, cherty dolomites, quartzites, and shales (Nagaraja Rao, *et al.*, 1987). The Papaghni and Chitravati groups of rocks from the Cuddapah Super Group are present in the research region. The Papaghni group consists of the following formations: a) Gulcheru formation, which consists of quartzite, arkose, and conglomerate; and b) Vempalli formation, which consists of dolomites, chert, mudstone, quartzite, basic flows, and intrusive. The Chitravathi group consists of the following formations: (a) Pulivendula formation, which consists of quartzite with conglomerate; (b) Tadipatri formation, which consists of shales, dolomite, and quartzite; and (c) Gandikota formation, which consists of quartzite and shale (Basu, *et al.*, 2009).

Case study 2: Yavatmal District

The cotton-growing Yavatmal area ($19^{0}26'$ to $20^{0}42'$N latitude and $77^{0}18'$ to $79^{0}98'$E longitude, Fig. 2) covers 13582 square kilometres (4.41% of the state) and has a population of 20,77144 (2.63% of the state's population). Under the huge valleys and plains of the Wardha and Painganga rivers (Fig. 2), 43% of rural families are destitute. Yavatmal district is located in the Deccan Plateau, Hot Semi-Arid Eco-Region[6], as well as the Western Maharashtra plateau, Hot Moist Semi-Arid Eco-Subregion (6.3). Velayutham, *et al.*, (1999). The mean annual rainfall ranges from 1,125mm in eastern Wani to 889mm in western Darwha and 1099.5mm in central Yavatmal, with a westward trend.

SPI values were calculated for each week. Near-normal dry times account for 63% of the total, with normal wet periods accounting for 19.73%, severely wet periods accounting for 5.71%, moderately wet periods accounting for 4.72%, extremely wet periods accounting for 4.28%, and moderately dry weeks accounting for 2.41%. Prolonged dry spells during critical cotton growth stages (branching and blooming) sometimes coincide, resulting in yield loss. Maximum temperatures in this area reach 40^{0} Celsius in April and May, with a diminishing tendency from 36.5^{0} Celsius in June to 28.5^{0} Celsius in December, with fluctuations varying from 0.280 Celsius to 0.51^{0} Celsius over a 35-year period (1971 to 2005). From June to December, the climate in the area is ideal for cotton growing (Abira, 2015). The seasonality index based on rainfall pattern was determined to be more than one, indicating that the majority of the rain occurred in three months or less (July, August, and September) (Guhathakur and Saji, 2013).

The district has 34.4 percent of its cultivated area dedicated to food crops and 52.19 percent to fibre crops, with Jhari Jamini tehsil having the lowest percentage of food crops (23.35%) and Umarkhed tehsil having the largest percentage of fibre crops (31.22%). The land holding of 2-5 ha accounts for 40.12% of the overall district, while the holding of 5-10 ha accounts for 28.26%. The total area under cultivation is 8.84 lakh ha, with 9475 ha under double cropping and a cropping intensity of 101%. The low cropping intensity indicates that rainfed farming dominates the region, with only a limited region under double cropped. Yavatmal is mostly an agricultural district, with 85 percent of the population employed in agriculture. The economic performance of this district has always included some progress in the agriculture sector. Contrary to popular opinion, the district is less efficient in agriculture due to low soil fertility and basaltic plateau topography. Cotton growers in the region are committing suicide due to the increasing cost of Bt cotton production, which costs roughly rupee 7000 to 8000 for non-irrigated land and rupee 15,000 to 16,000 for irrigated land.

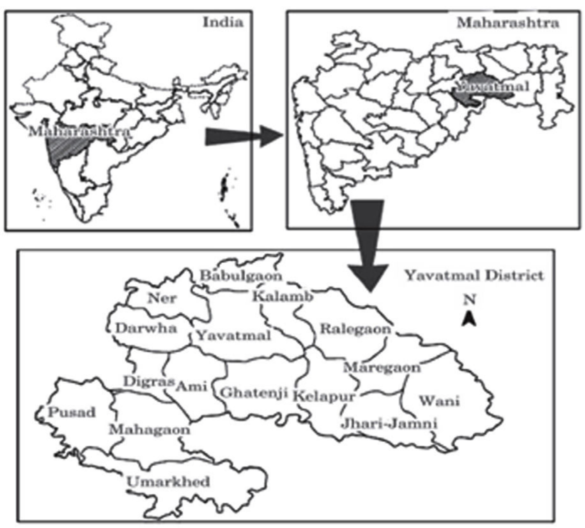

Fig. 2: Location map of Yavatmal district, Maharashtra

Case study 3: Majuli Island

The Majuli island (93^0 30' - 94^0 35' E and $26^0$50' - $27^0$10' N) is in the Jorhat district. The island's elevation varies between 60 and 85 metres above mean sea level. The island is bounded in the north by the Kherkutia Suti, in the south by the Subansirii, and in the north by the Brahmaputra (Fig. 3). The island is note worthy for its seventy bils (local names for bodies of water) that break up the monotony of flat geography. According to historical documents, the Brahmaputra River was located north of Majuli around the late 17^{th} century. There is no convincing evidence of the Brahmaputra's southerly movement. The migration was most likely induced by earthquakes and floods that occurred frequently between 1661 and 1696.

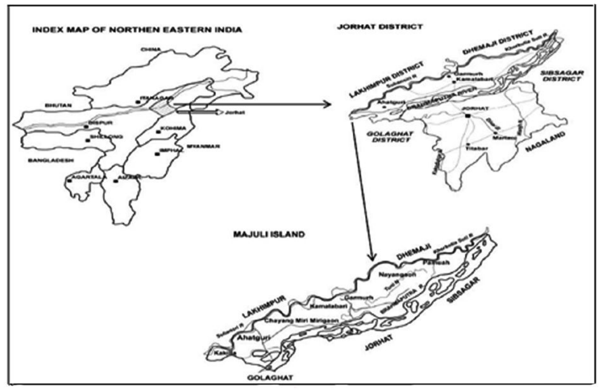

Fig. 3: Location map of Majuli island, Assam

(Bhuyan, 1968).

The island's climate is subtropical, with warm humid summers and chilly dry winters, and an annual rainfall of 1900mm. According to the Kopper system, this island has a humid mesothermal gangetic climate (Barthakur, 2004). From April through October, the island is largely impacted by southwest tropical monsoons, as well as infrequent winter showers. The monsoon season receives the highest rainfall (62-65% of the total for the year), followed by the pre-monsoon (20-23%), post-monsoon (6-8%), and winter (2-3%) seasons (Bhaskar, *et al.*, 2010). The average maximum temperature varies from 23.6^0 to 31.7 Celsius, while the minimum temperature ranges from 10.0^0 C to 24.2^0 Celsius. The average low temperature in December/January is roughly 10 degrees Celsius, while the peak temperature in July/August is 32^0 Celsius.

The island has a low cropping intensity (the ratio of total cultivated area to net sown area multiplied by 100, 102%), with an average rice output of 487kg/ha in the post-rainy season (November-February) and 1325 kg/ha in the rainy season (June-November), compared to the district average productivity of 1700 kg/ha. Rice is grown on moist soils during the rainy season and is known as the region's "bread basket." The conversion of wetlands to agricultural use has resulted in increased flooding frequency and intensity, substantial bankline erosion, disruption of water flow management, and loss of environmental quality. Agriculture on the island can only be developed if these wetland resources are examined for effective land use planning (Vadivelu, *et al.*,2005 and Bhaskar, *et al.*, 2010). A broad distribution of aquepts and fluvents with stratified textures, free carbonates, and substantial organic carbon in surface layers has been documented in the Brahmaputra valley (Dey and Sehgal, 1997 and Bhaskar, *et al.*, 2009). These low lands are critical for agricultural development, but little is known about how to use and enhance them sustainably.

Climate Analysis

The aridity index of De Martonne (1926).

