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OPTIMIZING AGRICULTURAL PRODUCTIVITY IN MINING-PROXIMATE LANDSCAPES: A SOIL-SITE SUITABILITY ASSESSMENT

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ABSTRACT

Land resource management that is sustainable is an effective way to reduce negative environmental impacts on intensive agriculture and industrial activities such as granite mining. For crop-appropriate land uses, and for land productivity for the region in Tumkur District, the 1,022-ha area in the Muddakkanahalli micro-watershed, impacted greatly by active granite quarrying, was evaluated. Nine different soil series have been determined in order to formulate a sustainable alternative land use plan and representative pedons for their morphological, physical and chemical characteristics were characterized. Most soils are deep (100 to 150 cm) to very deep (>150 cm), as found by the study of the physical condition. The subsurface horizons ranged from sandy clay to clay, but the surface was sandy loam to sandy clay. The bulk density ranged from 1.25 to 1.54 Mg m^{-3}, the maximum water holding capacity ranged from 21.34% to 61.91%, and the sand fraction ranged from 28.02% to 69.02%. Values in the pH range from 6.53 to 8.69, indicating a slightly acidic to alkaline chemical composition of the soils. Non-saline soils have an electrical conductivity (EC) value from 0.09 to 1.15 dS m^{-1}. In addition, OC (0.12% to 0.60%) was present in the soil and was found to be low. The base saturation was comparatively high, 65.93% to 86.63% as well as the cation exchange capacity (CEC) ranged from 12.60 to 37.24 cmol (p+) kg^{-1}. The majority of the micro-watershed was classified as Class IIs, or 778.2 ha (76.1%), according to land capability classification, indicating adequate cultivable land with slight limitations in depth, texture, or gravelliness. In contrast, Class VIII comprised 185.5 ha (18.1%) of non-cultivable quarry rock lands. From FAO guidelines, soil-site suitability was determined for the selection of ten major regional field and horticultural crops. The analysis has identified the main limitations to be gravelliness, texture, rooting depth, drainage, and nutrient availability. For example, sub-surface gravelliness of land limits large areas to marginal suitability (Class S3) for staple crops like maize and finger millet. To overcome these limitations, a geospatial data-driven potential land-use plan was created. The study recommends mapping-unit-based interventions such as organic manure application, contour bunds, application of split nitrogen fertilizers, use of intercropping systems (e.g. finger millet with cowpea) and appropriate horticultural crops like custard apple, sapota and lime. Adopting these different land-use approaches will help maximize resource use, increase agricultural productivity and promote sustainable farming in mining-degraded landscapes.
***Keywords*:** Mining-Proximate Landscapes, Agricultural Productivity, Suitability Assessment, Land resource management

Introduction

The sustainable management of soil resources is the cornerstone of food security, environmental preservation and regional health and prosperity. Yet, across India, soil and land degradation are among the increasing threats. Soil and water are very valuable resources for life on earth, influencing all the elements of society and the environment. Soil quality deterioration resulting from human activities, namely heavy-field agriculture, deforestation, pollution and mining, has implications for the ecosystem, crop yield and environmental health (Manoharachari *et al*., 2017). Land evaluation is a fundamental component of land use planning and becomes a link in the chain that helps in sustainable land resources management (Sharma *et al*., 1994; Yadav and Patil, 2024). Defined by FAO (as it is used in our study), "a linkage" between the soil resources inventory and the sustainable land use planning process. Land Capability Classification (LCC) is a valuable conservation-oriented model that includes some of the inherent physical properties in slopes and soil depth and erosion; however, is insufficient for predicting crop performance. In terrain near to industrial places such as granite mines use of LCC needs to be combined with crop-specific suitability assessment for the viability of arable land and best management of nutrients (Abdel Rahman *et al*., 2016). Granite is a popular dimension stone that is manufactured for construction purposes, but extraction can cause habitat loss, biodiversity loss and water pollution. The clearing of vegetation during mining allows erosion and runoff contamination of the surrounding area. As a result, evaluation of the environmental effect of the granite industry has come to be important for sound resource allocation. Propelling a shift in land-use patterns through proximity to industry, the farmers have abandoned traditional crops and resorted to commercial growth through applying chemical fertilizers. Indicating the magnitude of this vulnerability, the Indian Bureau of Mines reported on November 19 that the granite mining footprint in India exceeds 60,000 hectares with Karnataka being one of the top producing states. Karnataka itself accounts for almost 40 percent of the country's granite production, with more than 15,000 hectares under mining operations. About 35 million tons of granite were produced in India in 2023 of which around 14 million tons were produced in Karnataka. The Karnataka agricultural industry is characterized by a notable quantity of active quarries, namely more than 300, and thus, requires a harmonious linkage between economic extraction, environmental regulations, and sustainable land management to meet the ever-growing demand.

At the landscape scale, a watershed the geo-hydrological unit with water flowing to some common point is the ideal scale for carrying out those sustainable management practices. The main objective of watershed management is to save soil and water. However, unscientific land use practices, poor growth methods, and the clearance of native vegetation will bring about the degradation of watersheds. The recent emphasis on watershed-based holistic development has been proposed as a possibility for increasing productivity and sustainability in rainfed regions (Joy *et al*., 2005; Sharda, 2011; Yadav and Patil, 2024). Moreover, poor nutrition and water management techniques contribute to decreasing topsoil and essential nutrients. To address these problems, systematic management practices based on the properties of local soil and crop types are necessary. Understanding the region's soil potential, as defined by the various soil types, their geographic distribution, and their physical and chemical constraints, has paramount importance to both avoiding degradation and optimising soil productivity. Mapping these variations precisely and developing logical, scientific standards for interpreting land resources has become an issue of increasing importance. The scientifically robust methodologies to determine land suitability must be applied to each respective region in order to determine the best development options for both agriculture and horticulture. Recent innovations in geospatial technology demonstrate great potential for application for this purpose; by incorporating field-based soil surveys and Geographic Information System (GIS) frameworks, researchers are able to carry out high fidelity multi-criteria land suitability analyses (Vyas *et al*., 2024; Karpagam, 2025). It necessitates the combination of high resolution spatial data with field-scale soil resource inventories to obtain land suitability for the crops of the study area. Bearing in mind these considerations, this assignment aimed at assessing land capability and suitability in the Muddakkanahalli micro-watershed, Sira Taluk of Tumkur district classifying different soil types to plan alternative land use plan to increase agricultural productivity. This research, where these characteristics of physical and chemical soil are linked with local field and horticultural crops with distinct requirements (maize, finger millet, groundnut, mango and pomegranate), creates a framework that is data informed and strategic to mitigate long term effects of granite mining and maximize production utilisation from natural resources in a sustainable manner.

Materials and Methods

The study was carried out in Muddakkanahalli micro-watershed, situated at Sira Taluk Tumkur District of Karnataka, India (Fig. 1). Geographically, the watershed is situated at 13º 49’ 44.77” North latitude and 76º 48’ 6.6” East longitude with a total geographical area (TGA) of 1,022 hectares. Located in the Central Dry Zone (Agro-climatic Zone 4) of the Karnataka plateau, the region features hot, moist, semi-arid climate with an average annual rainfall between 453.5 and 717.7 mm, most of which is received during Kharif season. The micro-watershed elevation ranges between 450–900 meters above mean sea level. The study area is characterized by the geological location dominated by the Archean complex, dominated by granite and granite gneiss, for which there is active commercial granite quarrying. Following excavation of the pit, the sides of the pit were cleaned and ped faces were exposed to the sun. The top to bottom aspect of the exposed face was looked at for property changes of the soil. Boundaries of stratification between layers were indicated on the side of the profile pit face and studied. Different soil properties detected in the excavated soil profile, including designation of horizons, depth, soil colour, soil texture, soil structure, consistency, roots' type and size, pores and so forth, were identified and described. Ten profiles (Fig. 3), were analysed in various landforms of the micro-watershed and were identified as master profiles. Two of the pedons belonged to identical soil series and nine pedons were analysed for their morphological, physical and chemical properties. The characteristic site as well as location of the typifying pedons are presented in Table 1. Soil samplings were air-dried, ground, sieved (<2 mm) and tested for soil physical, physico-chemical and chemical characteristics. As soil samples, particle size analyses were performed by international pipette method (Piper, 2010). The pH and EC were determined at 1:2.5 soil: water (Jackson, 1973). Organic carbon (OC) was obtained with the following method (Walkley and Black, 1934). $CaCO_3$ equivalent (%) determined by (Piper, 2010). Cation exchange capacity (CEC) of the soils was determined using a method with 1 N sodium acetate at pH 8.2, per Bower (1952). Base saturation can be calculated for a number of soils where the extracted bases are summed, divided by CEC (by 1 N sodium acetate) and multiplying by 100. Exchangeable sodium % (ESP) calculated as exchangeable sodium to CEC ratio (ESP). To implement alternative land use planning for sustainability, the identified soil series were determined to be capable and suitable. The soils were divided into capacity and capability classes according to their natural limitations (i.e., slope, erosion, drainage, depth, texture, and/or graveliness), based on the threshold standards set by Klingebiel and Montgomery. The use of land for the ten key regional crops—field crops (maize, finger millet, groundnut, red gram, soybean), and horticultural crops (mango, sapota, lime, custard apple, pomegranate) was assessed by reference to the FAO. The climatic and soil-site characteristics of the mapping units were aligned with particular optimum requirements of crops, as represented in the categories of Highly Suitable (S1), Moderately Suitable (S2), Marginally Suitable (S3) and Currently Not Suitable (N1).

