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Application of WOA and AHP for identification of soil and land potential zones towards sustainable watershed management

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Abstract

Declining agriculture lands and their productivity are the alarming indicators of pressure with which these natural resources are fulfilling requirements of all the stakeholders of ecosystem mainly of formidably increasing human population under antagonizing effects of climate change. To restrict and minimize this wide gap of demand and supply, individual and collective potentials of soil and land have to be explored to address their limitations with specific remedial measures land parcels were segregated into different potential zones in accordance with their favorable and limiting factors in Raipally sub watershed belonging to Krishna river catchment. To achieve this land resources inventory (LRI) of the study area (6621 ha) was conducted on a base map of 1:7920. Weightage values of properties like soil depth, texture, slope, erosion status, EC, OC, available N, P₂O₅, K₂O, S, Ca, Mg, Zn, Fe, Cu, Mn, B derived by applying AHP to determine the weights of these multiple and heterogeneous criteria indicating relative importance. Different thematic layers identified in the study with their respective weightages were further integrated with each other in ArcGIS 10.6.1 tool as per weighted overlay technique using the spatial analyst tool. Finally by applying WOA, the land parcels of the study area identified with High (1454ha), Medium (3242 ha), Low (1654 ha), and Very low (270 ha) groups of Soil and Land Potential (SLP) zones out of total study area and mapped using GIS. Such studies can be made as integral part of decision support system in recommendation of soil and water conservation measures, crop suitability, and nutrient management at parcel level of a micro watershed for sustainable enhancement of land productivity.

Keywords: Land resource inventory (LRI), GIS, analytic hierarchic process (AHP), weighted overlay analysis (WOA), soil and land potential (SLP) zones, productivity

1. Background

The soil, where food begins, as part of the ecosystem, the services rendered in the life cycle of many creatures and hosting several natural phenomena are very critical in making life possible on planet Earth. Soil has multifaceted role in supporting plant growth, regulating water flow, cycling nutrients, and hosting a vast array of biodiversity which confirms soil as one of the bases of our terrestrial ecosystems. Perspective on soil services as critical role in functioning of biogeochemical in many different direct and indirect ways including climate control, water quantity and quality, nutrient cycling and being the habitat of an overwhelming biodiversity has increasingly moved beyond its permissive range when man is intervening to explore for his own needs. The global demand for agricultural products is expected to grow at 1.1 per cent per year from 2005/2007-2050 (Lichtfouse et al., 2009) from projected a population of 9.15 billion in 2050 as per United Nations. Rapidly eroding resources are making the task of food production more daunting. At the same time due to natural and manmade activities the potential of land and its use is changing at an alarmingly pace. Across the world, in different geographies availability of productive soil and land for cultivation of most essential food crop cultivation itself is becoming scarce. Challenges like climate change, land use change and mammoth demand from ever-growing world population making scenario from hard to harsh. Mounting pressure to produce more food and shelter on shrinking soil and land resources,

accelerating the rate of depletion in productive capability of soil, as most of the time lands are put under different use without giving due importance to their potential and limitations. The simultaneous increase in population and irregular urban spread has increased the pressure on the utilization of agricultural resources and that may leave the land in lack of nutrition (Elaalem *et al.*, 2011; Hovhannisyan and Devadoss, 2020; Jonah and May, 2020). Under such circumstances, need of the hour is to assess present status of soil and land with respect to their qualitative and quantitative parameters so that demand for soil services can be strengthened to make it balanced and sustainable, in long and preserve it for coming generations.

In this endeavour, strategies should be devised for increasing productivity based on suitable interventions as per specific potentials and limitations of land parcels. The land potentials and issues of its limitations are directly related to status of soil availability with a given set of physical, chemical and biological properties to support crop growth. An intervening approach with appropriate measures like suitable soil and water conservation methods, adoption of crops based on soil and land properties and nutrient management practices can bring major positive change in productive potential of land. As performance of any given crop will be at its optimum only when they are under suitable weather, soil and land conditions. Capability of soil and land resources to support or hinder the growth and development of a crop under congenial weather conditions will be decided by their individual and collective influence of physical, chemical and biological properties of soil (Parikh *et al.*, 2012). Research findings indicate that any land cannot be considered as suitable for any crop, as requirement and preference of a crop for different soil and land features differs from one another. Land suitability is the fitness of a given type of land for a defined use (FAO, 1976)^[1]. Each character of the soil and land will be having both favourable and unfavourable influence on growth and development of a crop. The critical soil functions influencing productivity within any soil are those that provide physical support, a rooting medium, available water, aeration, and essential nutrients (Karlen, 2011). Indicators like soil depth (effective rooting depth), texture, water holding capacity, bulk density, soil organic carbon, CEC and status of erosion are vital information in evaluation of soil and land for their productive and sustainable management. Limitations and potentials of the land, sets the base line for land use planning (Bandyopadhyay *et al.*, 2009).

Land Resources Inventory (LRI) which includes detailed soil & land survey and their characterization for assessment of limiting and potential factors is decisive in planning to ensure suitable land use and sustainable management for growth and development of crop plants. Land utility for crop production based on site specific data on soil fertility, land character, water availability and crop management at mapping unit level will be the key factor in enhancing crop productivity (AbdelRahman *et al.*, 2016)^[2]. Integration of sitespecific information on the status of each factor of soil and land generated through LRI on micro watershed (MWS) or sub watershed (SWS) basis on large scale base map guides different stake holders including farmer in understanding the abilities and potentials of his land. Apart from that a robust scientific and sustainable decision support system generated at a micro and sub watershed level on the basis of LRI data sets will assist in detailed project planning in micro watershed or sub watershed. Strategies, approaches and practices applied for implementing the sustainable land

management programs have to be problem and area specific. The mechanism to assess the effectiveness of practices, policies and strategies followed in the implementation should be included in the follow up actions (Ghosh *et al.*, 2018). A system of land use and its management plan as per potential of soil and land with high accuracy with suitable crop plan becomes very essential in deciding site specific interventions to ensure most sustainable and economic results. Crops will be forced to restrict their abilities to utilize available and favourable factors of production if soil and land are not suitable. Therefore, to strengthen the decision support system of sustainable enhancement of productivity, site specific crop suitability can be made as an important and integral part of it. Intensive data on inherent properties of site-specific nature, influence on each other's potential and capabilities plays vital role in evaluating land suitability for different crops there by becomes critical inputs in making strategies of increasing productivity and making agriculture suitable for sustainable development of (ElBaroudy 2016; Falasca *et al.*, 2012 and Pramanik, 2016).

