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RESEARCH PAPER

Soil-site suitability assessment for major cereal crops in the Ganjigatti sub-watershed, Karnataka using remote sensing and geographic information systems

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Abstract: Land evaluation is the assessment of the suitability for specified land uses. Land evaluation and quantitative land use systems analysis support the planning of sustainable use of land. Twenty-one soil series and their phases (sixty-one) identified and mapped during land resource inventory were evaluated for their soil-site suitability for major cereal crops in Ganjigatti sub-watershed, Dharwad district in Hilly zone (zone 9) of Karnataka for sustainable land use planning. The soil series were AKT (Attikatti), ASR (Adavisomapura), BGD (Bagadgeri), BGH (Bigudihala), BNK (Bhogenagarkoppa), BTP (Bettadapura), GJG (Ganjigatti), HNL (Hirehonnalli), HRG (Harugeri), KDK (Kadanakoppa), KMD (Kamadhenu), KRK (Kuradikeri), MLP (Mahalingpur), MRK (Mishrikoti), MVD (Mevundi), RMN (Ramanhala), SDK (Sangedevarakoppa), SGL (Singtalur), SSK (Surashettykoppa), UGK (Ugginakeri) and YSJ (Yelisirunj). Based on texture, depth, slope, erosion, graveliness and stoniness, the twenty-one soil series were mapped into sixty-one mapping units by using *Arc* GIS version 10.8. The soils were evaluated for potential soil site suitability for major cereal crops *viz.,* rice, wheat, maize, sorghum and pearl millet. Majority of soil mapping units are moderately (S2) and marginally suitable (S3) for cultivation due to moderate to severe limitations in climate, soil, drainage and slope per cent. The soil series BGD and MLP were currently not suitable due to very severe limitations of soil depth. These results could be used as baseline information for identifying specific soil resource constraints for sustainable production of these cereal crops in the study area.

Key words: *Arc* GIS, Cereal crops, Crop suitability classification, Ganjigatti sub-watershed, Soil depth

Introduction

To evaluate the potential and limitations of a specific land parcel for agricultural uses, a scientific method of land evaluation is necessary (Rositer, 1996). The negative environmental impacts of land use and the environmental sustainability of agricultural production systems have recently gained attention. In developed nations, intensive agriculture has been associated with issues like declining soil fertility, stagnant yield levels, and uncontrolled soil erosion, whereas in developing nations, intensive agriculture is linked to issues like overuse of natural resources and a lack of inputs like chemical fertilizers (Fresco, 1990; Lanen Van *et al.,* 1992). In this context, there is a more emphasis on the land evaluation for better land use options. The sustainability of agriculture is maintained via efficient land usage. According to FAO (1976), evaluating a land involves "the process of assessment of land performance when used for specified purposes." It entails carrying out and interpreting surveys and studies on landform, soils, vegetation, climate, and other relevant land factors for a comparison between prospective land use and/or specific land use. According to Wambeke and Rossiter (1987), land evaluation is the ranking of soil units based on their capacity to produce the maximum returns per unit area while preserving the natural resources for use in the future. Thus, interpretive groupings help assess the potential of various soils and make predictions about how they would behave under various management strategies. The most popular interpretive grouping used for land appraisal is the Land Suitability Classification (FAO, 1976). There are four steps in land evaluation: a) Characterising current soil, climate, and land use conditions; b) Creating soil-site criteria for crop requirements; c) Matching crop requirements with current soil and climate conditions; d) Finally, selecting the crop that best fits the situation as an alternative crop strategy. Therefore, soil-site suitability assessment is very crucial for selecting potential crops for a region and climatic conditions.