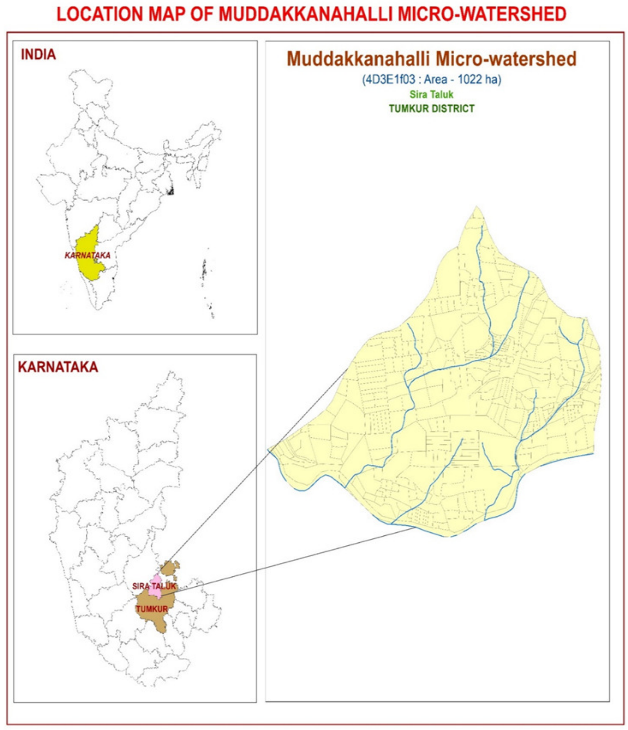

Fig. 1: Location map of Muddakkanahalli micro-watershed, Sira taluk, Tumkur District

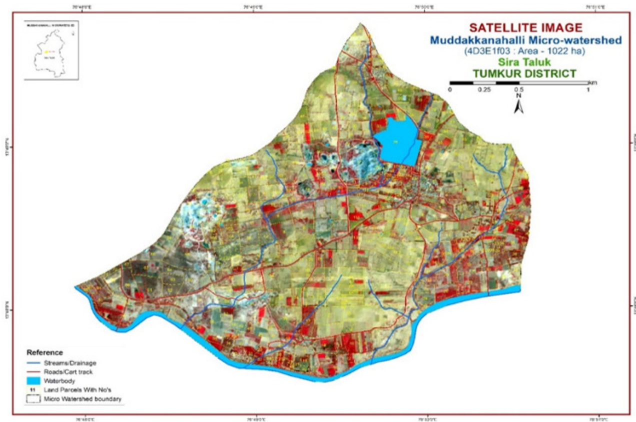

Fig. 2: FCC map of Muddakkanahalli micro-watershed, Sira taluk, Tumkur District

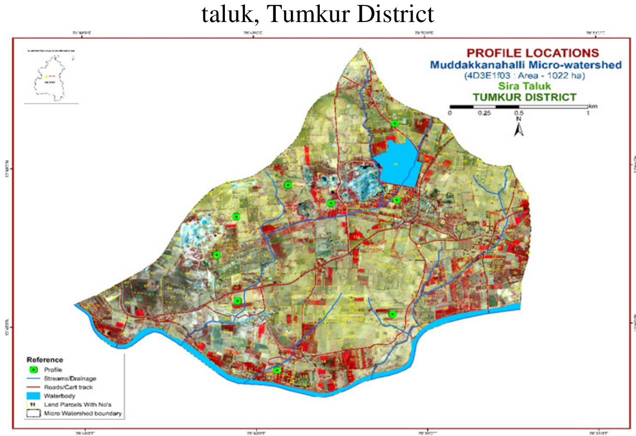

Fig. 3 : Profile locations around mining areas of Muddakkanahalli micro-watershed, Sira taluk, Tumkur District

Table 1: Location and site characteristics of soil profiles studied in Muddakkanahalli micro-watershed, Sira taluk, Tumkur District

S. No.	Characteristics	Pedon 1	Pedon 2	Pedon 3	Pedon 4	Pedon 5	Pedon 6
1	Location	Gajjarahalli village	Valakallu village	Holakallu village	Holakallu village	Maddakkanahalli village	Holakallu village
2	Latitude	13º 48’ 9.23” N	13º 48’ 26.66” N	13º 48’ 41.132” N	13º 48’ 41.132” N	13 º 48’ 47” N	13º 48’ 46” N
3	Longitude	76º 49’ 1.96” E	76º 48’ 54.80” E	76º 49’ 1.815” E	76º 49’ 1.815” E	76 º 49’ 20” E	76º 49’ 35” E
4	Altitude	618 m	617 m	680 m	643 m	645 m	640 m
5	Landform	Upland	Upland	Upland	Upland	Lowland	Lowland
6	Physiographic class	Dsa-G 259 a	Dsa-G 259 d	Dsa-G 254	Dsa-G 254	Dsa-G 32	Dsa-G 32
7	Profile position	Mid part of upland	Lower part of upland	Mid part of upland	Mid part of upland	Mid part of lowland	Lower part of lowland
8	Geology	Granite gneiss	Granite gneiss	Granite gneiss	Granite gneiss	Granite gneiss	Granite gneiss
9	Drainage	well	well	well	well	moderately well	moderately well
10	Flooding	No	No	No	No	No	No
11	Erosion	Slight	Slight	Slight	Slight	Slight	Slight
12	Land use	Arecanut, Coconut	Coconut	Fallow land	Fallow land	Fallow land	Fallow land
13	Vegetation	-	-	*Prosopsis juliflora*	*Prosopsis juliflora*	*Prosopsis juliflora*	*Pongamia pinnata*
14	Coverage of gravel (Vol % < 25)	<15	<15	<15	<15	<15	<15
15	Ground water depth (m)	>50	>50	>50	>50	>50	>50
16	Runoff	medium	slow	medium	medium	slow	slow
17	Soil slope %	1-3	0-1	1-3	1-3	0-1	0-1
18	Topography of surrounding	Nearly level	level	Nearly level	Nearly level	Level	Level
19	Plot (Survey) no.	78	105	82	82	21	92

Table 1: Location and site characteristics of soil profiles studied in Muddakkanahalli micro-watershed, Sira taluk, Tumkur District

SI. No.	Characteristics	Pedon 7	Pedon 8	Pedon 9
1	Location	Maddakkanahalli village	Badakkanahalli village	Badakkanahalli village
2	Latitude	13º 49’18.19” N	13º 49’10” N	13º 48’54.12” N
3	Longitude	76º 49’68.50” E	76º 50’25” E	76º 50’45.38” E
4	Altitude	653 m	657 m	646 m
5	Landform	Upland	Upland	Upland
6	Physiographic class	Dsa-G 254	Dsa-G 259 d	Dsa-G 25
7	Profile position	Mid part of upland	Mid part of upland	Mid part of upland
8	Geology	Granite gneiss	Granite gneiss	Granite gneiss
9	Drainage	Moderately well	well	well
10	Flooding	No	No	No
11	Erosion	Slight	Slight	Slight
12	Land use	Fallow land	Fallow land	Groundnut
13	Vegetation	Tamarind	*Pongamia pinnata*	Neem
14	Coverage of gravel (Vol % < 25)	<15	<15	<15
15	Ground water depth (m)	>50	>50	>50
16	Runoff	medium	medium	medium
17	Soil slope %	1-3	1-3	0-1
18	Topography of surrounding	Nearly level	Nearly level	level
19	Plot (Survey) no.	36	85	80