Efforts have been made by various researchers around the world, in identifying potential zones with due importance to the characters of soil and land through multicriteria analysis at different scales. In particular, relative importance of individual properties of soil and land with their most limiting and favourable influence in terms of ratings over crop growth and development have been established by several scientific studies (O'geen, 2008)^[3]. By exploring basic and applied research findings to find out Soil and Land Potential Index (SLPI), present investigation was carried out in Raipalli SWS which comprise of ten micro watersheds covering an area of 6622 ha, situated in between 17° 36' 00" to 17° 40' 0" N latitude to 77° 22' 0" to 77° 28' 00" E longitude of Humanabad taluk, Bidar district, Karnataka state. Outcomes of LRI datasets were processed through Analytical Hierarchy Process (AHP) for individual and set of characters of soil and land (Mapping unit) to identify the weightage (%) for potential rating of the different soil and land properties to assess the influence of these properties in deciding the potential of a given land parcel towards achieving higher accuracy in establishing soil and land potential zones using Weighted overlay analysis (Feizizadeh and Blaschke, 2013). The outcome was compared with the crop suitability categories (S1 to N) generated based on land resource inventory. Further, delineation of soil and land potential zones was done with the help of spatial analyst tool like weighted overlay analysis, integrated with multi-criteria analysis on GIS platform (Ennaji *et al.*, 2018). The study also focused on identifying the most influential property of a land parcel in deciding the crop suitability along with mapping their spatial distribution.

Such site specific data base can be a part of decision support system for bringing out the site specific recommendations for each parcel or individual survey number of the farmer at MWS or SWS scale. The analysis not only guides in identifying important limiting factors for cultivation of a crop and enables decision makers to develop a crop management system for increasing the land productivity (Mueller *et al.*, 2010) but the study also focused on identifying the most influential property of a land parcel in deciding the crop suitability along with mapping their spatial distribution. The outcome of such study can be made as an integral part of decision support system (DSS) for prioritization of the area in the MWS for planning and implementation of development activities by institutions at macro level and by individual farmer at farm level.

2.2 Land Resource Inventory (LRI)

As a per field activity to interpret physiography, landscape, geology, land use, land cover, drainage pattern, slope, and its aspect, segregation of slope into different slope classes done on a contour map of 2.0 meters with the support of visual interpretation of satellite image was done considering distinguishable variations in spectral signature, shape, size, pattern and texture in reconnaissance mode. Surface land features like soil texture, extent of erosion, slope, aspect and amount of gravel/rock fragments cover on the surface were studied at a grid interval of 320 m.

Surface soil samples (650) were collected from different grid locations for further lab analysis. Soil profiles were opened at 78 representative locations in different transects spread across the Raipally sub watershed (SWS) and horizon wise soil properties in the profile were recorded. (Soil Survey Staff, 1993) [4].

2.3 Data Used

2.3.1 Base maps spatial data used:

Table:

Sensor	Scale/Resolution (m)	Swath Width(km)	Spectral Bands(μ m)
SOI(Toposheet)	1:100001:50,000	-	-
LISS-VI	5.8 m	24-50km	0.5-0.59(Green)
			0.62-0.68 (Red)
			0.77-0.86 (near IR)
Cartosat 1	2.5m	Pan-F 30 km	0.5-0.85(Panchromatic)
		Pan-A 25 km	
Geology map	1:50,000		
DEM	2m		

Raipalli Sub-watershed delineated on a revenue map which depicted major drainage line, village boundaries, survey number of land parcels at 1:7920 scale was used as base map for survey. The interpretation of spatial data (merged image of

Cartosat-II and LISS-IV) was confirmed during LRI of the study area. Toposheet from survey of India and Geology map at the scale of 1:10,000 were also used to study geology, landforms and drainage pattern.

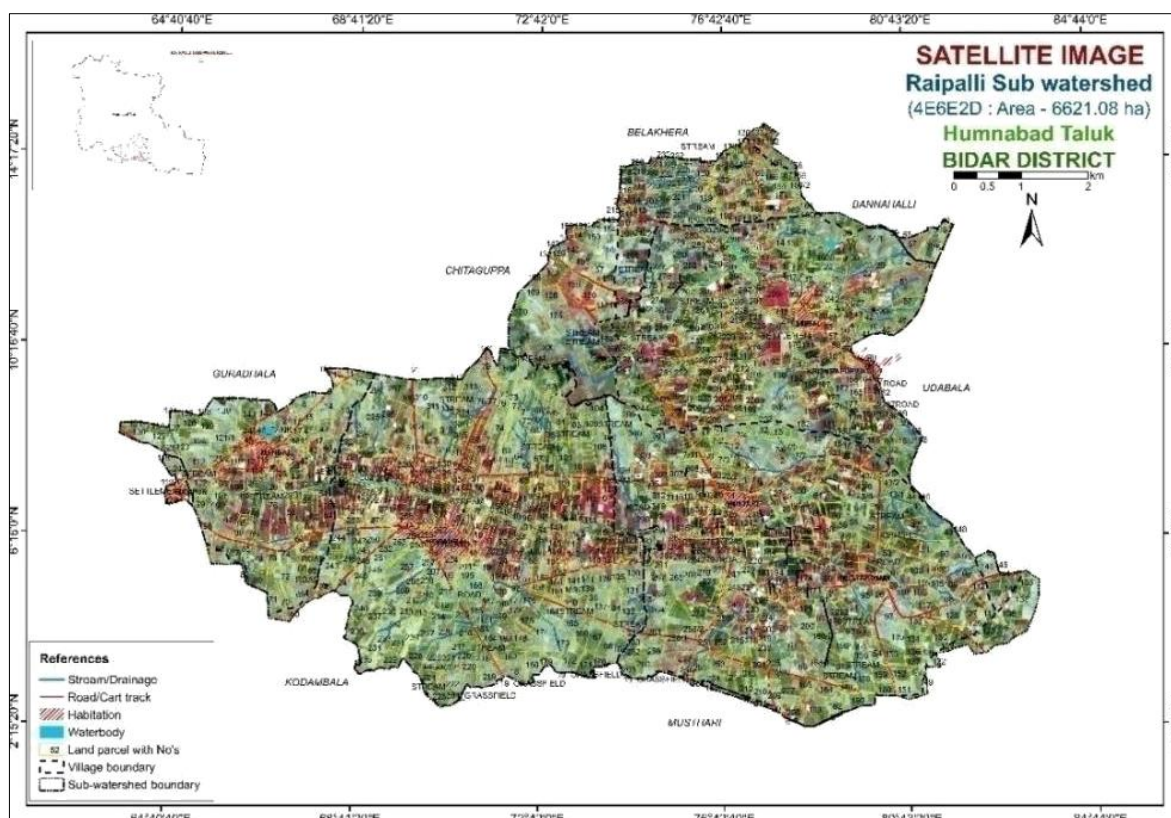


Fig 3: Satellite image of Raipalli sub-watershed

2.3.2 Establishment of Soil Series and Mapping Units

In the selected transect, profile sites were located by considering the land scape, physiography, slope, soil color and other surface features which indicates the change in the soil and land

characters. In the selected sites, profile (vertical cut showing the soil layers from the surface to bed rock or till weathered parent material) were opened up to 200 cm or to the depth limited by rock or hard substratum and studied in detail for all their

morphological and physical characteristics which distinguish different horizons. Horizon wise soil samples were collected and analyzed for various chemical and physical properties by following standard procedures. The soil and site characteristics were recorded for all profile sites on a standard Proforma as per the guidelines given in USDA Soil Survey Manual. Apart from the transect study, profiles were studied at randomly selected spots in the transect of similar soil and land characters in the SWS. Based on the soil-site characteristics, the soils were grouped into different soil series. Soil depth, texture, color, amount and nature of gravel cover, nature of substratum and horizon sequence were the major identifying characteristics of soil series occurring in the area. Characterization of soils of the study area was done with the help of data obtained from lab analysis of sur