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

$$I_{dm} = \text{Aridity Index (De Martonne)} = \frac{AAR}{(AAT+10)}$$

Where AAR = Annual average rainfall inmm., AAT = Average daily temperature over the year °C.

The monthly value of the De Martonne Aridity Index is calculated by the following equation: Im = 12p′/t′ + 10 where p′ and t are the monthly mean values of precipitation and air temperature for the driest month (considered January, February, March, April, May for Kadapa district). When the value of Idm is lower than 20 then the land in this month needs to be irrigated (Zambakas, 1992).

Classification of Climate Based on Aridity Index

Aridity Index	Climate Type
0-10	Arid
10-20	Semiarid
20-24	Mediterranean
24-28	Semi-Humid
28-35	Humid
35-55	Very Humid
>55	Extremely Humid

Seasonality Index

A seasonality index (SI) permits a quantification of the variability of precipitation through the year using a single Fig.. A commonly used SI is that derived by Walsh and Lawler (1981):

$$SI = \frac{1}{R}[Xn - R / 12]$$

R−where R is the total annual precipitation for the particular year understudy and Xn is the actual monthly precipitation for month n. The classlimits of seasonality index and representative rainfall regime is shown as below:

Seasonality of Rainfall Based on SI

Rainfall Regime	Seasonality Index(SI)
Very equable	0-0.19
Equable but with a better wet season	0.2 0to 0.39
Rather seasonal with a shorter dry period	0.40 to 0.59
Seasonal	0.60-0.79
Markedly seasonal with a longer dry period	0.80 to 0.99
Most rains are 3 months or less	1.0 to 1.19
Extreme, almost all rain in 1or 2 months	>1.20

Standardized Precipitation Index

The SPI is the number of standard deviations that the observed value would deviate from the long term mean for a normally distributed random variable. The mathematical equation used to compute SPI is given as under.

$$SPI = (x_i^c - \bar{x})/\sigma$$

Where SPI is standardized precipitation index, X is rainfall and σ is standard deviation of rainfall with a subscript "i" signifying location and superscript "c" for time scales (monthly or seasonal). The positive sum of the SPI for all the months within a drought event can be termed the drought's "magnitude" as 2.0+ extremely wet, 1.5-1.99 –very wet, 1.0-1.49 –moderately wet, -0.99 to +0.99 near normal, -1.0 - -1.49; moderately dry, -1.5 - -1.99 severely dry and > -2.0 extremely dry Droughtis indicated by SPI values of "1 or below (Edward and McKee, 1997).

Assessment of Geodiversity

The process for determining the degree of geodiversity is based on delimitation by geomorphological units and an inventory of the physical elements of each unit using the following:

- *Abiotic Element Analysis:* Geological, geomorphological, hydrological, and pedological features of the research region are investigated, and a complete geomorphological map is created.
- *Unit Formation:* Geomorphological units are the foundation for assessing geodiversity and are defined through geomorphological maps, aerial photography, and field work.
- Geodiversity is used to generate an index that ties the variety of physical elements to the roughness and surface of the units. T the following formula is used:

Eg R / lnS = Gd

Where Gd stands for Geodiversity Index, Eg = number of various physical elements (geological, geomorphologic, hydrological, and pedological) of the units; R = Roughness coefficient of the unit; S = Surface area of the unit (km^2).

"G" represents the geodiversity value, "N" represents the number of abiotic subcomponents in the area, "R" represents the rugosity coefficient, "ln" represents natural logarithm, and "S" represents the actual surface. It was multiplied by and "N" to determine the total number of natural elements present in the study area. The slope values were evaluated in degrees using the range supplied by Serrano, *et al.* (2009), and "R" was determined using the numerical equivalent between 1 and 1.4 proposed by Pellitero, *et al.* (2015). Among the slope classifications, the numerical value of the class extending over the largest region was picked (Kopar and Çakır, 2013). The natural logarithm of S was used to replace "S" in the formula's denominator (Serrano, *et al.*, 2009). Serrano (2007) divided the values acquired from the technique on the research region into five categories:

Geodiversity Class Using Geodiversity Index

Geodiversity value	Geodiversity class
0-15	Very low
15-25	Low
25-35	Medium
35-45	High
>45	Very high

Soil Survey and Land Evaluation

The geopedological technique (Zinck, 2013) was used for local physiographic study. This method was utilised to quickly cover bigger areas by creating a link between geomorphology and soils. The landform map was created using standard procedures (Soil Survey Division Staff, 2017), with fourteen landforms identified over basaltic, limestone, sandstone, shale, and granitic landscapes in Pulivendula tehsil using IRS-P6-LISS-IV data on a 1:25000 scale (Case study 1). IRS-LISSIV data Case study 2) was used to identify thirteen landforms in basaltic landscapes of Yavatmal district on a 1:50000 scale. The IRS-ID (Indian Remote Sensing Satellite) geocoded satellite images of the 18th of January, 2003 on 1:50000 scale were visually evaluated (Jensen, 1986) and designated seven geomorphic units in the Majuli island flood plains according to the classification of Nanson and Croke (1992). Soil profiles were morphometrically evaluated (Schoeneberger, *et al.*, 2012), and soils were classified to the subgroup level according to Soil Survey Staff (2014). The methodology for correlation of soil series in the field was carried out in accordance with the guidelines provided by Reddy, *et al.* (2006). The soil resource information system was created using a collection of GIS files and a relational database management system. ARCINFO was used to digitise topographical maps, which resulted in the spatial soil data. Each polygon's topology was set up, and all spatial data was projected with a polyconic projection.

Land Evaluation

Suitability of Crops

The land suitability for cultivating various crops, including groundnuts in Pulivendula tehsil, cotton in Yavatmal district, and rice on Majuli island, is being assessed in this study. The principles followed include the fact that the suitability of a land is examined and categorised with respect to specific types of use, and land suitability refers to usage on a sustainable basis. Appropriate tables were created, including a table of relevant physicochemical data and land qualities, as well as their diagnostic characteristics. The different types of land use have been characterised in terms of climatic and soil characteristics. Tables of factor rating supplying the land characteristics appropriateness ratings were also created, as well as the land qualities rated in all mapping units. To determine the mapping units' existing and projected applicability, a conversion table was created for the matching process to compare the rated factor rating and crop needs. The class of the land was the lowest suitability (S); for example, if the land had S1 and S2, the class was assigned S2. The ability to address current restrictions was used to determine potential appropriateness (Sys, *et al.*, 1991).

Suitability for Irrigation

The following stages were used in land evaluation for irrigation:

Step 1: A soil map and current land use/land cover map were created as inputs into GIS.

Step 2: Limiting symbol equations were employed to define the soil and salinity limitations of each series in the numerator and topographical and drainage constraints in the denominators.

Step 3: Create a capacity index for each soil series identified in the district using soil texture, depth, $CaCO_3$ content, salinity/alkalinity, drainage, and slope.

Step 4: Soil units were assigned a rating by multiplying the fraction of each soil type by the soil rating assigned to it. Non-irrigable elements of a complex should not be rated in addition to irrigable portions to establish the final soil category. The following parametric evaluation was proposed for irrigation and derived priority areassuitable for irrigated agriculture using Geomedia. The parametric evaluation technique Sys, *et al.*, 1991 & 1993) was used to assess the granulometrical and physicochemical properties of a soil profile. The many land features that determine the soil suitability for irrigation are graded, and an irrigation capability index (Ci) is calculated using the following formulae:

$$Ci = A * B/100\ C/100\ D/100\ E/100\ F/100$$

Where Ci is the irrigation capability index, A is the soil texture rating, B is the soil depth rating, C is the $CaCO^3$ status rating, D is the salinity/alkalinity rating, E is the drainage rating, and F is the slope rating. The capability classes are determined by the capability (or suitability) index value (Ci). The flow chart of methodology used in three case studies in three agroecological regions is depicted in Fig.