Results and Discussion

Characterization of soil pedon

There were nine soil series from the study region identified by morphological, physical and chemical characteristics. Balapura (very gently sloping upland, 1–3% slope): deep (100–150 cm), dark reddish brown to dark red (5YR 3/4 to 2.5YR 3/6), sandy clay loam to sandy clay, >35% gravel, Ap-Bt horizon. Chikkamadhure (nearly level upland, 0–1% slope): very deep (>150 cm), dark yellowish brown to dark grey (10YR 4/4 to 10YR 4/1), sandy clay loam to clay, gravel-free, Ap-Bw horizon. Aregujjanahalli (very gently sloping upland, 1-3% slope): deep (100-150 cm), dark reddish brown throughout (2.5YR 2.5/3), sandy loam to sandy clay loam, >35% gravel, Ap-Bt horizon. Kumchahalli (very gently sloping upland, 1-3% slope): deep (100–150 cm), dark reddish brown throughout (2.5YR 2.5/3), sandy clay loam throughout, gravel-free, Ap-Bt horizon. Thimmasandra (nearly levelled lowland, 0-1% slope): very deep (>150 cm), dark brownish to dark greyish brown (7.5YR 3/4 to 10YR 3/3), sandy clay to clay, gravel-free, Ap-Bw horizon. Sirur (near levelled lowland, 0-1% slope): deep (100-150 cm), dark brownish to very dark greyish (7.5YR 3/4 to 10YR 4/2), sandy clay to clay, gravel-free, Ap-Bw horizon. Kamarahalli (nearly level to very gently sloping upland, 0-3% slope): deep (100-150 cm), dark brown to very dark greyish brown and dark yellowish brown (7.5YR 3/4 to 10YR 3/2 and 10YR 4/4), sandy clay loam to clay, >35% gravel, Ap-Bw horizon. Bidanagere (nearly level to very gently sloping upland, 1-3% slope): deep (100-150 cm), brown to dark reddish brown (7.5YR 4/4 to 2.5YR 3/4), sandy loam to clay, >35% gravel, Ap-Bt horizon. Hooradhahalli (nearly level to very gently sloping upland, 1-3% slope): deep (100-150 cm), dark reddish brown (2.5YR 3/4), sandy clay, >35% gravel, Ap-Bt horizon. Morphological features of the representative soil pedons. As described earlier, the representative pedons, Balapura, Aregujjanahalli, Kumchahalli, Sirur, Kamarahalli, Bidanagere and Hooradhahalli series were deep, while the series Chikkamadhure and Thimmasandra were found to be very deep. The fact that deep to very deep soils are often associated with lower topography (Seth *et al.*, 2017). The low groundwater availability in upland soils for long-term period due to this process (removal of finer grains) that deposits them in the lower part of the midland may potentially lead to the change of shallowness in accordance to physiography. The deep solum is attributed by geography and slope gradient (Sireesha and Naidu, 2013). Ap horizon associated with crop cultivation is observed in all soil series but changed with depth. Bt sub-surface horizons were found in Balapura series, Aregujjanahalli series, Kumchahalli series, Bidanagere and Hooradhahalli series whereas in Chikkamadhure, Sirur, Thimmasandra, and Kamarahalli series sub-surface horizons were observed as Bw. The formation of Bt horizon is the result of illuvial accumulation of clay, while Bw horizon results from modified B horizon and soils are at the primitive phase of maturation concerning colour and structure. The colour ranged from dark reddish brown to dark red, dark yellowish brown to dark grey and dark brown to very dark greyish brown among the soil series found. The topography of the pedon, the chemical and mineralogical composition of the soil, their texture, and the moisture regimes can all be the culprits that provide such variance to soil color in pedons. The same results were reported by Sireesha and Naidu. The lower organic matter content of the subsurface layer compared with surface soil gave the above the brighter colour. Pulakeshi *et al.* also observed a similar phenomenon. Therefore, the soil is potentially red owing to the presence of Fe-bearing minerals, possibly coated over the soil particles, as well as with oxidation and increased leaching of bases, resulting in sesquioxide existing horizons (Sheela Rani, 2010). The brown colour in surface horizon could be found due to the presence of high organic carbon and brown to yellowish red in the sub-surface due to extreme weathering conditions together with dominance of limonite given heavy rainfall and high temperature. Chroma of the horizons was 2 or above which indicates well drained soil conditions (Ravindra Naik, 2014). Some series have shown gleiying due to water saturation (Bhattacharyya *et al.*, 2009) when chroma of 2 or less than 2 at the lower horizons of the pedons. Soil structure was shown to be mostly moderate, medium, sub-angular blocky in majority of the soil series barring the Balapura, Chikkamadhure, Kamarahalli and Bidanagere series which displayed weak medium sub-angular blocky over their surface horizons while Thimmasandra and Sirur series and Chikkamadhure showed strong medium sub-angular blocky over the sub-surface horizons.

Table 2: Morphological characteristics of representative pedons of Muddakkanahalli micro-watershed, Sira Taluk, Tumkur District

Horizon	Depth (cm)	Boun-dary	Colour (moist)	Structure	Consis-tency	Roots
(Pedon 1) Balapura series						
Ap	0-16	as	5YR 3/4	1 m sbk	ss & sp	-
Bt1	16-45	cs	2.5YR 3/4	2 m sbk	ms & mp	-
Bt2	45-70	cs	2.5YR 2.5/4	2 m sbk	ms & mp	-
Bt3	70-99	cs	2.5YR 2.5/4	2 m sbk	ms & mp	-
Bt4	99-106	cs	2.5YR 3/6	2 m sbk	ms & mp	-
(Pedon 2) Chikkamadhure series						
Ap	0-28	as	10YR 4/4	1 m sbk	ss & sp	f vf t

Bw1	28-52	cs	10YR 3/2	3 m sbk	ms & mp	f vf t
Bw2	52-74	cs	10YR 2/1	3 m sbk	vs & vp	-
Bw3	74-103	cs	10YR 2/1	3 m sbk	vs & vp	-
Bw4	103-127	cs	10YR 3/1	3 m sbk	vs & vp	-
Bw5	127-156	cs	10YR 4/1	2 m sbk	ms & mp	-
Bw6	156-175	cs	10YR 4/1	2 m sbk	ms & mp	-
(Pedon 3) Aregujjanahalli series						
Ap	0-20	as	2.5YR 2.5/3	2 m sbk	s0 & p0	f vf t
Bt1	20-50	as	2.5YR 2.5/3	2 m sbk	ms & mp	f vf t
Bt2	50-70	as	2.5YR 2.5/4	2 m sbk	ms & mp	f vf t
BC1	70-97	cs	2.5YR 3/4	2 m sbk	ms & mp	-
BC2	97-126	cs	2.5YR 3/4	2 m sbk	ms & mp	-
(Pedon 4) Kumchahalli series						
Ap	0-21	as	5YR 3/3	2 m sbk	ms & mp	f vf t
Bt1	21-50	cs	2.5YR 3/3	2 m sbk	ms & mp	f vf t
Bt2	50-74	cs	2.5YR 3/4	2 m sbk	ms & mp	f vf t
Bt3	74-119	cs	5YR 4/4	2 m sbk	ms & mp	-
(Pedon 5) Thimmasandra series						
Ap	0-17	as	7.5YR 3/4	2 m sbk	ms & mp	f vf t
Bw1	17-37	cs	10YR 3/3	2 m sbk	ms & mp	f vf t
Bw2	37-67	cs	10YR 3/2	3 m sbk	vs & vp	f vf t
Bw3	67-94	cs	10YR 3/2	3 m sbk	vs & vp	-
Bw4	94-120	cs	10YR 3/2	3 m sbk	vs & vp	-
Bw5	120-160	cs	10YR 3/3	3 m sbk	vs & vp	-

Table 2 : Morphological characteristics contd….

Horizon	Depth (cm)	Boun-dary	Colour (moist)	Structure	Consis-tency	Roots
(Pedon 6) Sirur series						
A1	0-11	as	7.5YR 3/4	2 m sbk	ms & mp	f vf t
A2	11-23	cs	7.5YR 3/6	2 m sbk	ms & mp	f vf t
Bw1	23-50	cs	10YR 4/2	3 m sbk	vs & vp	-
Bw2	50-84	cs	10YR 3/1	3 m sbk	vs & vp	-
Bw3	84-120	cs	10YR 3/1	3 m sbk	vs & vp	-
Bw4	120-147	cs	10YR 4/2	3 m sbk	vs & vp	-
(Pedon 7) Kamarahalli series						
Ap	0-12	as	7.5YR 3/4	1 m sbk	ss & sp	m vf t
Bw1	12-38	cs	7.5YR 3/2	2 m sbk	ms & mp	ff
Bw2	38-59	cs	7.5YR 4/4	1 m sbk	ms & mp	ff
Bw3	59-80	cs	10YR 4/4	1 m sbk	ms & mp	-
BC	80-116	cs	10YR 4/4	1 m sbk	ms & mp	-
(Pedon 8) Bidanagere series						
Ap	0-14	as	7.5 YR 4/4	1 m sbk	s0 & p0	m vf
Bt1	14-27	as	5YR 3/4	2 m sbk	ms & mp	m vf
Bt2	27-46	as	2.5YR 3/4	2 m sbk	ms & mp	c vf
Bt3	46-76	cs	2.5YR 3/4	2 m sbk	ms & mp	f vf
Bt4	76-83	cs	2.5YR 3/4	2 m sbk	ms & mp	-
(Pedon 9) Hooradhahalli series						
Ap	0-18	as	2.5YR 3/4	2 m sbk	ms & mp	m vf
Bt1	18-36	cs	2.5YR 3/4	2 m sbk	ms & mp	c vf
Bt2	36-58	cs	2.5YR 3/4	2 m sbk	ms & mp	ff
BC	58-94	cs	5YR 3/4	2 m sbk	ms & mp	-