samples with respect to their chemical and physical properties apart from surface features. Brief description of soil series identified in the study area is furnished in Table No.1. Soil

mapping units were identified based on the interpretation of data in the MWS. The mapping units based on their potentials and limiting characters were grouped into different management units on the basis of similarity of requirements in management practices as mentioned in Table no. 2. During the intensive field survey, polygons of mapping units were marked on the tracing sheet overlaid on base map of 1:7920 scale. The data obtained from lab on physical and chemical properties of surface and profile soil samples, were used to develop various thematic layers like Soil texture, Soil depth, Slope, Soil erosion, Organic Carbon and Soil map using ArcGIS 10.6.1 software. The thematic layers for all these contributing parameters were superimposed by weighted overlay method (rank and weight wise thematic maps and integrated with one another). Two categories of soil and land potential zones were identified to generate the final map of soil and land potential zone as high and low soil and land potential zones.

Table 2: General description of soil series identified and mapping units

Soil series & Pedon number	Brief description			
	Physiography	Classification and identifying characters	Soil Mapping units (SMU)	Area (ha) & %
Bhadrapur (BDP) P1	Upland	Classification: Loamy-skeletal, mixed, isohyperthermic, Lithic Ustorthents type. Physiographic position: Nearly level uplands. Geology: Laterite. Depth of the soil: 0-25 cm (Very shallow). Soil colour: dark reddish brown. Soil texture: sandy clay loam to Clay	BDPhB2g1, BDPhB3g2, BDPhC2, BDPiA1, BDPiA2, BDPiB1, BDPiB2, BDPiB2g1, BDPiB3, BDPiB3g1, BDPiB3g2, BDPmA1	600.19 ha 9.06 %
Kodambal (KDM) P2	Upland	Classification: Clayey, mixed, isohyperthermic (Paralithic) Haplustals. Physiographic position: Nearly level upland (side slope). Geology: Laterite. Depth of the soil: 25 to 50 cm (shallow). Soil colour: Dark red to dark reddish brown. Soil texture: Sandy clay to clay	KDMcB3, KDMhA1, KDMhA1g1, KDMhB2, KDMhB2g2, KDMhB3g1, KDMhB3g2, KDMhC3, KDMhD2, KDMiA1, KDMiA2, KDMiB1, KDMiB2, KDMiB2g1, KDMiB3, KDMiB3g1, KDMmA1, KDMmB1, KDMmB2	1465.40 ha 22.14 %
Musthari (MST) P3	Upland	Classification: Very fine, Kailinitic, isohyperthermic, Kanhaplic Haplustals. Physiographic position: Nearly level upland (side slope). Geology: Laterite. Depth of the soil: 50-75 cm (moderately shallow). Soil colour: dark red to dark reddish brown. Soil texture: sandy clay to clay	MSThA1, MSThA1g1, MSThA2g1, MSThB1, MSThB2, MSThB2g1, MSThB2g2, MSTiA1, MSTiA2, MSTiB1, MSTiB2, MSTiB2g1, MSTiB2g2, MSTiC3, MSTmA1, MSTmB2	871.45 ha 13.02 %
Ainapur (ANR) P4	Midland	Classification: Clayey-skeletal, Kaolinitic, isohyperthermic,	ANRhA1, ANRhA2, ANRhB1, ANRhB2g1, ANRhB2g2, ANRiA, ANRiB, ANRiB2, ANRmA1	515.12 ha

		KanhaplicHaplustalfsPhysiographic position: Upland to mid-uplandGeology: LateriteDepth of the soil: : 75-100 cm (moderately deep)Soil colour: Dark reddish brown to red, clayey soilsSoil texture: Gravelly sandy clay to clay		8.00 %
Mustarwadi (MWD) P5	Midland	Classification: Very fine, Kailinitic, isohyperthermic, KanhaplicHaplustalfs typePhysiographic position: Midland to mid-upland on Nearly level to leveled sloping class.Geology: LateriteDepth of the soil: >150 CM (Very deep)Soil colour: dark reddish brownSoil texture: clay to sandy clay loam	MWDhB1, MWDhB2, MWDhB3, MWDhC2g1, MWDhD3g2, MWDiA1 MWDiB1, MWDiB2, MWDiB3g1, MWDiC2, MWDiD2, MWDmA1, MWDmB1, MWDmB2	865.70 ha 13.10 %
Mudhnal (MNL) P6	Lowland	Classification: Loamy-skeletal, Kailinitic, isohyperthermic, KanhaplicHaplustalfs typePhysiographic position: Nearly leveled LowlandsGeology : LateriteDepth of the soil: 75-100 cm (Deep)Soil colour: dark reddish brownSoil texture: sandy clay to sandy clay loam	MNLhA1, MNLhA1g1, MNLhB1, MNLhB2g1, MNLhC2g2, MNLhC3g2MNLiA1, MNLiB2, MNLiB2g1, MNLiC2, MNLiC3, MNLiC3g1, MNLmA1, MNLmB1, MNLmB2	531.11 ha 8.02 %
Raipalli (RPL) P7	Lowland	Classification: Very fine, smectitic, isohyperthermic, TypicHaplustertsPhysiographic position: Nearly leveled LowlandsDepth:>150 cm (very deep).Soil colour: very dark greyish brown to very dark grey.Soil texture: Clay.	RPLhA1, RPLhB3g2, RPLiA1, RPLiA1g1, RPLiB1, RPLiB2, RPLiB2g1, RPLiC2, RPLmA1, RPLmA2, RPLmB1, RPLmB2	1505.06 ha 22.50 %
Others				237.70 ha (3.60 %)
Total				6619.40 ha (100 %)
Abbreviations of mapping units	h=Sandy clay loam, i=Sandy clay, m =Clay, A=Nearly level (0-1%), B= Very gently sloping (1-3%), C=Gently sloping (3-5%), D=Moderately sloping (5-10%), 1=Slight erosion, 2=Moderate erosion, 3= Severe erosion, g1=Non gravelly (<15%), g2= Gravelly (15-35%), g3= Very gravelly (35-60%)			

2.3.3 Finalization of soil maps

The area under each series was further divided into phases and their boundaries delineated on the cadastral map based on the variations observed in the texture of the surface soil, slope, erosion, presence of gravels, stoniness, etc. A phase is a sub division of a soil series based mostly on surface features that affect its use and management. The delineated mapping units are shown on the map in the form of symbols. During the survey

about 19 transects representing different landforms occurring in the watershed were identified and about 71 profiles were opened for detailed soil and site characterization. All the profile locations are indicated on the sub watershed map.