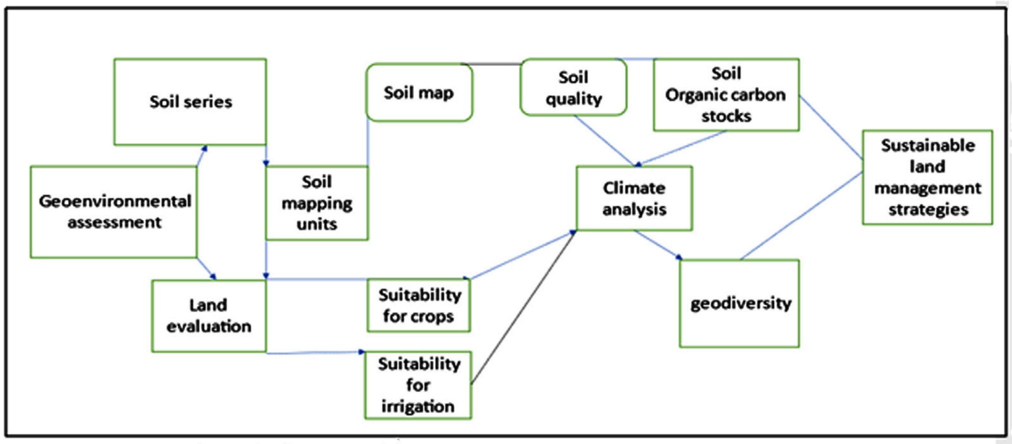

Fig. 4: Scheme of work flow in the study

4. Integrating geodiversity with soil map and suitability assessment.

RESULTS AND DISCUSSION

The methodology developed was based on evaluations of agro-ecosystems that provide environmental goods and services that directly or indirectly meet human needs (De Groot, *et al.*, 2002). The agro environmental framework was developed and tested in three unique agroecological zones representing different geologic formations, as follows:

Case 1: Pulivendula Tehsil, Kadapa District

The Geodiversity Analysis

The geodiversity evaluation was performed with abiotic components under consideration of subcomponents comprising 68. (Table 1). The surface area and rugosity coefficient of each geomorphic unit were computed to create the geodiversity index. The geodiversity of the entire Pulivendula is 31.38, indicating modest diversity, with a rugosity coefficient of 3.38. There are 10 abiotic subcomponents described under lithology, with geological structures of 16 and morphogenetic systems of 11. Surprisingly, the research area contains nine erosional features that indicate talus slopes, steep cliffs, and stripped valley floors. The region's principal depositional features include lava flows, deltas, alluvial terraces, stalactites, and Papagni River terraces. Fluvial and mass movement on hill slopes are the primary geomorphic processes. According to Soil Survey Staff (2014), the 11 soil subgroups in the area have been identified.

The geodiversity study is then applied to the 9 prominent landforms of Pulivendula tehsil (Table 2). The gently sloping middle sector represents 27.88% of the total area and it has 27 abiotic elements and a geodiversity value of 2.57, which classifies it as very low. The colluvial lower sector (from 8,200 to 240 metres above sea level) stands for 21.54 percent of the total area, with a geodiversity score of 14.04 (very low) and substantial erosional and landslip processes. With 56 elements and a diversity score of 28.23, highly dissected plateau remnants (3, 240 to 550m) occupy 16.18% of the area (medium). The elongated ridges[1] and dissected hill summits/remnants exhibit medium variety and cover 8.94% of the total area. The percentage of area covered by hills with medium geodiversity is 25.12, while other units cover 72.34. The proportion of area between medium diversity and low to very low geodiversity units is assessed to be 0.34, showing that middle and lower colluvial sectors have extremely low geodiversity but medium in hills.

Geoenvironmental Assessment

The Pulivendula tehsil contains four unique ecosystems: hills/ridges (54135 ha), interhill basins (6163ha), upland upper sectors (39092 ha), and colluvio-alluvial sectors (28542ha). Hills and ridges cover 32.8 percent of the land area, while undulating upper sectors used for groundnut-based cropping systems cover 36.82 percent. During drought periods, groundnut planted in shallow stony red soils of hills and ridges, as well as undulating upper sectors, suffers from severe water stress and suffers significant crop loss. The colluvial-alluvial sectors (22%) and interhill basins (4.68% of total area) are extensively used for banana and citrus cultivation. The results of mixed cropping sorghum/pigeon pea/groundnut/cotton/bengal gram are more economically enumerative as compare to low productive groundnut as sole (Bhaskar, *et al.*, 2019).The field images of agricultural landscapes at the study site made clear that hills are open and totally exposed to varying degrees of erosion. The hills have a largely rocky surface cover. Locals are not paying enough attention to conserving and protecting biodiversity in geological landscapes, as evidenced by the field images.

Nowadays, the upland areas in the western sections of the tehsil are intensively used for commercial banana cultivation using a drip technique, but they are ploughed for groundnut in red soils during kharif. Neglected areas of colluvio-alluvial sectors are severely infected with Prosopis and have surface salt encrustations as well as calcium carbonate concretions in the sub soils. Groundnut is the most common agricultural land use, while banana and rice are farmed under irrigation in interhall/colluvio-alluvial areas. The field evidence clearly supports the adoption of agro ecology concepts in the region in order to optimise nutrient cycling, crop productivity through time (Conway, 1985), and soil biological activity at the landscape level (Altieri, *et al.*, 2015). Technically, this region is characterised as "production syndrome," with such a defined set of management practises that are mutually less responsive and are not explained by the cumulative effects of individual methods (Andow and Hidaka, 1989). There are four predominant agricultural typologies in the rural territories of Pulivendula, based on geology, altitude, and soil characteristics, as follows:

- Rainfed arable fields in plains-hills with groundnuts and millets.
- Citrus-covered arable lands and plains-hills pastures (0-200 m.).

Table 1: Geodiversity potential of Pulivendula Tehsil

Abiotic subcomponents	Abiotic subcomponent elements	The number of elements
Lithology	Basalt, Vempalli formations, Pulivendula quartzite, shale, limestone, granite-gneiss	10
Geological structures	Sedimentary: parallel bedding, cross bedding, ripples, and mud cracks as well as synaeresis cracks, pits and mound structure, flute casts, groove and striation casts, liesegang rings (ring like structure: laminated ring-like structures)	16
	Faults: anticline, syncline, horst and graben, lineaments	
Morphogenetic systems	Structural: cuseta, hogback, structural ridge, structural plateaus, mesa and domes	11
	Fluvial: water channel with floodplains, alluvial plains, piedmont zones, valley fills and solution forms, klippe (solitary outcrop of the nappe in the middle of autochthonous material) and window structures	
Erosional formations	Gorges, sharp ridges, caves, alluvial stripped slopes, talus slopes, abrasion platforms, cliffs, rock debris, surface stone cover	9
Depositional landformations	Lava flows, delta, alluvial terraces, stalactite, river terraces	5
Current processes	Fluvial mass movements	2
Geological age	Precambrian, archean	2
Hydrographic component	Rivers, streams/streamlets	2
Soil taxonomy	Soil subgroups (Typic Paleustalfs, Typic Rhodustalfs, Calcic Haplustalfs, Lithic Haplustalfs, Typic Haplustalfs, Lithic Haplustepts, Vertic Haplustepts, Typic Haplustepts, Lithic Ustorthent, Typic Ustorthent, Sodic Haplustert)	11
	Total components	68
	Surface area (ha)	127463
	Rugosity coefficient	1.1
	Geodiversity index	6.36
	Geodiversity class	Very high