Table 3 : Physical characteristics of representative pedons of Muddakkanahalli micro-watershed, Sira Taluk, Tumkur District

Horizon	Depth (cm)	Particle size distribution (%) Sand (2.0-0.05)	Silt (0.05-0.002)	Clay (<0.002)	Tex-ture	MWHC (%)	B.D (Mg m^{-3})
(Pedon 1) Balapura series							
Ap	0-16	55.18	12.62	30.70	scl	33.98	1.35
Bt1	16-45	52.98	13.19	32.83	sc	37.36	1.39
Bt2	45-70	51.43	12.33	35.64	sc	39.21	1.39
Bt3	70-99	46.68	13.57	39.15	sc	41.77	1.41
Bt4	99-106	42.24	12.95	43.68	sc	41.25	1.45
(Pedon 2) Chikkamadhure							
Ap	0-28	53.79	11.65	34.56	scl	42.61	1.26
Bw1	28-52	41.65	12.14	45.11	c	47.44	1.28
Bw2	52-74	38.88	11.39	48.93	c	48.63	1.31
Bw3	74-103	36.01	10.91	52.68	c	49.57	1.32
Bw4	103-127	31.92	12.39	55.19	c	52.38	1.38
Bw5	127-156	28.50	12.71	58.39	c	55.61	1.41
Bw6	156-175	28.02	12.37	59.31	c	56.32	1.43
(Pedon 3) Aregujjanahalli							
Ap	0-20	66.88	13.31	19.10	sl	32.05	1.25
Bt1	20-50	59.51	14.48	25.42	scl	43.87	1.27
Bt2	50-70	45.73	14.66	39.11	sc	45.13	1.28
BC1	70-97	41.60	15.38	42.52	sc	45.68	1.33
BC2	97-126	38.68	15.91	45.11	scl	40.05	1.25
(Pedon 4) Kumchahalli							
Ap	0-21	54.30	9.92	35.00	sc	40.05	1.25
Bt1	21-50	51.98	9.55	36.47	sc	43.87	1.27
Bt2	50-74	51.34	11.11	36.50	sc	45.13	1.28
Bt3	74-119	46.55	10.25	41.20	sc	45.68	1.33
(Pedon 5) Thimmasandra							
Ap	0-17	54.09	8.75	36.16	sc	40.08	1.26
Bw1	17-37	51.22	9.25	38.75	sc	41.29	1.28
Bw2	37-67	48.71	10.29	40.00	sc	43.17	1.32
Bw3	67-94	47.51	9.25	41.25	sc	43.66	1.33
Bw4	94-120	43.76	12.74	42.50	c	45.89	1.38
Bw5	120-160	40.96	14.29	43.75	c	47.74	1.42
(Pedon 6) Sirur series							
Ap	0-11	50.64	7.85	40.51	sc	43.38	1.38
A11	11--23	43.78	10.21	45.01	c	46.61	1.41
Bw1	23-50	41.35	9.15	47.51	c	47.93	1.42
Bw2	50-84	37.49	11.35	50.16	c	49.23	1.45
Bw3	84-120	34.77	11.12	52.11	c	52.19	1.47

Table 3: Physical characteristics contd…

Horizon	Depth (cm)	Particle size distribution (%) Sand (2.0-0.05)	Silt (0.05-0.002)	Clay (<0.002)	Tex-ture	MWHC (%)	B.D (Mg m^{-3})
(Pedon 7) Kamarahalli series							
Ap	0-12	52.47	12.25	34.28	scl	46.05	1.31
Bw1	12-38	45.30	14.18	39.73	c	48.13	1.32
Bw2	38-59	44.85	14.18	40.28	c	50.88	1.34
Bw3	59-80	43.21	15.18	41.23	c	61.91	1.34
BC	80-116	42.70	13.95	43.03	c	55.02	1.25
(Pedon 8) Bidanagere series							
Ap	0-14	69.02	10.03	19.95	sl	21.34	1.25
Bt1	14-27	44.23	11.68	35.01	sc	43.14	1.31
Bt2	27-46	43.37	12.33	43.63	c	44.89	1.38
Bt3	46-76	42.08	11.93	45.28	c	47.94	1.44
Bt4	76-83	40.79	12.10	46.43	c	47.43	1.28
(Pedon 9) Hooradhahalli series							
Ap	0-18	55.05	8.45	35.90	sc	39.12	1.36
Bt1	18-36	50.62	9.17	39.55	sc	41.50	1.42
Bt2	36-58	47.93	11.05	40.15	sc	46.90	1.45
BC	58-94	46.08	9.65	43.68	sc	41.72	1.30

Table 4: Chemical properties of representative pedons of Muddakkanahalli micro-watershed, Sira Taluk, Tumkur District

Horizon	Depth (cm)	pH (1:2.5)	EC (1:2.5) dS m^{-1}	OC (%)	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CEC	BS (%)
					cmol (p^{+}) kg^{-1}					
(Pedon 1) Balapura series										
Ap	0-16	6.66	0.12	0.45	6.08	3.15	0.18	0.10	12.90	73.89
Bt1	16-45	6.91	0.13	0.39	6.23	4.93	0.31	0.22	15.11	78.80
Bt2	45-70	6.85	0.21	0.28	7.03	5.98	0.12	0.41	17.11	79.18
Bt3	70-99	7.15	0.23	0.27	7.98	6.86	0.14	0.16	20.20	75.10
Bt4	99-106	7.57	0.29	0.25	8.97	7.03	0.15	0.09	20.80	78.19
(Pedon 2) Chikkamadhure series										
Ap	0-28	7.12	0.27	0.41	11.58	6.12	0.06	0.02	26.97	65.93
Bw1	28-52	7.68	0.34	0.38	12.13	7.89	0.08	0.06	30.01	67.17
Bw2	52-74	8.27	0.61	0.32	12.89	7.93	0.08	0.07	31.27	67.07
Bw3	74-103	8.24	0.81	0.25	13.64	8.54	0.12	0.09	32.59	68.70
Bw4	103-127	8.22	0.94	0.21	14.77	9.69	0.15	0.09	33.60	73.51
Bw5	127-156	8.44	1.04	0.16	15.98	10.23	0.18	0.12	35.29	75.12
Bw6	156-175	8.51	1.15	0.12	16.23	13.69	0.23	0.09	37.24	81.21
(Pedon 3) Aregujjanahalli series										
Ap	0-20	7.62	0.15	0.39	6.39	3.30	0.04	0.01	12.60	77.24
Bt1	20-50	7.65	0.16	0.33	6.81	4.65	0.06	0.03	15.41	75.20
Bt2	50-70	7.79	0.16	0.21	7.32	5.61	0.05	0.05	16.20	80.48
BC1	70-97	7.81	0.19	0.20	7.99	6.32	0.08	0.04	16.70	86.56
BC2	97-126	7.96	0.22	0.20	9.94	7.17	0.08	0.04	19.90	86.63
(Pedon 4) Kumchahalli series										
Ap	0-21	6.53	0.11	0.46	5.64	3.96	0.18	0.03	12.97	75.66
Bt1	21-50	6.81	0.13	0.35	6.54	4.22	0.15	0.07	14.29	76.84
Bt2	50-74	7.52	0.13	0.19	6.84	4.71	0.25	0.09	15.09	78.79
Bt3	74-119	7.43	0.15	0.13	6.82	4.54	0.32	0.06	14.54	80.74
(Pedon 5) Thimmasandra series										
Ap	0-17	6.81	0.09	0.40	6.72	4.31	0.16	0.10	16.95	66.61
Bw1	17-37	7.11	0.11	0.37	6.89	4.48	0.17	0.10	17.24	67.52
Bw2	37-67	7.23	0.14	0.29	7.89	5.75	0.20	0.12	20.13	69.36
Bw3	67-94	7.52	0.16	0.23	9.21	6.19	0.21	0.19	21.25	74.35
Bw4	94-120	7.65	0.17	0.20	9.39	6.88	0.27	0.22	21.51	77.92
Bw5	120-160	7.78	0.19	0.20	10.09	7.64	0.36	0.31	23.08	79.72
(Pedon 6) Sirur series										
Ap	0-11	7.51	0.22	0.33	8.45	5.57	0.11	0.08	20.45	69.49
A11	11--23	7.64	0.38	0.31	8.95	6.09	0.13	0.09	21.90	69.68
Bw1	23-50	7.81	0.44	0.29	9.45	6.95	0.14	0.09	23.45	70.92
Bw2	50-84	8.09	0.51	0.21	9.84	7.85	0.16	0.11	25.31	70.96
Bw3	84-120	8.21	0.82	0.19	11.84	7.91	0.16	0.15	27.49	72.97
Bw4	120-147	8.33	1.02	0.17	12.16	8.29	0.20	0.17	28.40	73.31

Table 4: Chemical properties contd….