The soil map of the sub watershed shows the distribution of 130 mapping units occurring in the sub watershed (Fig. 7). The map unit description is provided in the accompanying Table 2. The series map shows the occurrence of soil series identified and

mapped in the watershed. The phase map, which shows the sub division of the series into management units based on surface texture, slope, erosion, gravels, rock out crops etc, shows the distribution of 130 phases mapped in the sub watershed. Each phase or mapping unit delineated on the map has similar soil

and site characteristics. In other words, all the farms or survey numbers included in one phase will have similar management needs and they have to be treated accordingly. The detailed description of each phase mapped in the sub watershed and their area of occurrence is provided in maps (Appendix 2 and 3).

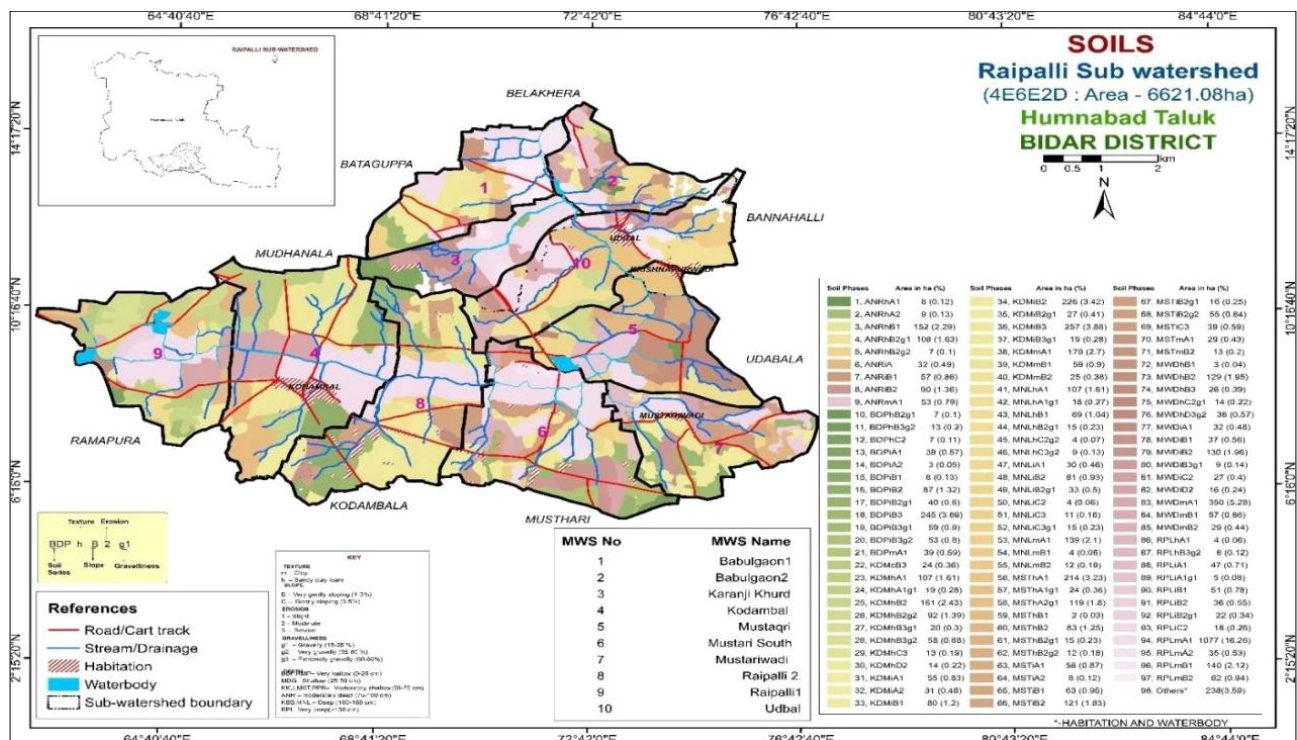


Fig 4: Map showing different soil mapping units in Raipalli Sub-watershed

2.3.4 Generation of thematic maps

Finalized maps were digitized and processed through ArcGIS 10.7. Further the corresponding conceptual data collected during survey as well the soil analytical data were attached to these polygons using soil phase map unit as unique IDs. Then, the colour coded symbological maps were generated for soil depth, soil phase, land morphological characteristics and suitability maps were generated. Discrete soil physico-chemical properties were interpolated using Kriging with lowest nugget values (exponential model) was generated and these outputs raster data were converted to vector polygons to make soil fertility classifications with legends. The final maps layout was carried out in ArcGIS 10.7.

2.3.5 Deriving the weights using analytic hierarchy process (AHP)

The relative importance values were determined following Storie index (Storie, 1978 and O'geen, 2008) [3] where a saaty's scale score of 1 to 9 of the respective importance were obtained. A pair wise comparison matrix is derived using Storie methods 9 point importance scale based on thematic and fertility layers used for soil and land suitability. The AHP captures the idea of uncertainty in judgments through the principal Eigen value and the consistency index (CI) (Saaty's, 2008) [5]. Consistency Index (CI) as deviation or degree of consistency was derived using the following equation:

$$CI = \frac{(\lambda_{max} - n)}{(n - 1)}$$

Where λ_{max} is the largest Eigen value of the pair-wise comparison matrix and n is the number of classes. Consistency Ratio (CR) is a measure of consistency of pair wise comparison matrix and is given by equation.

$$CR = \frac{CI}{RI}$$

Where RI is the ratio Index (Saaty, 2008 and Alonso and Lamata, 2006) [5]. The value of RI for different n values is given in Table .3 and 4

When CR value is less than 0.10, the matrix indicates a reasonable consistency. The calculated results of weight would be accepted when the consistency ratio was satisfactory (Saaty's, 2008 and Imoro et al., 2012) [5]

2.3.6 Weighted overlay analysis

Based on the degree of role played by the different soil and land characters in deciding the productivity, they have been rated from 1 to 9 through storie rating index (O'geen, 2008) [3]. Thematic layers of different surface and sub-surface characters with their respective ratings were analyzed through AHP (Agarwal et al., 2013) [6] method to get their weightages. The analytical hierarchy process is a multi-attribute land evaluation technique which allows to determine the weights of these multiple and heterogeneous criteria indicating relative importance (Zhang et al., 2015) [7]. Different thematic layers identified in the study with their respective weightages were further integrated with each other in ArcGIS 10.6.1 tool as per weighted overlay technique using the spatial analyst tool.

Soil and Land Potential zones

$$\begin{aligned}
 &= 9.49(SD)_{i=1-6} + 5.18(ST)_{j=1-4} \\
 &+ 9.37(SL)_{K=1-4} + 5.49(SE)l \\
 &= 1 - 3 + 7.40(pH)_{m=1-4} \\
 &+ 2.47(EC)_{n=1} + 11.16(OC)_{o=1-5} \\
 &+ 4.32(N)_{p=1-2} + 6.23(P_2O_5)_{q=1-3} \\
 &+ 6.23(K_2O)_{r=1-3} + 4.32(S)_{s=1-2} \\
 &+ 4.32(Ca)_{T=1-2} + 4.32(Mg)_{u=1-2} \\
 &+ 4.32(Zn)_{v=1-2} + 6.78(Fe)_{w=1-2} \\
 &+ 4.32(Cu)_{x=1-2} \\
 &+ 4.32(Mn)y = 1 - 2 + 4.32(B)_{z=1-2}
 \end{aligned}$$

Through weighted overlay analysis, potential zones of different mapping units as High, Medium, Low, Very Low were obtained.