Table 2: Geodiversity with respect to landforms

Landforms	Elements	Surface area (km2)	Roughness	lnS	Geodiversity Index	Geodiversity Class
Elongated ridges (750-350 m MSL)	63	8442.90 (6.62)	4	9.04	27.87	Medium
Dissected Hills/Summits (550 – 260 m above MS	45	2962.15 (2.32)	4.5	7.99	25.33	Medium
Highly dissected plateau remnants (550 -240 m above MSL	56	20263.65 (16.18)	5	9.91	28.23	Medium
Isolated hills/mounds (430-260 m above MSL)	43	8756.61 (6.87)	3.5	9.07	21.31	Low
Inter-hill basins (360-320 m above MSL)	36	5815.34 (4.56)	2	8.66	14.53	Very low
Undulating Upper sectors (360-300 m above MSL)	34	10205.83 (8.01)	1	9.25	7.36	Very low
Gently sloping middle sectors (300-240 m above MSL)	27	35535.58 (27.88)	3.5	10.47	2.57	Very low
Colluvial lower-sectors (240-200 m above MSL)	41	27457.78 (21.54)	3	10.22	14.04	Very low
Narrow valley floors (220-180 m above MSL)	26	4440.84 (3.48)	4.5	10.70	7.28	Very low
Rock outcrops	45	3222.27 (2.53)	4	8.07	25.06	Medium
Total (area in ha/%)		1,27,462.9 (100)				

- Mixed arable lands under banana in hills (201-600m. a.s.l.).
- Mined barren hills (more than 600s.l. and above.

Soil Mapping

After field correlation, twenty-five soil series were discovered, and 43 mapping units were designed as series association. Among the 43 soil mapping units, eight are associated with hills/ ridges with rock out crops and shale rock type. These area's are sandy loam to clay loam soils, extremely shallow, some what excessively drained, and mildly alkaline. Fig. 3 shows that the eight soil mapping units cover 54812 hectares (42.62% of the total area).

The undulating uplands covers 39092 ha (30.4% of the total) and are separated into 12 soil mapping units. The Vemula soils (20-1,667 hectares, 1.2%) are calcareous and strongly alkaline, with a clay surface texture and gravelly clay subsoil. Velpula soils (21-1,326 ha, 1.0%), Parnapalle in Lingala mandal (22-446 ha, 0.3%), and Velpula-Vemula association in Tondur mandal (28-712 ha, 0.5%) are the most common mapping units. This mapping unit is associated with deep, generally well-drained, calcareous, strongly to moderately alka line black soils with high shrink swell potentials. Colluvic and alluvial plains soils cover 28542 ha (22.19% of total land area), with series associations of Tondur-Pernapadu,[30] Pernapadu-Gondipalle,[33] Goturu-Gondipalle[36] and Agadur-Pernapadu[36,41]

Estimation of Soil Erosion

Annual soil loss was calculated by combining rainfall erosivity, soil erodibility, topographic, cover management, and also other characteristics used in USLE. The study area contains six types of soil erosional mapping units. The soil erosion risk zones are listed in ascending order based on area estimates as follows: (39142 ha, 31.16%) > high (276696 ha, 22.05%) > medium (23378 ha, 18.6%) > extremely high (16364 ha, 13.03%) > low-medium (12025 ha, 9.57%) > very high (7007 ha, 5.58%). When data is structured by landform, three soil erosion risk zones are identified in hills and ridges. The high-medium soil loss zone covers 32308 ha (25.13% of total land), followed by 15417 ha in the high erosion risk zone (11.98%), and 7087 ha (5.51%) in the extremely high erosion risk zone. Due to the high LS factor and slope gradient of more than 30%, the mean soil loss in hills and ridges is 34.97±34.75 t/ha/year. The inter hill basin includes 20 soil mapping units covering 35.19% of the total area (45255 ha), with soil loss of 115 t/ ha/year. The average soil loss is 10.96 t/ha/year, with a deviation of 23.82 t/ha/year, indicating a severe erosion risk.[7] Of the 20 SMUs are classified as medium erosion risk zones, with an average soil loss of 3.25± 0.55 t/ha/year.

The projected area under medium class is 22497 hectares (17.5% of total area). Six SMUs in the high-medium class encompass 6843ha (5.3%) of the total land area, with a mean soil loss of 12.87±12.87 t/ha/year. This class has a total soil loss of 45.07 t/ha/year. Only three SMUs are classified as having low-medium erosion risk zones, with a total soil loss of 4.51 t/ha/year over an area of 8817ha (6.86% of total area). The average soil loss is 1.503±0.27 t/ha/year, with a variance of 18.26%. SMU Balapanur is rated as having a very high erosion risk zone encompassing 6559 ha (5.1%), whereas Santhakovur is classified as having a high-risk zone covering 548 ha (0.43%). This landscape unit is commonly used for groundnut banana based cropping systems in places where crop management and soil erodibility factors determine the differential rates of erosional status. The fifteen SMUs in colluvial-alluvial pediplains occupy 28542 ha (22.19%), with a total soil loss of 48.7 t/ha/year and a mean soil loss of 32.45 ± 37.39 t/ha/year. The five SMUs at high erosion risk encompass 11731 ha (9.12%), with a total oil loss of 84.64t/ha/yr and a mean of 16.92±1.66t/ha/yr. The four SMUs in colluvial-alluvial pediplains are characterised as extremely eroded areas and cover 9986 ha (7.76%) with a total soil loss of 364 t/ha/yr and a mean of 91.02 ± 8.23 t/ha/yr.

The percent area under low-medium erosion is 1.66 (2134ha), and the percent area under high medium erosion is 853ha (0.66%) in Pernapadu-Gondipalle[33] unit. The various soil components in the different landscape units may explain the differences in the results. In the study area, as expected, high erosion rate was recorded in the steeper slope area that spans from 30 to 83% and the steeper slope land use of agricultural fields. Soil conservation practises in highly degraded areas are prioritised. Sustainable land management options must be prioritised in light of topographical characteristics, land use cover status, and community interests. Agroforestry, terracing, and a cut-and-carry system can be used to manage erosion in the steep slopes of the Palakonda range of Pulivendula.

Soil Quality Assessment

The SQIs for each soil mapping unit in Pulivendula tehsil are divided into three categories: high (% Q rating > 65), medium (% Q rating 35 to 65), and low (35% Q rating). The hills and ridges have 8 units with medium SQI ratings. The soil units are associated with shallow soils and rock out crops. Twenty-two soil units in the inter hill basin are categorised as medium to high quality. The soils in this landform show a strong positive connection of pH with exchangeable Ca due to calcareousness. In colluvio-alluvial sectors, 15 units are assessed as medium soil quality, with soil pH, Zn, and Olsen's P below threshold levels, while the rest units are classed as having good soil quality.

Suitability for Banana

The suitability of 43 soil mapping units for banana are evaluated using Sys *et al.* (1993). The SMUs from 1 to 8 on hills and ridges (54812ha, 42.62% of total area) are not suited for banana cultivation but respond well to inputs and conservation measures. The twenty soil mapping units in the interhill basin cover 45255 ha (35.19% of the total area). Only 8 SMUs (namely,12,18,21,23,24,25,26,28) are moderately suitable but require careful management of organic carbon. This unit occupies 14.13 percent of the land in the inter hill basin (18174 ha), although 7 SMUs (22688 ha, 17.65% of the area), namely11,13,14,17,19,20,27, are marginally suitable due to subsoil calcium carbonate, poor organic carbon, strong alkalinity, coarse fragments, and low available K and DTPA-Zn. Soil mapping units (SMU 29 to 43) in colluvio-alluvial plains (28542 ha, 22.19%) feature very deep, moderately well drained, calcareous and strongly to moderately alkaline black soils with significant shrink-swell potential. Only five SMUs 32,38,40, 41,43 are slightly suitable for banana production (Fig. 3). The findings of land evaluation for drip irrigation suggest that 13 units are moderately suitable for banana. Nine SMUs (34502 hectares) are highly suited, whereas eight SMUs (13882ha) are moderately suitable.