Horizon	Depth (cm)	pH (1:2.5)	EC (1:2.5) dS m^{-1}	OC (%)	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CEC	BS (%)
					cmol (p^{+}) kg^{-1}					
(Pedon 7) Kamarahalli series										
Ap	0-12	7.80	0.19	0.51	8.50	4.00	0.23	0.10	16.87	76.05
Bw1	12-38	7.94	0.20	0.39	10.00	6.00	0.18	0.10	21.32	76.36
Bw2	38-59	8.02	0.30	0.30	11.51	6.50	0.14	0.12	23.56	77.55
Bw3	59-80	8.44	0.42	0.27	11.89	7.95	0.17	0.14	26.01	77.47
BC	80-116	8.69	0.58	0.24	12.00	6.50	0.18	0.14	26.78	70.28
(Pedon 8) Bidanagere series										
Ap	0-14	7.41	0.12	0.60	7.50	3.00	0.16	0.10	14.57	73.85

Bt1	14-27	7.48	0.14	0.48	8.51	4.50	0.16	0.08	17.49	75.76
Bt2	27-46	7.55	0.15	0.27	9.12	5.00	0.20	0.06	18.87	76.21
Bt3	46-76	7.73	0.15	0.18	10.19	5.50	0.22	0.06	19.44	82.15
Bt4	76-83	7.79	0.19	0.15	11.50	5.50	0.26	0.11	20.78	83.59
(Pedon 9) Hooradhahalli series										
Ap	0-18	7.47	0.10	0.57	8.00	4.50	0.20	0.11	16.57	77.31
Bt1	18-36	7.85	0.12	0.45	9.50	5.50	0.26	0.16	19.59	78.71
Bt2	36-58	7.89	0.12	0.39	10.51	5.00	0.27	0.15	19.92	79.97
BC	58-94	8.01	0.12	0.30	11.00	5.50	0.24	0.12	20.13	83.76

Variation in the form was also attributed to agricultural practices performed in the field, addition of organic material, and pressure from above surface, resulted structure was formed both in surface horizons and sub-surface horizons (Rajashekar, 2018). Similarly witnessed by Nagendra and Patil (2015). The redoximorphic state of sesquioxides that may produce bright red or reddish-brown colour may be contributing to sub-angular blocky structure (Verma *et al.*, 2012). Kumchahalli, Hooradhahalli, Thimmasandra and Sirur series soils exhibited moderately sticky and moderately plastic consistency in surface horizons, whereas Balapura, Aregujjanahalli, Kamarahalli series soils displayed slightly sticky and slightly plastic consistency in surface horizons and moderately sticky and moderately plastic consistency in sub-surface horizons. While Chikkamadhure series gave slightly sticky and slightly plastic to very sticky and very plastic consistency, Thimmasandra, Chikkamadhure and Sirur series gave moderately sticky and moderately plastic to very sticky and very plastic consistency. This variation in texture composition and also clay mineral composition contributed to inconsistency of soils (Dasog and Patil, 2011). Pramod (2015) and Harshitha (2018) also reported similar results. Other morphological features such as clay cutans appearance were evident in Balapura, Aregujjanahalli, Kamarahalli, Hooradhahalli, Bidanagere and Kumchahalli series. The Sirur and Kamarahalli series also had slight effervescence in subsurface horizons, which could be due to the accumulation of calcium carbonate (Amara *et al.*, 2015). The physical properties of representative soil pedons. In certain soil series, texture in surface horizons varied from sandy clay, sandy clay loam to sandy loam. The sandy clay textures of subsurface horizons in Thimmasandra and Sirur series varied from sandy clay to clay, while sandy clay texture appeared in Balapura, Aregujjanahalli and Kumchahalli series. Soil textures of subsurface horizons of Chikkamadhure, Sirur, Kamarahalli, and Bidanagere series were found to be clay. The sand content decreased in frequency with increasing depth in all soil series. Sand distribution ranged from 28.02 to 69.02 per cent. The sand content was higher than that in silt and clay fractions. Higher concentrations of sand particles were attributed to both the silicaceous and granite gneiss parent material present in these soils (Anjali and Hebbara, 2018). The clay content increased by depth with increasing soil sequence. Higher clay content was seen in the Chikkamadhure and Sirur series with intervals ranging from 34.56 to 59.31 per cent and 40.51 to 55.09 per cent respectively. The growth in clay content with depth resulted from illuviation. The slower rate of weathering explained the high sand content and low clay content. The results were also obtained by Pulakeshi *et al.* (2014) and Patil *et al.* (2018). Silt distribution was found to be between 7.85 and 15.91 per cent. Silt content exhibited an irregular trend with depth in soils of the study area. The principal source of the irregular distribution is due to changing parent material weathering behavior. Denis and Patil (2015) have reported comparable results. Textural variability is predominantly related to the type of parent material used, amount of weathering, topography and time and is related to weathering condition and topography. Bulk density of soil in different soil series were 1.25 to 1.54 Mg m-3 under varying depth on the scale of varying grain sizes that shows a progressive trend as depth is increased. It was highest in Bw4 horizon of Sirur series. This bulk density increase with depth is caused by an increase in above horizon pressure and decrease in organic matter content. The added surface soil pressure led to bulk density increases with depth while decreased organic matter levels were observed (Nagendra and Patil, 2015). The same result was reported by Anjali and Hebbara (2018). Soil maximum water holding capacity of soil in various soil series between 21.34 and 61.91 per cent. Maximum water holding capacity was found significantly higher in Kamarahalli series (46.05 to 61.91 %) compared with the other series of soil because of the higher clay content of Kamarahalli series. The quantity of clay and organic carbon present in the soil will have an impact on the water holding capacity of the pedons. These results were consistent with the results reported by Bhavya *et al.* (2017). Increases in clay content and increased water holding capacity with depth is related and (Dasog and Patil, 2011). Yitbarek *et al.* provided the same finding (2016). Chemical properties of representative pedons. Soils were slightly acidic to neutral in Balapura (6.66 to 7.57), Kumchahalli (6.53 to 7.43), and Thimmasandra (6.81 to 7.78) series. It is also the case for Chikkamadhure (7.12 to 8.51), Kamarahalli (7.80 to 8.69), Bidanagere (7.41 to 7.79), Hooradhahalli (7.47 to 8.01), Aregujjanahalli (7.62 to 7.96), and Sirur (7.51 to 8.33) series being neutral to alkaline. The pH continuously increased with depth starting from a low of 6.53 in Ap horizon of Kumchahalli to high of 8.69 in BC horizon of Kamarahalli due to base leaching, parent material, topography and calcareous nature of lower horizon (Dasog and Patil., 2011; Devi *et al*., 2015; Naik *et al*., 2020). Electrical conductivity (EC) showed non-saline conditions from 0.11 to 1.15 dS m-1, the surface levels were value of 0.09 (Thimmasandra) & 0.27 (Chikkamadhure), and the subsurface value was 0.11 (Bw1, Thimmasandra) & 1.15 (Bw6, Chikkamadhure). EC increased with depth, with salts leaching from percolating rainwater in free-drainage conditions (Manojkumar, 2011; Pramod, 2015; Tumbal and Patil, 2015). Organic carbon (OC) was consistently low (0.12 to 0.60 per cent) and reduced with depth owing to higher oxidation at higher temperature in the subsurface and greater litter collection at the surface (Pramod, 2015; Vasundhara *et al*., 2020). Surface OC was maximum in Bidanagere (0.60 %), Hooradhahalli (0.57%) and Kamarahalli (0.51 %) because of vegetative additions (Ravikumar *et al*., 2010) whereas subsurface OC ranged from 0.12 % at a minimum level (Bw6, Chikkamadhure) to a maximum of 0.48 % (Bt1, Bidanagere). The exchangeable bases on the exchange complex had Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}, indicating a preference of divalent to monovalent adsorption (Madhu, 2012; Pramod, 2015; Anjali and Hebbara, 2018). The values ranged from 5.64 to 16.23 cmol (p+) kg^{-1} for Ca^{2+}, 3.15 to 13.69 cmol (p+) kg^{-1} for Mg^{2+}, 0.04 to 0.36 cmol (p+) kg^{-1} for Na^{+}, and 0.02 to 0.41 cmol (p+) kg^{-1} for K^{+} with Mg^{2+} coming in lower amounts than Ca^{2+} due to its mobility (Krishna *et al*., 2017; Kumar and Hundekar, 2018). The values of ions were elevated based in a depth with higher clay content and pH while the lowest are attributed to the higher plant uptake (Narsaiah *et al*., 2018). Hence, CEC varied from 12.60 to 37.24 cmol (p+) kg^{-1} and increased with depth in accordance with clay illuviation (Sulieman, 2015; Rajashekar, 2018; Vasundhara *et al*., 2020). Surface CEC ranged from 12.60 (Ap, Aregujjanahalli) to 26.97 (Ap, Chikkamadhure). Subsurface CEC varied from 14.29 (Bt1, Kumchahalli) to 37.24 (Bw6, Chikkamadhure); the generally lower CEC is associated with Kaolinite minerals in Alfisols and crop uptake. Base saturation ranged from high (65.93 to 86.63 per cent), which in return suggested low rainfall and low leaching (Meenkshi *et al*., 2017). Lower depth of base caused base saturation to increase (Ram Prasad and Govardhan, 2011; Tumbal and Patil, 2015): the surface values ranged from 65.93 (Ap, Chikkamadhure) to 77.31 (Ap, Hooradhahalli), and subsurface values from 67.07 % (Bw2, Chikkamadhure) to 86.63 % (BC2, Aregujjanahalli).