2.3.7 Deriving Storie soil and Land Potential Index (SLPI)

The Storie Land Productivity Index (SLPI) was estimated for the different mapping units of the study area using the model produced by Storie (1978) as:

$$\begin{aligned}
 SLPI(\%) &= (Factor A/10) \times (Factor B/10) \\
 &\times (Factor C/10) \times (Factor X/10) \\
 &\times 100
 \end{aligned}$$

Where, SLPI is the Storie Land Potential Index, A is the soil Depth, B is the surface texture, C is the slope/gradient, and X is the dynamic properties like drainage, soil chemical properties, physical properties, fertility level, erosion etc. Each factor is rated on a scale from 0 to 10, the actual percentages being multiplied by each other. Storie Index ratings were previously a score between the numbers 0 to 100 (Mulengera and Payton, 1999)^[8].

3. Result and Discussion

Rational utilization of finite natural soil resources needs science based approaches for conservation of precious soil resources for sustainable production of food in long run. To achieve sustainability and ecological harmony, soil resources have to be given top most priority. There is a need to understand nature and properties of soil and land for framing effective management practices for their utilization and conservation. The development of different characters of soil and land is decided by the factors like geology, climate, physiography, land use and management practices of a given location. Influence of these factors creates different potentials and limitations to the soil for its utilization for crop cultivation. To realize the capabilities and lacunae of different soils there is a need to study in depth regarding different physical, chemical, fertility characters of soils for scientific characterization and classification for subsequent evaluation of their potentials. The information on soil and land potential (SLPI) generated can be used for planning for soil and water conservation, crop planning and nutrient management strategies. In this background an investigation was conceived to identify different soil and land potential zones in Raipalli sub-water shed coming under Humnabad Taluk of Bidar District in Karnataka state, India through processing of selected physical, chemical and fertility properties of soil and land AHP and WOA on GIS platform. The

results obtained have been presented and discussed under different heads as mentioned below.

- Assessment of Soil chemical and fertility properties of Raipalli sub watershed.
- Potentials weightage values of soil and land characters
- Soil and land potential index values for different mapping units in Raipalli sub – watershed.
- Distribution of Soil and land potential zones in Raipalli Sub-watershed.

3.1 Assessment of surface/subsurface features.

Surface and subsurface features of the study area were assessed by considering four major criteria namely soil texture, slope, status of erosion hazards and most importantly the depth of soil. Among four textural classes belonging to moderately coarse to fine textural groups (Soil Survey staff, 1996) (Natarajan A and Deepak Sarkar, 2009) reference as per Field guide Sujala-II identified, maximum area of 2303 ha (34.78 %) soils were found with clay texture. When we refer three physiographic positions existing in the study area namely upland, mid land and low land, these fine clay soil are typically found in low lands due to the fact that processes of illuviation where rain and runoff water detaches the finer fraction of soil from upland and mid lands and deposits in the low land under the guidance of slope resulting in formation of alluvial soil (Schulp and Verburg, 2009) ^[9]. Whereas large area of 4058 ha (61.28%) was belonging to sandy clay loam and sandy clay soil texture. This status of soil texture may be mainly due to influence of parent material as soils of the study area are derived from laterite. Secondly as these soils are found on upland and midland physiographic position where finer particles of soil tends to detached and displaced at the lowlands (Akamigbo and Asadu,1982) ^[10], (Areola and Faniran, A. 1978) ^[11].

Land parcels of the study area were found distributed on five different slope classes such as Nearly leveled (0 -1%), Very gently sloping (1-3%), Moderately sloping (5-10%), Gently sloping (3-5%) and Moderately sloping (5-10%) (Soil Survey Staff, 1993) ^[14]. In particular an area of 3289 ha (49.67%) identified with Very gently sloping and 2866 ha (43.29%) with Nearly level were major slope classes among all the classes identified. As these land parcels found located at low land and lower part of midlands, clearly indicating association of Nearly level and Very gently sloping classes with low land physiography. Similarly, existence of Gently sloping covering area of 161ha (2.43%) on Mid land and Moderately sloping class occupying an area of 68ha (1.03%) on uplands confirm the influence of physiographic positions in deciding slope of these land units (Laekemariam *et al.* 2016) ^[12]

Table 3: Status of Surface/Sub surface features of Raipalli SWS

Criteria/Parameter	Class/category	Area (ha)	Area (%)
Texture	Clay	2303	34.78
	Sandy clay loam	1707	25.78
	Sandy clay	2351	35.50
	Sandy loam	24	0.36
Slope	Nearly level (0-1%)	2866	43.29
	Very gently sloping (1-3%)	3289	49.67
	Gently sloping (3-5%)	161	2.43
	Moderately sloping (5-10%)	68	1.03
Erosion	Slight	3445	52.03
	Moderate	2024	30.56
	Severe	915	13.82

Depth	Very deep (>150 cm)	2401	36.26
	Shallow (25-50 cm)	1465	22.13
	Deep (100-150 cm)	531	8.02
	Very shallow (0-25 cm)	600	9.06
	Moderately deep (75-100 cm)	515	7.78
	Moderately shallow (50-75 cm)	871	13.16

Relative impacts of factors like rain fall, soil texture, slope and physiography on erosion can be clearly distinguished through the results of the study area (Aiet al, 2020). Areas belonging to low lands with Nearly leveled slope class were found with slight erosion covering an area of 3445 ha (52.03%) are the least affected by erosion hazard protected by slope and physiographic position they situated. Instead, these areas are at the receiving end where denudation and deposition of detached soil particles from uplands which will be happening continuously as a natural process. Co existence of land parcels on midland physiography with Very gently sloping to Moderately sloping can be evidenced by presence of moderate erosion hazards covering an area of 2024 ha (30.56%). Impact of Gently to Moderately sloping classes on uplands were found detrimental as an area of 915 ha (13.82%) were affected with Severe erosion hazards (Tian, *et al* 2023) [13].

There was a general increase in soil depth downslope, indicating potential fluvial transport processes involving erosion and deposition. All the established seven series of Raipalli SWS were categorically divided into three distinct groups of upland, mid-upland and low land Physiography. In upland category Bhadrapur (P1), Kodambal (P2) and Mustari (P3) were grouped, while in the mid upland two prominent series Ainapur (P4) and Mustarwadi (P5) were included, where as in the third category of low land region Mudnal (P6) and Raipalli (P7) series were included. In the upland scenario, the solum depth varied from 13 to 50 cm with very shallow to shallow with a lithic (P1)

to paralithic (P2 and P3) contact within 50 cm depth. This feature limited the root penetration especially for deep rooted crops. In mid-upland physiography profile depth varied from 55-183 cm with moderately deep (P4) to very deep (P5) soils. However in low lands the profile depth varied from 150 to 170 cm which were very deep soils (P6 and P7). Taking depth into

consideration these mid-upland and low land soils proved to have no limitation for deep rooted crops. The variation in depth over the catenic sequence may be attributed to denudation, transportation, sedimentation and deposition along the slope.