Case Study 2. Yavatmal District, Maharashtra

Geodiversity Analysis

Sheth (2005) describes the main elements of Indian and Deccan geology. The contact of the Deccan lavas with the pre-volcanic basement is not exposed over a considerable area of the province. Along the province's southern and south-eastern edge, the Deccan lavas cover a complex Archaean and Proterozoic basement. The Vindhyan sedimentary basin (mid-late Proterozoic), the Gondwana sedimentary basin (Carboniferous to Jurassic early Cretaceous), late Cretaceous Bagh and Lameta deposits, and Archaean and early Proterozoic crystalline rocks overlie varied geological formations in the province's northern and north-eastern sections, i.e., Central India (granites, gneisses and metasediments).

The region's basaltic landscapes feature 68 abiotic components, including 16 geological formations and 10 lithological elements. There are 11 morphological structures in all, including structural and fluvial features. This region includes 11 soil subgroups classified in the orders of entisols, inceptisols, and vertisols. The 9 erosional formations and 5 depositional formations are dominating with mass movement and river activities. The geodiversity in the region is assessed as high, with an index score of 63.6. (Table 3).

The topography varies from modestly sloping to high rocky hills and offers panoramic views from a variety of positions. The rocky outcrops, which appear on the ridge lines of hills and in patches throughout the slopes, are a distinguishing feature of this region. Narrow, twisting roads follow the contours of the hills and skulk through forested area. The land form analysis shows that this district has dominant rocks of Deccan Traps (basalt) with thirteen identifiable land units such as hills and ridges, Isolated hills/elongated hills, mesa, butte, intervening valley, upper plateau, escarpments, upper pediplain, middle plateaus, lower plateaus, lower pediplains, gently to moderately sloping alluvial plains, very gently to gently sloping plains, flood plains, gullied and stony gravelly waste.

Thirteen landforms were recognized and the area beneath each landform in Wani valley's basaltic and sedimentary strata was estimated. Hills and ridges cover 170970 ha (12.6% of total area), plateaus (upper, middle, and lower) cover 398240 ha (29.34%), isolated hills, mesas, buttes, and escarpments cover 240854 ha (17.74%), pediplains (upper and lower) cover 390330ha (28.76%), and plains cover 109352 ha (8.05%). The land form map shows that plains are largely concentrated in Pus and Penganga valleys in the southwestern portions of the district, and in Wani valley in the eastern Yavatmal plateaus, whereas plateaus, hills, and ridges are mostly found in the northern and central parts of the Yavatmal and Darwha areas,

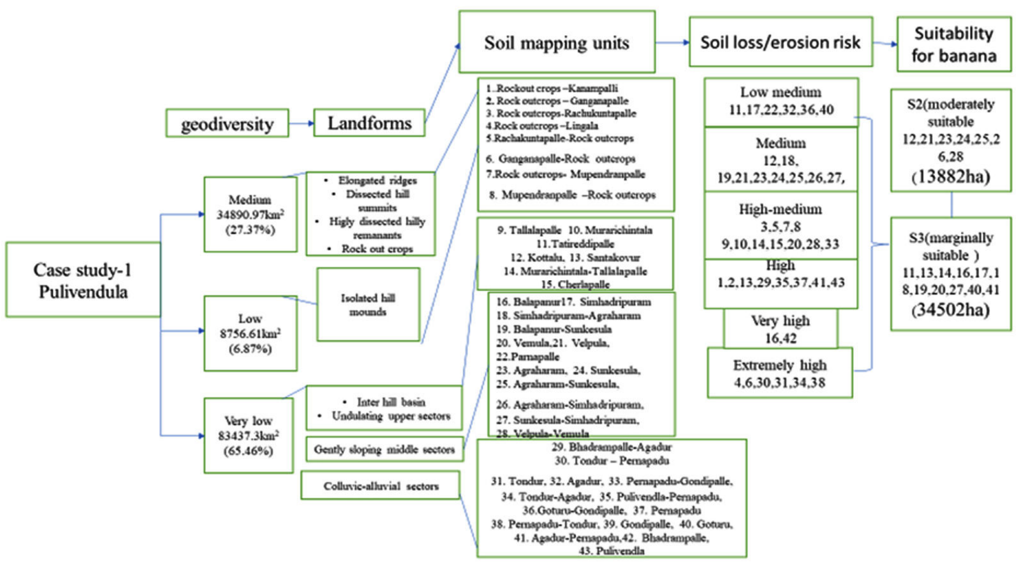

Fig. 3: The schematic diagram of geodiversity linked to soil units and their evaluation for banana under drip irrigation

and solitary hills, mesas, buttes, and escarpments in combination with plateaus are found in the central and southwestern parts. Yavatmal has 13 landforms outlined on a 1:50000 scale.

Hills and edges over 500 m mean sea level include 46 elements covering 1709.70 km2 with a roughness coefficient of 5 resulting in a geodiversity value of 30.9 to classify as medium. Upper, middle, and lower plateaus have roughness ranging from 4.0 to 4.5 and medium geodiversity. These units are mostly medium in terms of geodiversity. Low geodiversity (15 to 25) is found in isolated hills, buttes, and mesas, as well as deep escarpments, lower pediplains, and rocky gullied landforms of basaltic terrain. Upper pediplains with erosional formations and slightly to very gently sloping fields with mire depositional formations have relatively little geodiversity (Table 4).

The land in between the rocky outcrops is largely pastoral, with sheep, goats, and user requested grazing. Rural homes and farms are few and far between. NRSC obtained thirty-two satellite images of P6G3 geocoded products on a 1:50000 scale for the Yavatmal district between

April 11 and May 10, 2006. The April-May images are useful for defining croplands under irrigated agriculture due to the tonal contrast of bright red to red, which may indicate the greenness of foliage at different stages of crop growth phenological condition (healthy or infected). In black cotton, the fallow lands resemble greenish blue to dark grey (Deccan – trap areas). Fallow lands appear small and non-contiguous in irrigated lands. They look huge in size, contiguous, and with a restricted piece of crop land in un-irrigated or dry (farming) areas. Regular gaps in crop field indicate the presence of fallow lands. Because of surface irregularities and a lack of vegetation cover, the texture is medium to coarse. The stony waste lands range in size with uneven and discontinuous shapes very coarse to coarse to medium texture, linear to contiguous and dispersed in pattern (subject to varied rock type). It appears as steep hill slope crests, solitary hillocks, plateaus, and eroded plains in conjunction with barren and exposed rock/stony/waste. These are broadly classified into three types: I forest lands, (ii) cultivated areas, and (iii) barren rocky and coal mining fields. The overall projected forest area is 249088.3ha (18.8% of total area). Forest covers 8.8% of the land area, 2.0% is moderately dense, and 7.9% is degraded grazing and forest. The total cultivated area is 930961.8 ha (70.3% of total area). The district has 7.8% double cropped area and 13.6% triple cropped area. The estimated area under cultivated undulating uplands with 20 3% stone cover and moderate erosion covers 15.17% of total area (183283 ha), whereas triple cropped area (30% of area) in gently sloping plains covers