Land capability classification

The land capability classification is the general term for categorizing soils by their limitations and it aims to accentuate the hazards that may be present in various soils. It acts as a basis to determine a soil area's appropriateness and condition for cultivation, grazing and forest plantation. Soils were grouped into capability class and sub class based on capability to grow crops and pasture plants without deterioration over an extended period of time. Land capability classification was performed for Muddakkanahalli micro-watershed and shown in Table 5. The soils of Muddakkanahalli micro-watershed formed two classes of land capability classes II and VIII. It has been classified under types of land capability sub-classes, according to their susceptibility to wetness/drainage and soil (depth, gravelliness, texture and salinity/alkalinity). Of the total area, 1022 ha, 778.2 ha (76.1 %) is good cultivable land with slight soil limitations (depth, gravelliness, texture, salinity/alkalinity), and 185.5 ha (18.1 %) belong to granite quarry area belonging to class VIII and limitations that preclude their use for commercial, plant production and limited to recreation, wildlife or aesthetic.

Table 5: Land capability classes of area in Muddakkanahalli micro-watershed, Sira taluk, Tumkur District

Land capability classes	Description	Area	
		ha	%
IIs	Good cultivable land having slight soil (depth, gravelliness, texture, salinity/ alkalinity) limitation	778.2	76.1
VIII	Uncultivable rock lands (Quarry)	185.5	18.1
Others (Habitation and waterbody)		58.3	5.7
Total		**1022**	**100**

Land suitability classification for major crops

Land suitability is the fitness of a given type of land for a defined use. The land may be considered in its present condition or after improvement. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses. The soil properties from the study area were matched with soil-site suitability criteria of different crops and arrived at soil-site suitability sub-class.

Land suitability for Finger millet

Finger millet (*Eleusine coracana*) is hardy and well known as dryland crop cultivated in both tropical and subtropical regions. It can be grown in rich loam to weak shallow upland soil with low organic matter content in a large variety of soils. It grows better within 4.5-8.0 pH range. The land suitability classes for finger millet are presented in Table 6. The study area comes under three land suitability classes *viz.* S1, S2 and S3 having limitations of gravelliness and texture. Land suitability study for finger millet revealed that class S1 covered an area of 43.6 ha and comes under highly suitable land with no limitation for finger millet and class S3 covered a major area of 303.7 ha which is marginally suitable land having texture as a limitation. About 291.2 ha area comes under marginally suitable land with gravelliness as limitation. It was followed by S2nz class covering area of 118.1 ha which is moderately suitable having nutrient availability and calcareousness as limitation. Class S2g occupied 21.6 ha area, which is moderately suitable land with gravelliness as limitation. The main constraint for the growth of finger millet was gravelliness which was also found in the findings of Geetha *et al.* (2019).

Land suitability for Maize

Maize (*Zea mays*) is one of the most robust crops with great adaptability to complex agro-climatic conditions. It can be grown effectively in various habitats, ranging from loamy sand to clay loam. Soils with high organic matter content, high water-holding capacity, and neutral pH are ideal for improved productivity. However, maize is sensitive to moisture stress, particularly excess soil moisture and salinity stresses. Therefore, it is beneficial to avoid low-lying fields with poor drainage and high salinity. Fields with good drainage should be selected for maize cultivation.

In the Muddakkanahalli micro-watershed, the land suitability for maize indicated that about 43.6 ha area comes under class S1 (Table 6), which is highly suitable land without any limitations. Class S3g covered an area of 291.4 ha, which is marginally suitable land with gravelliness as a limitation. About 258.5 ha area was classified as S2tw, which is moderately suitable with texture and drainage as limitations. An area of 44.8 ha was classified as S2tn, indicating marginal suitability due to limitations in texture and nutrient availability. Additionally, 21.6 area ha was found in the S2g class, indicating moderately suitable land with gravelliness as a limitation. Although subsurface texture and topography showed no limitations, the land was marginally suitable for maize because of subsurface gravels and soil depth, as observed by Rajesh *et al.* (2018).

Table 06: Land suitability for different crops

Suitability Class & Limitations	Finger Millet	Maize	Groundnut	Red Gram	Soybean	Mango	Sapota	Lime	Custard Apple	Pome-granate
S1 (Highly suitable)	43.60 ha (4.20%)	43.60 ha (4.20%)	-	43.70 ha (4.20%)	43.60 ha (4.20%)	17.90 ha (1.70%)	65.20 ha (6.30%)	65.20 ha (6.30%)	110.50 ha (10.80%)	65.30 ha (6.30%)
S2g (Gravelliness)	21.60 ha (2.10%)	21.60 ha (2.10%)	-	21.80 ha (2.10%)	21.60 ha (2.10%)	-	154.20 ha (15.10 %)	154.10 ha (15.10%)	291.30 ha (28.60%)	154.10 ha (15.10%)
S2nz (Nutrient & calcareousness)	118.10 ha (11.50%)	118.30 ha (11.50%)	-	118.10 ha (11.50%)	162.90 ha (15.90%)	118.10 ha (11.60%)	118.20 ha (11.50 %)	162.90 ha (15.90%)	118.10 ha (11.60%)	118.30 ha (11.50%)
S2tn (Texture & nutrient)	-	44.80 ha (4.30%)	118.40 ha (11.70%)	44.80 ha (4.30%)	-	-	-	-	-	44.80 ha (4.30%)
S2tw (Texture & drainage)	-	258.50 ha (25.40%)	-	258.60 ha (25.30%)	-	-	-	-	-	258.30 ha (25.40%)
S2t (Texture)	-	-	65.20 ha (6.30%)	-	-	-	-	-	-	-

S2tg (Texture & gravelliness)	-	-	245.40 ha (24.10%)	-	-	-	-	-	-	-
S2w (Drainage)	-	-	-	-	258.30 ha (25.50%)	-	-	258.60 ha (25.50%)	258.30 ha (25.20%)	-
S2r (Rooting depth)	-	-	-	-	-	47.40 ha (4.70%)	-	-	-	-
S2rg (Rooting depth & gravelliness)	-	-	-	-	-	154.10 ha (15.20%)	137.20 ha (13.50 %)	137.40 ha (13.40%)	-	137.50 ha (13.60%)
S3g (Marginal - gravelliness)	291.20 ha (28.80%)	291.40 ha (28.70%)	-	291.20 ha (28.80%)	291.80 ha (28.50%)	-	-	-	-	-
S3t (Marginal - texture)	303.70 ha (29.70%)	-	349.20 ha (34.10%)	-	-	303.50 ha (29.60%)	303.40 ha (29.80 %)	-	-	-
S3r (Marginal - rooting depth)	-	-	-	-	-	137.20 ha (13.40%)	-	-	-	-

Land suitability for Groundnut

Groundnut (*Arachis hypogaea*) is an important oilseed crop suitable for cultivation in tropical areas. A distinct feature of this plant is its quick adaptability to a wide variety of climatic conditions. The land suitability classes for groundnut are presented in Table 6. The land suitability study of the area for groundnut showed that the majority of the area, i.e., 349.2 ha, is marginally suitable for groundnut (S3t), with texture as a limitation. An area of about 245.4 ha falls under the S2tg suitability class, which is considered moderately suitable land with texture and gravelliness as limitations. This was followed by class S2tn (118.4 ha), which refers to moderately suitable land with texture and nutrient availability as limitations. About 65.2 ha area was found in class S2t, which refers to moderately suitable land with texture as a limitation. Similar results were observed by Abdel Rahman *et al.* (2016).