Table 4: Status of Chemical and fertility properties of Raipalli SWS

Criteria/ Parameter	Class/category	Area (ha)	Area (%)
pH	Neutral (pH 6.5-7.3)	3978	60.08
	Slightly acid (pH 6.0-6.5)	1723	26.02
	Moderately acid (pH 5.5-6.1)	292	4.41
	Slightly alkaline (pH 7.3-7.9)	390	5.89
Electrical conductivity	Non saline (<2 dsm)	6383	96.41
Nitrogen	Medium (280-560 Kg/ha)	4026	60.81
	Low (140-280 Kg/ha)	2357	35.60
Phosphorous	Medium (23-57 Kg/ha)	4122	62.25
	Low (11.5-23 Kg/ha)	2096	31.65
	Very Low (<11.5 Kg/ha)	166	2.51
Potassium	Medium (145-337 Kg/ha)	2597	39.23
	Low (72-145 Kg/ha)	3203	48.37
	Very Low (<72 Kg/ha)	584	8.81
Sulphur	Medium (10-20 ppm)	3142	47.45
	Low (<10 ppm)	3242	48.96
Organic carbon	Very High (>1.00 %)	1649	24.90
	Low (<0.25-0.5 %)	1807	27.29
	Medium (0.5-0.75 %)	1513	22.85
	Very Low (<0.25 %)	407	6.14
	High (0.75-1.00 %)	1008	15.23
Calcium	Sufficient (>1.5 ppm)	2010	30.35
	Deficient (<1.5 ppm)	4374	66.06
Magnesium	Sufficient (>1.0 ppm)	1886	28.49
	Deficient (<1.0 ppm)	4497	67.92
Boron	Low (<0.5 ppm)	4073	61.52
	Medium (0.5-1.0 ppm)	1921	29.01
	High (>1.0 ppm)	389	5.88
Copper	Deficient (<0.2 ppm)	463	6.99
	Sufficient (>0.2 ppm)	5921	89.42
Iron	Sufficient (>4.5 ppm)	6214	93.85
	Deficient (<4.5 ppm)	169	2.56
Zinc	Sufficient (>0.6 ppm)	2169	32.76
	Deficient (<0.6 ppm)	4215	63.65

Table 5: Potentials weightage values of soil and land characters

Criteria	Subclasses	WEIGHTS	% of W (Sub-classes)	% of W (Criteria)
Boron	Low (<0.5 ppm)	0.019112	1.911220715	6.78
	Medium (0.5-1.0 ppm)	0.024044	2.404438964	
	High (>1.0 ppm)	0.024661	2.466091245	
Calcium	Sufficient (>1.5 ppm)	0.024044	2.404438964	4.32
	Deficient (<1.5 ppm)	0.019112	1.911220715	
Copper	Deficient (<0.2 ppm)	0.019112	1.911220715	4.32
	Sufficient (>0.2 ppm)	0.024044	2.404438964	
Electrical conductivity	Non saline (<2 dsm)	0.024661	2.466091245	2.47
Iron	Sufficient (>4.5 ppm)	0.024044	2.404438964	4.32
	Deficient (<4.5 ppm)	0.019112	1.911220715	
Potassium	Medium (145-337 Kg/ha)	0.024044	2.404438964	6.23
	Low (72-145 Kg/ha)	0.019112	1.911220715	
	Very Low (<72 Kg/ha)	0.019112	1.911220715	
Magnesium	Sufficient (>1.0 ppm)	0.024044	2.404438964	4.32
	Deficient (<1.0 ppm)	0.019112	1.911220715	
Nitrogen	Medium (280-560 Kg/ha)	0.024044	2.404438964	4.32
	Low (140-280 Kg/ha)	0.019112	1.911220715	

Organic carbon	Very High (>1.00 %)	0.024661	2.466091245	11.16
	Low (<0.25-0.5 %)	0.019112	1.911220715	
	Medium (0.5-0.75 %)	0.024044	2.404438964	
	Very Low (<0.25 %)	0.019112	1.911220715	
	High (0.75-1.00 %)	0.024661	2.466091245	
Phosphorous	Medium (23-57 Kg/ha)	0.024044	2.404438964	6.23
	Low (11.5-23 Kg/ha)	0.019112	1.911220715	
	Very Low (<11.5 Kg/ha)	0.019112	1.911220715	
PH	Neutral (pH 6.5-7.3)	0.024661	2.466091245	7.40
	Slightly acid (pH 6.0-6.5)	0.019112	1.911220715	
	Moderately acid (pH 5.5-6.1)	0.011097	1.10974106	
	Slightly alkaline (pH 7.3-7.9)	0.019112	1.911220715	
Suphur	Medium (10-20 ppm)	0.024044	2.404438964	4.32
	Low (<10 ppm)	0.019112	1.911220715	
Zinc	Sufficient (>0.6 ppm)	0.024044	2.404438964	4.32
	Deficient (<0.6 ppm)	0.019112	1.911220715	
Depth	Very deep (>150 cm)	0.024661	2.466091245	9.49
	Shallow (25-50 cm)	0.009864	0.986436498	
	Deep (100-150 cm)	0.022195	2.219482121	
	Very shallow (0-25 cm)	0.004932	0.493218249	
	Moderately deep (75-100 cm)	0.018496	1.849568434	
	Moderately shallow (50-75 cm)	0.014797	1.479654747	
Texture	Clay	0.014797	1.479654747	5.18
	Sandy clay loam	0.013564	1.356350185	
	Sandy clay	0.006165	0.616522811	
	Sandy loam	0.017263	1.726263872	
Slope	Nearly level (0-1%)	0.024661	2.466091245	9.37
	Very gently sloping (1-3%)	0.024044	2.404438964	
	Gently sloping (3-5%)	0.023428	2.342786683	
	Moderately sloping (5-10%)	0.021578	2.15782984	
Erosion	Slight	0.024661	2.466091245	5.49
	Moderate	0.019112	1.911220715	
	Severe	0.011097	1.10974106	

100.00

Table 6: Soil and land potential index values for different mapping units in Raipalli sub – watershed.

Soil MU	Factor A	Factor B	Factor c	Factor x	SLPI %
BDPhB2g1	0.2	0.55	0.975	1.812	19.431
BDPhB3g2	0.2	0.55	0.975	1.487	15.946
BDPhC2	0.2	0.55	0.95	1.691	17.673
BDPiA1	0.2	0.25	1	1.826	9.132
BDPiA2	0.2	0.25	1	1.703	8.515
BDPiB1	0.2	0.25	0.975	1.791	8.732
BDPiB2	0.2	0.25	0.975	1.678	8.18
BDPiB2g1	0.2	0.25	0.975	1.81	8.825
BDPiB3	0.2	0.25	0.975	1.678	8.18
BDPiB3g1	0.2	0.25	0.975	1.791	8.732
BDPiB3g2	0.2	0.25	0.975	1.468	7.155
BDPmA1	0.2	0.6	1	1.846	22.147
Average:					11.89
KDMcB3	0.4	0.7	0.975	1.494	40.789
KDMhA1	0.4	0.55	1	1.841	40.506
KDMhA1g	0.4	0.55	1	1.829	40.24
ANRha1	0.75	0.55	1	1.835	75.706
ANRha2	0.75	0.55	1	1.691	69.761
ANRhb1	0.75	0.55	0.975	1.799	72.335
ANRhb2g1	0.75	0.55	0.975	1.8	72.394
ANRhb2g2	0.75	0.55	0.975	1.643	66.065
ANRiA1	0.75	0.25	1	1.824	34.191
ANRiB1	0.75	0.25	0.975	1.812	33.121
ANRiB2	0.75	0.25	0.975	1.668	30.487
ANRmA1	0.75	0.6	1	1.824	82.059
Average:					59.56
MNLhA1	0.9	0.55	1	1.806	89.391
MNLhA1g1	0.9	0.55	1	1.818	89.974
MNLhB1	0.9	0.55	0.975	1.819	87.795
MNLhB2g1	0.9	0.55	0.975	1.759	84.885