Table 3: Geodiversity in Yavatmal district, Maharashtra

Abiotic subcomponents	Abiotic subcomponent elements	The number of elements
Lithology	Basalt, Vempalli formations, Pulivendula quartzite, shale, limestone, granite-gneiss,	10
Geological structures	Sedimentary: parallel bedding, cross bedding, ripples, and mud cracks as well as synaeresis cracks, pits and mound structure, flute casts, groove and striation casts, liesegang rings (ring like structure: laminated ring-like structures)	16
	Faults: anticline, syncline, horst and graben, lineaments	
Morphogenetic systems	Structural: cuseta, hogback, structural ridge, structural plateaus, mesa and domes	11
	Fluvial: water channel with floodplains, alluvial plains, piedmont zones, valley fills and solution forms, klippe (solitary outcrop of the nappe in the middle of autochthonous material) and window structures	
Erosional formations	Gorges, sharp ridges, caves, alluvial stripped slopes, talus slopes, abrasion platforms, cliffs, rock debris, surface stone cover	9
Depositional landformations	Lava flows, delta, alluvial terraces, stalactite, river terraces	5
Current processes	Fluvial mass movements	2
Geological age	Precambrian, archean	2
Hydrographic component	Rivers, streams/streamlets	2
Soil taxonomy	Soil subgroups (Typic Paleustalfs, Typic Rhodustalfs, Calcic Haplustalfs, Lithic Haplustalfs, Typic Haplustalfs, Lithic Haplustepts, Vertic Haplustepts, Typic Haplustepts, Lithic Ustorthent, Typic Ustorthent, Sodic Haplustert)	11
	Total components	68
	Surface area (ha)	127463
	Rugosity coefficient	1.1
	Geodiversity index	6.36
	Geodiversity class	Very high

Table 4: Geodiversity with respect to landforms

Landforms	Elements	Surface area (km2)	roughness	lnS	Geodiversity index	Geodiversity class
Hills and ridges with 2nd order streams at elevation above 500m	46.00	1709.70	5.00	7.44	30.90	Medium
Upper plateaus highly dissected above 500m	43.00	647.13	4.00	6.47	26.57	Medium

table Cont..

Middle plateaus at 350 to 500m, intensively used for cultivation	48.00	2412.18	4.50	7.79	27.73	Medium
Lower plateaus	45.00	974.72	4.00	6.88	26.15	Medium
Isolated hills	32.00	856.96	3.80	6.75	18.01	Low
Butte and mesas	39.00	856.96	2.60	6.75	15.01	Low
Escarpments	32.00	627.17	4.00	6.44	19.87	Low
Upper pediplains	43.00	1755.99	2.40	7.47	13.81	Very low
Lower pediplains	37.00	2147.30	3.40	7.67	16.40	Low
Gently to moderately sloping	27.00	458.28	2.90	6.13	12.78	Very low
Very gently to gently sloping alluvial plains	24.00	156.60	2.70	5.05	12.82	Very low
Intervening valleys	33.00	478.65	2.00	6.17	10.70	Very low
Stonygullied wastelands	36.00	472.54	2.80	6.16	16.37	Low
Total		13554.18		9.51		

13.62%, moderately eroded upper pediplains cover 8.3%, moderately eroded hill tops cover 7.3%, and plateau tops cover 5.4% of total area in the district. The barren rocky/coal mine/salt affected area accounts for 10.9% of total area (144948.9ha). The projected area is 5.4% salt affected areas, 3.3% coal surrounds, 1.7% stony wastelands, and 0.3% scrub lands in Wani valley's limestone ar.

Soils and their Morphology

The shrink-swell soils generated from Deccan trap basalt in Yavatmal district for cotton production have severe fertility limitations (Bhaskar, *et al.*, 2014). The basaltic landform accounts for 80% of the total geographical area, with the remaining occupied by sand stone/limestone/shale covered coal seams in the Wani valley's eastern reaches. Shrinks well soil series were detected, with morphological features ranging from dark grey to brown matrix with shallow Lakhi series to extremely shallow Gahuli on hills and ridges to moderately deep Katherwadi series and deep Kalamb series on central plateaus (Fig. 4). The slightly to very softly sloping alluvial plains are characterised by deep Arunavati with calcium carbonate enriched B layers and extremely deep Chanoda, Loni, Pandhurna, and Wani soil series with mildly alkaline clayey slicken sided zones. Except for the Nagdhari series, the intervening valleys feature Dhanki, Sindola, Wanodi, and Nagdhari soils with greyish brown to dark greyish brown/light yellowish brown matrix, moderately to severely alkaline, and slicken sides in subsurface strata. Hirdi, Apti series, Chikhalgaon, Penganga, and Ralegaon series are moderately to strongly alkaline, clay textured, and have slickensides to a depth of one metre, whereas Chanoda, Kharbhi, Saykheda, Wanoda, Wani, and Dhanki series have considerable slickensides to a depth of less than 150cm.

Soil Map

The soil map was constructed using 48 soil series associations as mapping units and 1037 polygons. The soil map shows that the soil mapping unit (SMU) - 3 (Lk-Roc-Mo) with 309 polygons covers 13.4% of the total area. This mapping unit covered sections of Yavatmal and the Darwha plateau in the north and northwestern regions (Fig. 4). The Wani valley, located in the eastern part of Yavatmal, has soil mapping units ranging from 39 to 48, with moderate delineations and an area of less than 1% under each delineation (Fig. 4). SMUs cover more than 5% of the total area in three units: Lakhi - roc - Moho (3, 12.3%) on the middle plateaus, Dhanki - Lakhi - Dhanora - Pandhurna (11, 5.01%) on isolated hills, and Lakhi - Borgaon - Arni - Dhanki (17, 7.28%) in the highlands. The increased number of dry days has had a significant impact on current land use patterns, which would almost probably necessitate irrigation to realise the site's full output potential. Changes toward warmer and drier circumstances, in general, have the potential to enhance salinity on predisposing (Várallyay, 1994) inadequately watered soils. It was found that if suitable soil management practises are not used on these geo landscapes, the decrease in organic matter content of agricultural soils and the prevailing drier conditions slow down the decomposition rate and change the direction of pedogenesis.

Cotton Suitability Assessment

The significance of climate for cotton based systems in Maharashtra is thoroughly investigated, and it is reported that rainfall of 250 to 325mm from squaring to peak flowering stage is critical

(Mandal, *et al.*, 2005). As a result, the environment of Yavatmal for cotton is moderately appropriate, with short dry intervals during the crucial stages of cotton from September to October. This region experiences 12 to 20 normal dry weeks followed by 3 to 8 weeks of rainy weeks, according to 35 years of daily rainfall data using the standard precipitation index (Bhaskar, *et al.*, 2011). Cotton, the primary kharif crop, accounts for 52% of total cultivated area and necessitates 2 to 10 irrigations after cessation, with a consumptive requirement of 650 to 1000 mm (Bonde and Shanmugam, 1990).