Land suitability for Redgram

Cajanus cajan, or red gram, is an important crop for pulses that is rich in protein. Because it fixes atmospheric nitrogen and improves the physical properties of the soil, it is crucial for preserving soil fertility. A significant amount of the protein required by the nation's vegetarian population is met by red grams. It may be grown on dry terrain since it is a drought-resistant crop, and its main use is as an intercrop with other crops. The suitability classes for red gram are depicted in Table 6.

Out of the total studied area, about 43.7 ha was found to be highly suitable for red gram, classified as S1. Approximately 291.2 ha area was classified as S3g, which refers to marginally suitable land with gravelliness as a limitation. This was followed by the S2tw class, which is moderately suitable land with texture and drainage as limitations, covering an area of 258.6 ha. The S2nz class occupied 118.1 ha area, which is moderately suitable land with nutrient availability and calcareousness as limitations. Additionally, the S2tn class occupied an area of 44.8 ha, which is moderately suitable with texture and nutrient availability as limitations, while the S2g class occupied 21.8 ha area, indicating moderately suitable land with gravelliness as a limitation. Similar work was carried out by Geetha *et al.* (2017) in the 48A distributary of Malaprabha Right Bank Command, specifically in the Giddadapalya Micro-watershed.

Land suitability for Soybean

Glycine max, or soybean, are a significant crop in the world because they yield both protein and oil. Cultivation thrives in regions with hot summers and ideal growth temperatures of 20 to 30 degrees Celsius. Although they may grow in a variety of soil types, damp alluvial soils with a high organic matter concentration are ideal for their development.

Soybean land suitability assessment in the study area showed that about 43.6 ha (Table 6) was found to be highly suitable for soybeans, classified as S1. Approximately 291.8 ha area fell under class S3g, which is marginally suitable due to gravelliness as a limitation. This was followed by class S2w, covering 258.3 ha area, which refers to moderately suitable land with drainage as a limitation. The S2nz class occupied 162.9 ha, indicating moderately suitable land with nutrient availability and calcareousness as limitations, and the S2g class occupied 21.6 ha area, which is moderately suitable with gravelliness as a limitation. The main limitations for soybean cultivation were found to be physical factors such as soil depth, gravelliness, and slope percentage, respectively (Chandrakala *et al*., 2019).

Land suitability for Mango

Tropical and subtropical regions are ideal for growing mango (*Mangifera indica*), sometimes referred to as the "king of fruits." It may grow in a variety of soil types but prefers deep, well-drained soils that are not always productive. But the crop cannot tolerate salinity.

The land suitability assessment for mango in the study area (Table 6) revealed that an area of 303.5 ha was classified as S3t, indicating marginally suitable land with texture as a limitation. This was followed by class S2rg, covering an area of 154.1 ha, which reflects moderately suitable land with rooting depth and gravelliness as limitations. Class S3r occupied an area of 137.2 ha, indicating marginally suitable land with rooting depth as a limitation. Additionally, class S2nz covered an area of 118.1 ha, representing moderately suitable land with nutrient availability and calcareousness as limitations. About 17.9 ha area was found to be in class S1, which refers to highly suitable land with no limitations for the cultivation of mango.

Land suitability for Sapota

Sapota (*Manilkara achras*) is a well-suited crop for tropical regions. Being a hardy tree, it can be grown on a wide range of soils as it flowers and fruits throughout the year. The soil should be well-drained without any hard pan, and deep, porous soils are preferred. It can tolerate the presence of salts in the soil and irrigation water to a certain extent.

The suitability classes for sapota are depicted in Table 6 The land suitability assessment for sapota in the study area revealed that 303.4 ha was classified as S3t, which is marginally suitable land with texture as a limitation. About 137.2 ha area was classified as S2rg, indicating moderately suitable land with rooting depth and gravelliness as limitations. Class S2g covered an area of 154.2 ha, indicating moderately suitable land with gravelliness as a limitation, whereas the S2nz class covered an area of 118.2 ha, referring to moderately suitable land with nutrient availability and calcareousness as limitations. An area of about 65.2 ha was classified as S1, which is highly suitable for the cultivation of sapota without any limitations. Madhusudhan (2019) and Prathibha *et al*. (2018) have both reported comparable findings on the constraints imposed by texture.

Land suitability for Lime

A subtropical climate is best suited for citrus fruits like lime (*Citrus aurantifolia*). Deep, well-drained loamy soils are ideal, and lime trees are sensitive to frost. The optimum temperature range is 20 to 30°C.

Soil suitability studies for Lime (Table 28) revealed that an area of 65.2 ha was classified as S1, which is highly suitable land with no limitations. An area of about 258.6 ha fell under the S2w suitability class, which is moderately suitable due to drainage limitations. The S2nz class, with limitations of nutrient availability and calcareousness, covered an area of 162.9 ha. This was followed by the S2g suitability class, indicating moderately suitable land with gravelliness as a limitation, covering an area of 154.1 ha. Class S2rg occupied an area of 137.4 ha, indicating moderately suitable land with rooting depth and gravelliness as limitations. Mahesh *et al*. (2019) reported that the micro-watershed is moderately suitable for lime cultivation with limitations related to texture and topography, and it is deemed not suitable due to constraints related to rooting depth and topography.

Land suitability for Custard apple

Custard apple (*Annona squamosa*) is a sweet, tropical fruit. It can grow well in all types of soil but fails to grow if the subsoil is poor drained and it requires hot dry climate during flowering and high humidity at fruit setting. The suitability of land for custard apple (Table 6) revealed that an area of 110.5 ha comes under class S1 which indicates highly suitable land for cultivation of custard apple. Class S2nz occupied an area of 118.1 ha indicating moderately suitable having nutrient availability and calcareousness as limitation. An area of about 291.3 ha was occupied under class S2g which refers to moderately suitable land with gravelliness as limitation followed by an area of 258.3 ha having moderately suitable land with drainage as limitation (S2w).

Land suitability for Pomegranate

Pomegranate (*Punica granatum*) adapts to a wide range of climatic conditions. It grows well in plains as well as on hills up to an elevation of 2000 m above MSL. It prefers well-drained, sandy loam to deep loamy or alluvial soils.

The land suitability classes for pomegranate are presented in Table 30. The suitability of land for pomegranate in the study area indicated that an area of 65.3 ha falls under class S1, which is highly suitable land with no limitations for cultivation. The S2tw class occupied an area of 258.3 ha, indicating moderately suitable land with texture and drainage as limitations. This was followed by an area of 154.1 ha under class S2g, indicating moderately suitable land with gravelliness as a limitation, and an area of 137.5 ha under class S2rg, indicating moderately suitable land with rooting depth and gravelliness as limitations. About 118.3 ha area falls under the S2nz class, indicating moderately suitable land with nutrient availability and calcareousness as limitations. This is followed by an area of 44.8 ha under the S2tn class, indicating moderately suitable land with texture and nutrient availability as limitations. Manjunatha *et al.* (2017) reported comparable findings.

Action plan for sustainable development

Potential land use plan

Potential land use of the respective soil mapping units of Muddakkanahalli micro-watershed is listed in the Table 6. These units have information on soil type, its constraints, drainage condition and topography. Each of these resource units were compared with the present land use and where the resources were not utilized up to its potential, a potential land use practice was suggested to give the weightage to the local needs of the people. Based on the land suitability studies, the potential land use was suggested for each parcel of land. The alternate crops suggested are finger millet, redgram, soybean, maize, groundnut, custard apple, sapota, lime, mango, and pomegranate and it is specific to each survey number which is provided in Table 7.