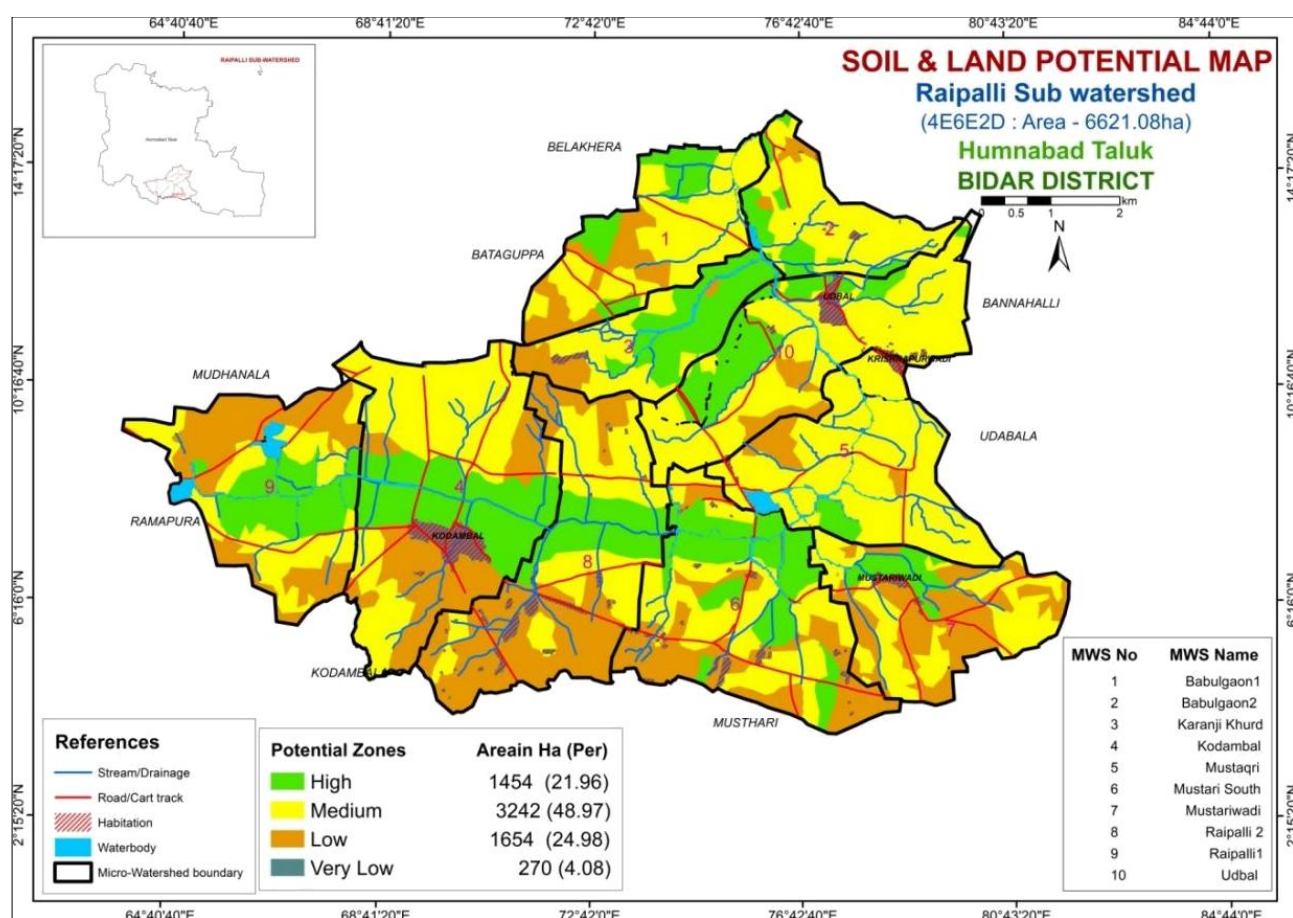
MNLhC2g2	0.9	0.55	0.95	1.637	76.969
MNLhC3g2	0.9	0.55	0.95	1.434	67.42
ANRha1	0.75	0.55	1	1.835	75.706
ANRha2	0.75	0.55	1	1.691	69.761
ANRhb1	0.75	0.55	0.975	1.799	72.335
ANRhb2g1	0.75	0.55	0.975	1.8	72.394
ANRhb2g2	0.75	0.55	0.975	1.643	66.065
ANRia1	0.75	0.25	1	1.824	34.191
ANRiB1	0.75	0.25	0.975	1.812	33.121
ANRiB2	0.75	0.25	0.975	1.668	30.487
ANRma1	0.75	0.6	1	1.824	82.059
Average:					59.56
MNLhA1	0.9	0.55	1	1.806	89.391
MNLhA1g1	0.9	0.55	1	1.818	89.974
MNLhB1	0.9	0.55	0.975	1.819	87.795
MNLhB2g1	0.9	0.55	0.975	1.759	84.885
MNLhC2g2	0.9	0.55	0.95	1.637	76.969
MNLhC3g2	0.9	0.55	0.95	1.434	67.42
ANRha1	0.75	0.55	1	1.835	75.706
ANRha2	0.75	0.55	1	1.691	69.761
ANRhb1	0.75	0.55	0.975	1.799	72.335
ANRhb2g1	0.75	0.55	0.975	1.8	72.394
ANRhb2g2	0.75	0.55	0.975	1.643	66.065
ANRia1	0.75	0.25	1	1.824	34.191
ANRiB1	0.75	0.25	0.975	1.812	33.121
ANRiB2	0.75	0.25	0.975	1.668	30.487
ANRma1	0.75	0.6	1	1.824	82.059
Average:					59.56
MNLhA1	0.9	0.55	1	1.806	89.391
MNLhA1g1	0.9	0.55	1	1.818	89.974
MNLhB1	0.9	0.55	0.975	1.819	87.795
MNLhB2g1	0.9	0.55	0.975	1.759	84.885
MNLhC2g2	0.9	0.55	0.95	1.637	76.969
MNLhC3g2	0.9	0.55	0.95	1.434	67.42