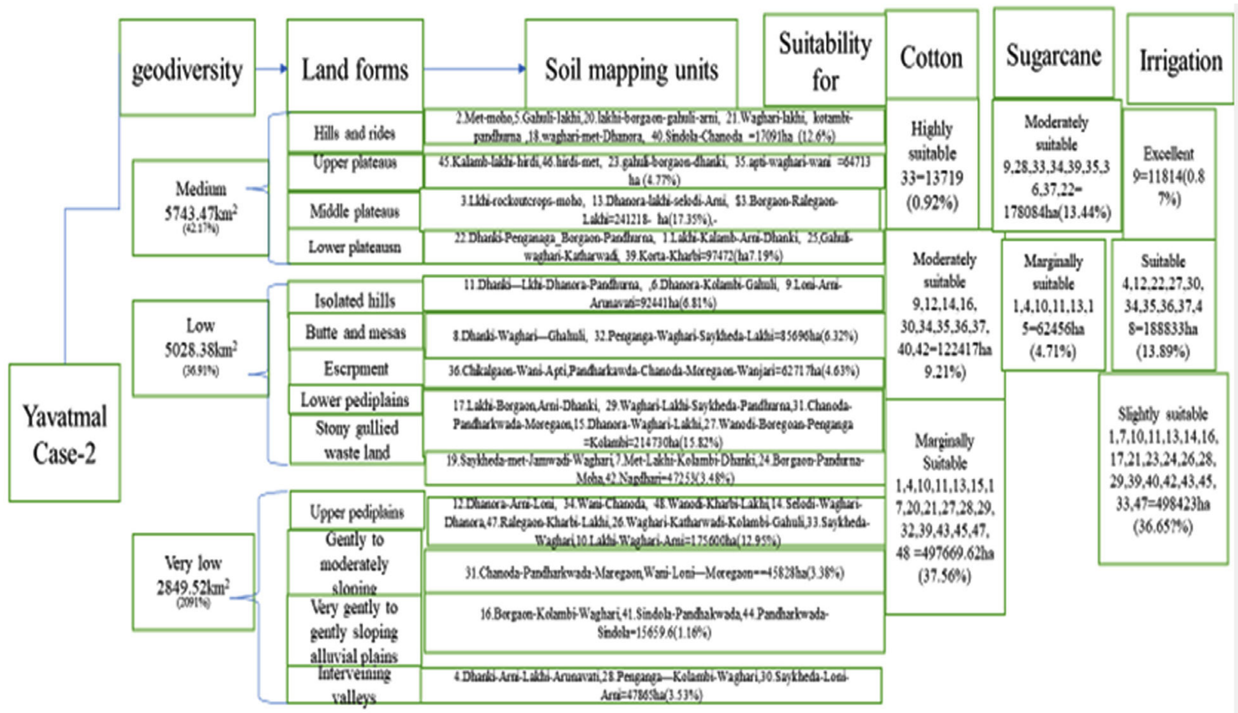

Fig. 4: The schematic diagram of linking geodiversity with land evaluation in Yavatmal district, Maharashtra

If rainfall is minimal and spread is poor, light watering from germination to the four leaf stage may be used. Cotton is susceptible to dryness from germination to the four leaf stage. This exercise is useful for identifying sensitive areas for crop sparing irrigation during short dry spells, as well as for cultivating rabi wheat in canal irrigated areas of the Pus, Arunavati, and Penganga valley regions.

Case study 3: Majuli Island

Majuli is an alluvial flood plain of the river Brahmaputra, and its current landform is the result of geomorphic processes such as fluvial movements of the Brahmaputra, Subansiri, Desang, Dikhow, and Dihang rivers acting in tandem with tectonic disturbances on the higher reaches of these rivers. Studies on the regimes of these rivers, as well as the material features of the current landform, show that the landform of the island is related with the time sequence of transfer and depositional process of sediments of the Brahmaputra and its tributaries, particularly the Subansiri river. The material feature implies that the landform is purely depositional in origin and is prone to substantial erosion owing to river action. The fluvial sediments brought by the Brahmaputra itself include part of the plains of Assam and Bangladesh through which the Brahmaputra flows. However, in some areas of Assam, the Indian basement is visible. The

Table 5: Geodiversity potential of Majuli

Abioticcomponents	Abiotic subcomponent elements	The number of elements
lithology	Alluvium	1
Geological structures	-	0
Morphogenetic systems	Fluvial: Sand bars, channel diversions and anabranching	4
Erosion formations	Bankline erosion,	1
Depositional formations	Oxbowls, channel fills, active floodplains, old flood plains, bils	5
Current processes	fluvial	1

Geologic age	Paleocene-Eocene age	2
Hydrographic component	Rivers, streams/stream lets,	2
Soil orders	Soil subgroups	6
	Total components	22
	Surface area (km2)	1100.85 (lnS=7.00)
	Rugosity coefficient	1.0
	Geodiversity index value	3.14
	Geodiversity class	Very low

Brahmaputra's flood plain is made up of alluvial features such as natural levees, pointbars, ox-bow lakes, and channel bars (Goswami, 1998). Abiotic subcomponent in the island are 22 with very low geodiversity (geodiversity of 3.14, Table 5). The abiotic subcomponents are mostly depositional formations with 6 dominant soil subgroups of aquepts and aqents. The six geomorphic units have 20 subunits in old floodplains but 12 for swamps with very low geodiversity (Table 5).

Land Forms

Landforms The IRS-ID (Indian Remote Sensing Satellite) geocoded satellite imageries of 18th January, 2003 were visually interpreted (Jensen, 1986) and delineated seven geomorphic units in the flood plains of Majuli island as per the classification of Nanson and Croke (1992). The pinkish with red tones (mustard fields during winter season) in the middle of the island indicated the flat to gently sloping active flood plains whereas light blue with whitish tinge tones, fine texture and associated with dark blue tones of water bodies indicated old alluvial plains. The tall grass lands of natural levees occurring along the river course have dark red tones with regular linear feature of fine texture whereas flat featureless channel fills in low lying areas have light bluish with white tones with laminar ripples with textural differences. The most conspicuous feature is unvegetated sand bars in the meandering reaches of island have white tones whereas tall grass lands have bright red tones. The lowlying water bodies in swamps have dark blue tones whereas abandoned channels have whitish blue tones.

Soil Characteristics

The detailed morphological, physical and chemical descriptions of thirteen soil series belonging to the order Entisols and Inceptisols were reported (Bhaskar, *et al.*, 2008). Brief description of hydric soils in fluvial landforms of Majuli Riverine Island are discussed as follows. The Kamalabari (Kb), Puranibari (Pb), Dakshinpat (Dh) and Bhakat (Bt) soil series are dominant on active flood plains covering 16.3% of the total area. These soils have Ap-AC-C horizon sequence, dark grey (10YR4/1) A horizons, clay loam to silt loam textures with moderate, medium subangular blocky structures. The AC horizons are dark grey (10YR4/1) and loamy but changed to loamy sand textures in C horizons. These soils are classified as Humaqueptic Fluvaquents (Kamalabari series, Kb), Humic Endoaquepts (Dakshinpat, Dh), Typic Fluvaquents (Bhakat, Bt) and Fluvaquentic Endoaquepts (Puranibari, Pb). Majuli (Mj, Typic Fluvaquents) and Garumara (Ga, Typic Endoaquepts) on sand bars (43.2% of total area) have olive grey to dark grey A horizons, coarse loamy texture and slightly alkaline pH. The Bharaki (Bi, Fluvaquentic Endoaquepts) and Bongaon (Bn, Typic Fluvaquents) soils in swamps have dark grey and silt loam textured with weak subangular blocky structures. The cambic B horizons have dark grey matrix with silt loam to silty clay loam textures and moderate angular blocky structures with neutral to slightly alkaline pH. Adielengi (Ae) and Chilkala (Ch) are dominant soil series in old flood plains with grey matrix, silty loam to silty clay textures and dark grey B horizons followed by sandy C horizons. These soils are classified as Typic Endoaquepts. The Gayangaon (Gy, Typic Endoaquepts) and Boritika (Ba, Fluvaquentic Endoaquepts) soils in channel fills have olive grey (5Y5/2), silty clay loam Ap horizons and dark grey (5Y3/1) or dark greyish brown (2.5Y4/2) silt loam textured and yellowish brown mottled B horizons. The Sonaribari soil series (Sb, Typic Endoaquepts) on natural levees have interbedding coarse to fine sediments of sand, silt and silty clay with olive grey matrix (Fig. 5). All soils are neutral to slightly alkaline except Kamalbari soil (P1) on active flood plains with moderately acid to neutral pH. The organic carbon varies from 9.7 g/kg (P2) to 19.5 g/kg (P3) in Ap horizons but decreased to 0.6 g/kg in C horizons of all soils (Table 3). Among exchangeable bases, calcium is dominant with values of 2.4 cmol/kg (Garumara, Ga)to 10 cmol/kg (Sonaribari, Sb). These soils have exchangeable Mg of 1.2 cmol/kg (Adielengi, Ae) to 5.2 cmol/kg (Bongaon, Bn), sodium of 0.31 to 0.8 cmol/kg and K of 0.08 to 0.5 cmol/kg. These soils have low cation exchange capacity (3.5 cmol/kg in C horizons of P2 to 20 cmol/kg in 2Bw2 (P4) with variable depth distribution. These soils have high to medium available nitrogen, low to medium available phosphorus and medium to high potassium contents. These soils are in general deficient in DTPA extractable zinc and manganese contents. The soil data set in Majuli island (1:50000 scale) was obtained from soil resource inventory on 1:50000 scale using Indian Remote Sensing (IRS-ID) satellite imagery and corresponding toposheets of Survey of India with the emphasis on transects that cut across the segments of inland valleys from the top to the bottom (Bhaskar, *et al.*, 2008).