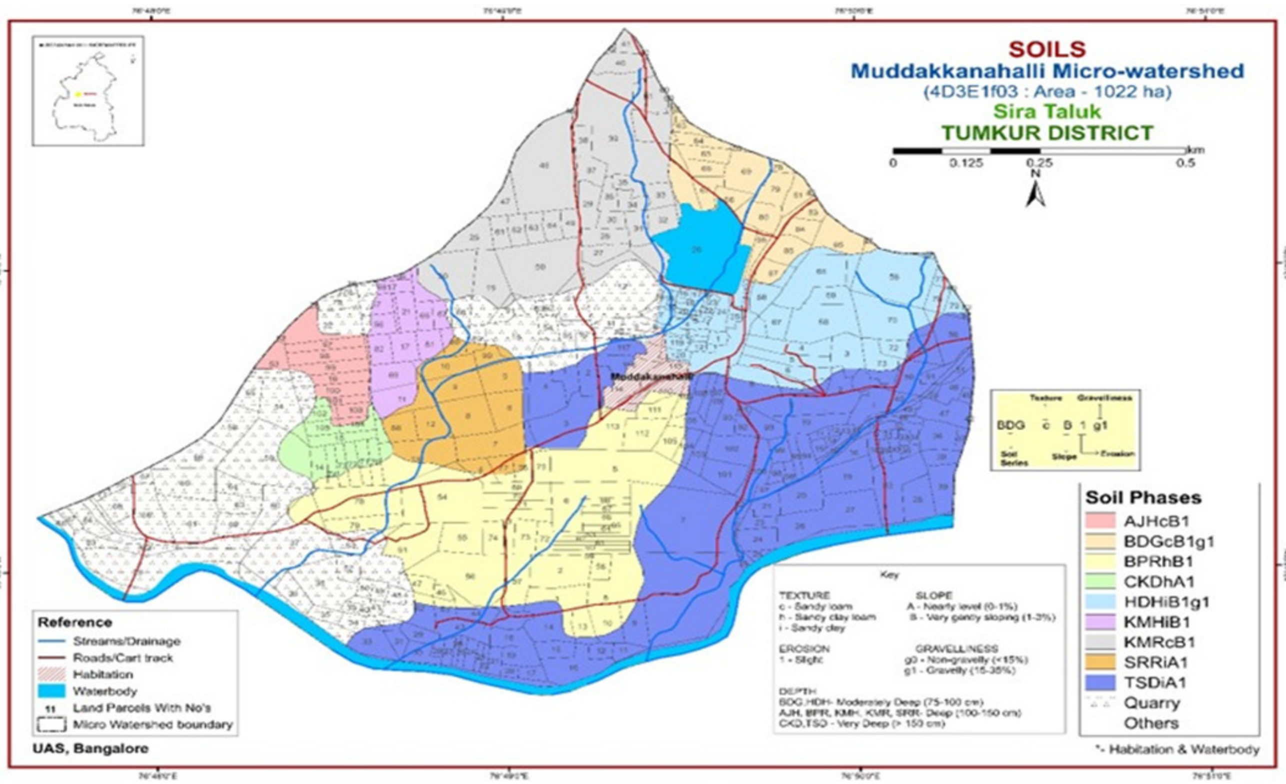

Fig. 4 : Soil mapping units of Muddakkanahalli micro-watershed

Table 7 : Proposed potential land crop plan for Muddakkanahalli micro-watershed, Sira Taluk, Tumkur District

Soil Map Units	Survey Number	Field Crops	Horticulture Crops	Suitable Interventions
BDGcB1g1	**Badakanahalli:** 58,65,87 **J.I. Maddakanahalli:** 33,39,62-70,78-88	**Sole crops:** Maize, Finger millet, Red gram, Groundnut, Soybean	**Fruit crops/Plantation crops:** Custard apple, Sapota, Lime, Pomegranate	• Application of organic manure • Use of short duration and drought resistant varieties • Sowing across slope in ridges and furrows • Split application of Nitrogen fertilizers • Strengthening of existing

				bunds • Construction of contour bunds/contour trench cum bunds
HDHiB1g1	**Badakanahalli:** 2-8, 50,56-59,65-73,78-80,82 **J.I. Maddakanahalli:** 1-8,13-25, 85-88,109,115,119-121	**Sole crops:** Maize, Finger millet, Red gram, Groundnut, Soybean	**Fruit crops/Plantation crops:** Custard apple, Sapota, Lime, Pomegranate	• Application of organic manure • Use of short duration and drought resistant varieties • Sowing across slope in ridges and furrows • Split application of Nitrogen fertilizers • Strengthening of existing bunds
AJHcB1 KMHiB1	**Holakallu:** 10,11,16,17,20-22,56-59,66-69,78-82,88,97-105 **Mosarukunte:** 52 and 53	**Sole crops:** Maize, Finger millet, Red gram, Groundnut, Soybean **Intercropping:** Finger millet + Cowpea (8:2), Finger millet + Field bean (8:2)	**Fruit crops/Plantation crops:** Custard apple, Sapota, Mango, Lime, Pomegranate **Intercropping:** Custard Apple + Finger millet	• Application of organic manure • Sowing across slope in ridges and furrows • Split application of Nitrogen fertilizers • Strengthening of existing bunds • Construction of contour bunds/contour trench cum bunds (for other surface texture)
BPRhB1	**Gajarehalli:** 1-10,13,14,37,42,44-47,51,53-79 **Holakallu:** 3,7,13,14,70-74 **J.I. Maddakanahalli:** 104-106,109-114 **Mosarukunte:** 60	**Sole crops:** Maize, Finger millet, Red gram, Groundnut, Soybean	**Fruit crops/Plantation crops:** Custard apple, Sapota, Mango, Lime, Pomegranate	• Application of organic manure • Sowing across slope in ridges and furrows • Split application of Nitrogen fertilizers • Strengthening of existing bunds • Construction of contour bunds/contour trench cum bunds
KMRcB1	**Balenahalli:** 40-42 **Holakallu:** 18-20,25,46-49,51,61-64,67,68,91 **J.I. Maddakanahalli:** 12,27-40,60,61,62	**Sole crops:** Maize, Finger millet, Red gram, Groundnut, Soybean **Intercropping:** Finger millet + Cowpea (8:2), Finger millet + Field bean (8:2)	**Fruit crops/Plantation crops:** Custard apple, Sapota, Mango, Lime, Pomegranate **Intercropping:** Custard Apple + Finger millet	• Application of organic manure • Sowing across slope in ridges and furrows • Split application of Nitrogen fertilizers • Strengthening of existing bunds • Construction of contour bunds/contour trench cum bunds • Addition of bio-fertilizers and micro-nutrients • Practice mulching • Drip irrigation • Addition of Green leaf manure • Application of Urea, Phosphatic fertilizers • Application phosphate solubilizing bacteria
SRRiA1	**Gajarehalli:** 4,54,76,77 **Holakallu:** 5-9,10-13,18,69,80,81,88-90	**Sole crops:** Maize, Red gram, Soybean	**Fruit crops/Plantation crops:** Custard apple, Lime, Pomegranate	• Application of organic manure • Growing of green manure crops in horticultural crops • Application of Nitrogen in split dose • Providing proper drainage

				• Addition of bio-fertilizers and micro-nutrients • Practice mulching
CKDhA1	**Holakallu:** 11,13-15,70-74,88,100-105 **Mosarukunte:** 54 and 59	**Sole crops:** Maize, Finger millet, Red gram, Groundnut, Soybean **Intercropping:** Finger millet + Cowpea (8:2), Finger millet + Field bean (8:2)	**Fruit crops/Plantation crops:** Custard apple, Sapota, Mango, Lime, Pomegranate **Intercropping:** Custard Apple + Finger millet	• Application of organic manure • Sowing across slope in ridges and furrows • Growing of green manure crops between the rows of horticultural crops • Split application of Nitrogen fertilizers • Strengthening of existing bunds • Addition of bio-fertilizers and micro-nutrients • Practice mulching • Drip irrigation
TSDiA1	**Badakanahalli:** 1-3,6-39,42,45-51,56,57,70-73,79,83 **Gajarehalli:** 1,7-34,42-45,57 **Holakallu:** 1-7 **J.I. Maddakanahalli:** 89-109, 114,116,117,118	**Sole crops:** Maize, Red gram, Soybean	**Fruit crops/Plantation crops:** Custard apple, Lime, Pomegranate	• Application of organic manure • Growing of green manure crops in horticultural crops • Application of Nitrogen in split dose • Providing proper drainage • Addition of bio-fertilizers and micro-nutrients • Practice mulching • Drip irrigation

Note:

- In BDGcB1g1 mapping unit, groundnut is marginally suitable because of subsurface red clay texture.
- In BDGcB1g1, HDHiB1g1 and BPRhB1 mapping units Maize, Finger millet, Redgram and Soybean crops are marginally suitable because of subsurface 35-60 per cent gravelliness.

Conclusion

The present study, therefore underscores the need to take into consideration the land capability and suitability assessments of crops in order to combat the degradative effects of proximate granite mining in Muddakkanahalli micro-watershed. Even though soil limitations such as severe gravelliness, poor texture and small rooting depth are major constraints to conventional cultivation of field crops, the region possesses a strong scope for hardy horticultural crops and intercrops. The alternate plans of land use provide a guideline to transform conventional agricultural practices to suitable crops such as custard apple, sapota and field crops. Finally, a combination of suitable crops along with efficient soil and water conservation practices would ensure optimal resource use, combating environmental degradation and ensuring agricultural sustainability.

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Conflict of interest

The authors declare no conflict of interest. All authors agree to publish it.

Declaration

We declare that all authors of this Ms. have made substantial contributions. We did not exclude any author who substantially contributed to this Ms. We have followed our ethical norms established by our respective institutions.

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