Soil MU	Factor A	Factor B	Factor c	Factor x	SLPI %	Soil MU	Factor A	Factor B	Factor c	Factor x	SLPI %
1					7						6
KDMhB2	0.4	0.55	0.975	1.66	35.613	MNLiA1	0.9	0.25	1	1.444	32.493
KDMhB2g 2	0.4	0.55	0.975	1.469	31.513	MNLiB2	0.9	0.25	0.975	1.663	36.487
KDMhB3g 1	0.4	0.55	0.975	1.793	38.452	MNLiB2g1	0.9	0.25	0.975	1.781	39.068
KDMhB3g 2	0.4	0.55	0.975	1.481	31.765	MNLiC2	0.9	0.25	0.95	1.649	35.237
KDMhC3	0.4	0.55	0.95	1.482	30.981	MNLiC3	0.9	0.25	0.95	1.447	30.931
KDMhD2	0.4	0.55	0.875	1.66	31.961	MNLiC3g1	0.9	0.25	0.95	1.759	37.595
KDMiA1	0.4	0.25	1	1.853	18.529	MNLmA1	0.9	0.6	1	1.431	77.268
KDMiA2	0.4	0.25	1	1.684	16.838	MNLmB1	0.9	0.6	0.975	1.807	95.157
KDMiB1	0.4	0.25	0.975	1.806	17.607	MNLmB2	0.9	0.6	0.975	1.619	85.247
KDMiB2	0.4	0.25	0.975	1.674	16.317	Average:					64.39
KDMiB2g1	0.4	0.25	0.975	1.793	17.478	MWDhB1	1	0.55	0.975	1.366	73.261
KDMiB3	0.4	0.25	0.975	1.482	14.453	MWDhB2	1	0.55	0.975	1.257	67.426
KDMiB3g1	0.4	0.25	0.975	1.806	17.607	MWDhB3	1	0.55	0.975	1.443	77.362
KDMmA1	0.4	0.6	1	1.853	44.471	MWDhC2g1	1	0.55	0.95	1.754	91.668
KDMmB1	0.4	0.6	0.975	1.793	41.948	MWDhD3g2	1	0.55	0.875	1.418	68.224
KDMmB2	0.4	0.6	0.975	1.674	39.161	MWDiA1	1	0.25	1	1.379	34.485
Average:					29.8	MWDiB1	1	0.25	0.975	1.368	33.336
MSThA1	0.6	0.55	1	1.853	61.147	MWDiB2	1	0.25	0.975	1.622	39.538
MSThA1g1	0.6	0.55	1	1.818	59.982	MWDiB3g1	1	0.25	0.975	1.753	42.728
MSThA2g1	0.6	0.55	1	1.818	59.982	MWDiC2	1	0.25	0.95	1.596	37.895
MSThB1	0.6	0.55	0.975	1.829	58.861	MWDiD2	1	0.25	0.875	1.609	35.193
MSThB2	0.6	0.55	0.975	1.697	54.603	MWDmA1	1	0.6	1	1.368	82.059
MSThB2g1	0.6	0.55	0.975	1.818	58.483	MWDmB1	1	0.6	0.975	1.379	80.696
MSThB2g2	0.6	0.55	0.975	1.662	53.467	MWDmB2	1	0.6	0.975	1.609	94.116
MSTiA1	0.6	0.25	1	1.828	27.419	Average:					61.28
MSTiA2	0.6	0.25	1	1.672	25.081	RPLhA1	1	0.55	1	1.362	74.897
MSTiB1	0.6	0.25	0.975	1.806	26.411	RPLhB3g2	1	0.55	0.975	1.016	54.492
MSTiB2	0.6	0.25	0.975	1.641	24.002	RPLiA1	1	0.25	1	1.35	33.75
MSTiB2g1	0.6	0.25	0.975	1.818	26.583	RPLiA1g1	1	0.25	1	1.35	33.75

MSTiB2g2	0.6	0.25	0.975	1.662	24.303	RPLiB1	1	0.25	0.975	1.338	32.619
MSTiC3	0.6	0.25	0.95	1.65	23.513	RPLiB2	1	0.25	0.975	1.206	29.393
MSTmA1	0.6	0.6	1	1.84	66.229	RPLiB2g1	1	0.25	0.975	1.338	32.619
MSTmB2	0.6	0.6	0.975	1.494	52.444	RPLiC2	1	0.25	0.95	1.182	28.081
Average:					43.91	RPLmA1	1	0.6	1	1.362	81.706
						RPLmA2	1	0.6	1	1.253	75.176
						RPLmB1	1	0.6	0.975	1.35	78.975
						RPLmB2	1	0.6	0.975	1.218	71.232
						Average:					52.22

Table 7: Distribution of Soil and land potential zones in Raipalli Sub-watershed

Potential_zones	Area_Ha	Area_Per
Very Low	270	4.09
High	1454	21.96
Low	1654	24.98
Medium	3242	48.97

**Fig 5:** Soil and land potential map**Conclusion:**

Fundamentally, coexistence of soil, land, physiography, land scape or geology of the region is an indicator of strong influence on one another with respect to their respective properties and features. Similarly, it was very clear that characters of soils of seven soil series found possessing with morphological, physical and chemical properties were found in accordance with soils series identified at their respective physiography. Very shallow to shallow soils of the study area were found highly influenced with high rainfall erosion hazards. Accordingly, the soils of Bhadrapur, Kodambal and Mustari were found low to moderate in their fertility status. As soil organic carbon was found to be the most influential factor for deciding the potential of land,

majority of these soils were found low in SOC. When soils of these series were assessed for their potential, they found falling in low to medium potential zone of the Raipalli SWS. Limitations like depth of soil, coarse soil texture, low available water capacity made the soils none to marginally suitable for selected agriculture and horticulture crops. Apart from that, such soils are recommended with soil and water conservation measures like contour bunding, trench cum bund and in case of severe erosion gully plugging. Soils of Ainapur, Mudnal, Mustarwadi and Raipalli were found in midland and low land physiographies. As these soils were subjected for illuviation the capabilities of these soils were found with potentials like improved water holding capacity, nutrient retention conditions and favourable depth for all the crops selected for evaluation

towards their suitability. Soil and land potential deciding criteria like SOC, depth and slope were found favourable for crop cultivation. Accordingly, soil mapping units belonging to Mustarwadi were rated with high potential weightage values and found falling in high potential zone. Among low land soils, in spite of favourable rooting depth soils of Raipalli series were identified with limitations like unfavourable texture and drainage conditions. Accordingly, such soils suitability was limited to few crops.

The overall conclusion from the present study is that potential of soil and land are majorly influenced by physiographic position and pedogenic process. Large area of Raipalli SWS situated in midland and mid upland were judged with falling under medium to high potential zone. Soils of high potential zone can be explored for cultivation of wide range of agriculture and horticulture crops with minimum interventions towards nutrient management and soil and water conservation measures. Low to very low potential zone were found concentrated in the uplands of the study area. Limitations like low soil organic carbon, very shallow to shallow depth, gently to moderately sloping lands coupled with moderate to severe erosion, constituted these zones where they require interventions of soil and water conservation measures, fertility improvement and hardy crops who can withstand limitations of these lands. The information on potentials of soil and land properties and their zones can be made as important decision support system to improve productivity of land in a most sustainable manner.

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