Capability and Quality of Soils

The nine soil indicators selected on the basis of Cameron, *et al.* (1998) present soil quality ratings for each soil mapping unit. The mean computed threshold values for nine soil indicators is as follows: - 50 for organic carbon, 53 for total nitrogen, 57 for structure, 59 for pH and available phosphorus, 67 for available water holding capacity, exchangeable bases and cation exchange capacity and 71 for texture. The low values are assigned to sensitivity to degradation (S), influence of properties on plant and animal health (I) and relationship to ecosystem processes (R). The soil unit wise indicators showing below threshold values in quality assessments are listedas: The texture in 9 units, organic carbon in 15 units, total nitrogen in 11 mapping units, available phosphorus, pH, exchangeable bases and cation exchange capacity in 12 mapping units and structure and available water holding capacity in 13 units (Fig. 5). Six mapping units 1, 2, 3, 5, 6 and 7 have low quality rating (<35%) with 1 to 3 soil indicators meeting the threshold requirements for crop production whereas eleven mapping units 4, 8, 10, 12, 13, 15, 16, 19, 20, and 21 have 4 to 5 indicators meeting threshold values of medium quality (35 to 65%) and eight mapping units 9, 11, 14, 18, 22, 23, 24 and 25 with 6 to 8 indicators meeting high quality ratings above 65%.

The arable soil mapping units (from class II to class IV) were grouped further in accordance with landforms and soil quality. The fourteen soil mapping unitsin class II (17306 ha, 15.72%), are further grouped as per quality rating into three categories such as low (2 units in active flood plains), medium (11 units) and high (1 unit). The Puranibari - Sonaribari soil mapping unit (18) has high quality of selected indicators above the threshold values except total nitrogen content whereas medium quality soils are seasonally flooded with shallow ground water tables through out year and neutral to slightly alkaline with low Potassium reserves. The low quality rating isdue to pH and total nitrogen (Bharaki – Chilkala - Adielengi, 3) and (Dakshinpat -Bhakat and Bharaki, 7).

The class III has 13 soil units covering 16.9 per cent of area but have only 1.11 percent (1217 ha) under high quality, 7.19 per cent (7903 ha) under medium quality and2.35 per cent (2583 ha) under low quality. The class IV has 14 units covering 8.22 percent of area (9046 ha), of which 3.88 per cent of area is under high quality soilassociations followed by 1.39 percent of area (1541 ha) under medium quality and 2.93 percent of area (3229 ha) under low quality. The soil quality and its relationship with capability classes implies that pH and organic matter are crucial in modifying soil structure and its influence in water retention and nutrient availability. The soil quality assessment in riverine islands with flat to gentle slopes is helpful to identify the areas subjected to ferrolysis (Brinkman, 1970) and compare units under differentrice management systems of special interest such as Bao and Boro/Ahu seasonal systems (Fig. 5). The soils in the island are saturated for more than 200 days per year with matrixchroma less than 2 and moderate structural B horizons. The fine loamy soils have mean clay content of 18 to 27 percent in Puranibari (Pb), Dakshinpat (Dh) but in other soils, the clay content is less than 16 per cent. It is ascertained from the literature that clay textures are superior to silt and sand textures for rice production (Moormann and Dudal, 1964). These soils are slightly acid to neutral with stratified layers and soft nodules of Fe and Mn oxides near the zone of fluctuating water tables (Vespraskas, 2000). These soils are subjected to ferrolysis due to repeated regular cycles of oxidation and reduction leading to silicate clay destruction with abrupt textural changes and leaching of exchangeable bases resulting to poor cation exchange capacity. The modifier "g*" is used as a special modifier to designate prolonged water logging and gleying in these soils with an additional modifier "e" for nitrogen management and "k" for nutrient imbalance such as Ca, K and Mg. All soils are deficient in available potassium where as 9.2% of soils are basic mostly occurring on channel fills with Fe deficiency when aerobic, Zn deficiency when water logged and high volatile N losses from broadcast N application. 35.3 percent of soils have low cation exchange capacity, less gradual N release and potential Fe toxicity if adjacent uplands have Fe rich soils. The flooded rice grown on these soils have high iron favouring deficiencies of phosphorus, potassium (Akagare type-1) and Zn deficiency (Tanaka and Yoshida, 1970). The soil mapping units in active and old flood plains have potassium deficiency (Bhaskar *et al.*, 2010b) as the ratio between exchangeable calcium and magnesium to exchangeable potassium is more than 100 (Tandon and Sekhon, 1988) and also have K saturation less than 1.5 per cent (Dobermann and Fairhurst, 2000).

CONCLUSIONS

The geodiversity in Pulivendula is medium but have medium geodiversity in elongated hills and ridges, dissected hills and plateau remanants. The results from suitability analysis of banana under drip irrigation show that 56091 ha of land in interhill basins and colluvio-alluvial deposits are evaluated as suitable (S2 and S3) for banana as against the current area of 22000ha. Further the study shows that 34502 ha of land is evaluated as highly suitable for drip irrigation system. We suggested land conservation directives such as construction of bench terraces with rocks and planted with vetiver grass on the edges of the terrace. It is strongly advocated in semi-arid regions to have long-term historic rainfall statistics to provide unique rainfall scenarios to express the agricultural and soil erosion risk associated with climate variability. The index of geodiversity is high in Yavatmal district and hot spot' of geodiversity where there are many different types of rocks viz., basalt associated sandstone, shale, dolomite and grantic cappings in the eastern edge, soils of subgroups of entisols, inceptisols and vertisols. The hills and plateaus are having medium geodiversity whereas lower pediplains, gently to very gently sloping areas in river valleys are with very low geodiversity and suitable for cotton based cropping systems.

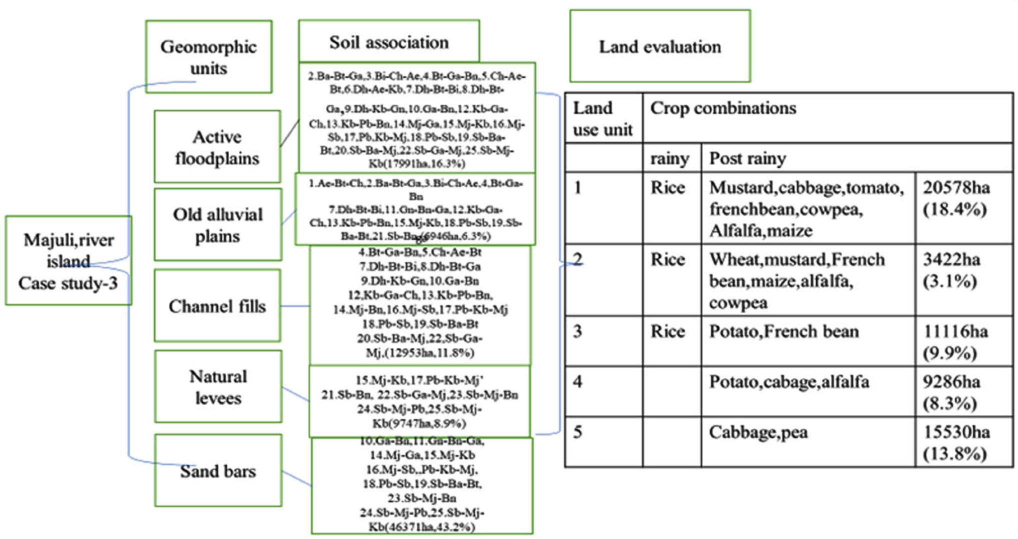

Fig. 5: Schematic diagram of pedoecological links with land evaluation

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