Remote sensing (RS) data can be used to delineate various physiographic units besides deriving ancillary information about site characteristics, *viz.*, slope, direction and aspect of the study area. However, detailed information on soil profile properties is essential for initiating crop suitability evaluation. Hence, soil survey data are indispensable for generating a soil map of the given region, which helps in determining crop suitability and cropping system analysis. RS data coupled with soil survey information can be integrated into the geographical information system (GIS) to assess crop suitability for various soil and biophysical conditions. The potential of the integrated approach for using GIS and RS data for quantitative land evaluation has been demonstrated earlier by several researchers (Hegde *et al.,* 2019; Chikkaramappa *et al.,* 2020). This research was conducted to show how remote sensing (RS) and geographic information system (GIS) data may be used together to evaluate soil-site suitability for the most common cereal crops farmed in the Ganjigatti sub-watershed of Karnataka, *viz.*, rice, wheat, maize, sorghum and pearlmillet.

Material and methods

The study area

The study was conducted in 2021–22, in the Ganjigatti sub-watershed (5B1A4F) of Dharwad district in Karnataka, situated between 15° 10^1 10.114″ to 15° 17^1 1.147″ N latitudes and 75° 0^1 57.672″ to 75° 4' 50.525″ E longitudes, with the highest elevation of 610 m above mean sea level. The total geographical area of the sub-watershed is about 4323.84 ha. The annual temperature ranges from 24.68 to 26.67 °C. The average rainfall in the sub-watershed was 917.00 mm (Fig. 1). Relative humidity varies from 28% in summer to 70% in winter. The average potential evapotranspiration (PET) is 150 mm and varies from 115 to 232 mm. The PET is always higher than precipitation in all the months except August and October. Generally, the length of growing period (LGP) for crops is 150 days and starts from 3rd week of June to third week of November.

Study method

After preliminary traversing of the entire sub-watershed using a 1:7,920 scale base map and satellite imagery, based on geology, drainage pattern, surface features, slope characteristics, land use, landforms and physiographic divisions, twenty-seven (27) soil profiles were selected and studied and their morphometric characteristics were recorded. Physical and chemical properties were estimated using standard procedures. A detailed soil resource inventory of the Ganjigatti sub-watershed was carried out and 21 series mapped into sixty-one (61) mapping units based on surface soil properties. After a detailed soil survey, crop suitability maps for major cereal or fruit crops growing in the Ganjigatti sub-watershed area at soil phase level were prepared by using the platform of *Arc* GIS V 10.8. Their suitability was assessed using the limitation method regarding the number and intensity of limitations (Naidu *et al.,* 2006). This evaluation procedure consists of three phases.

In phase I, the following landscape and soil characteristics (Table 1) were used to evaluate soil suitability: topography (% slope), wetness (flooding and drainage), physical soil characteristics (texture/structure, % coarse fragments by volume, soil depth in cm, $CaCO_3$ per cent), salinity (EC, dSm^{-1}) and alkalinity (ESP). The study locations were nearly level to moderately steep sloping and had never been flooded (F0). The drainage conditions were moderately well to well and sandy loam to clay in texture, as per the guidelines given by FAO (1976). Weighted mean of each property was calculated and soil-site characteristics of different soil units were obtained as shown in Table 1. These weighted average data have been used to evaluate the soil site suitability (FAO, 1976). In phase II, the landscape and soil requirements for these five crops (rice, wheat, maize, sorghum and pearlmillet) were taken from Naidu *et al*. (2006) as described by Sehgal (2005). In phase III, the land suitability under rainfed conditions has been assessed by comparing the landscape and soil characteristics with crop requirements at different limitation levels: no (0), slight (1), moderate (2), severe (3), and very severe (4). Limitations are deviations from the optimal conditions of a land characteristic, such as land quality, that adversely affect the kind of land use. If a land characteristic is optimal for plant growth, it has no limitation. On the other hand, when the same characteristic is unfavourable for plant growth, it has severe limitations for land evaluation types. Thus, the evaluation was done by comparing the land characteristics with the limitation levels of the crop requirement given by Naidu *et al.* (2006), as described by Seghal (2005). The number and degrees of limitations suggested the suitability class of each soil series for a particular crop, as given by FAO (1976).

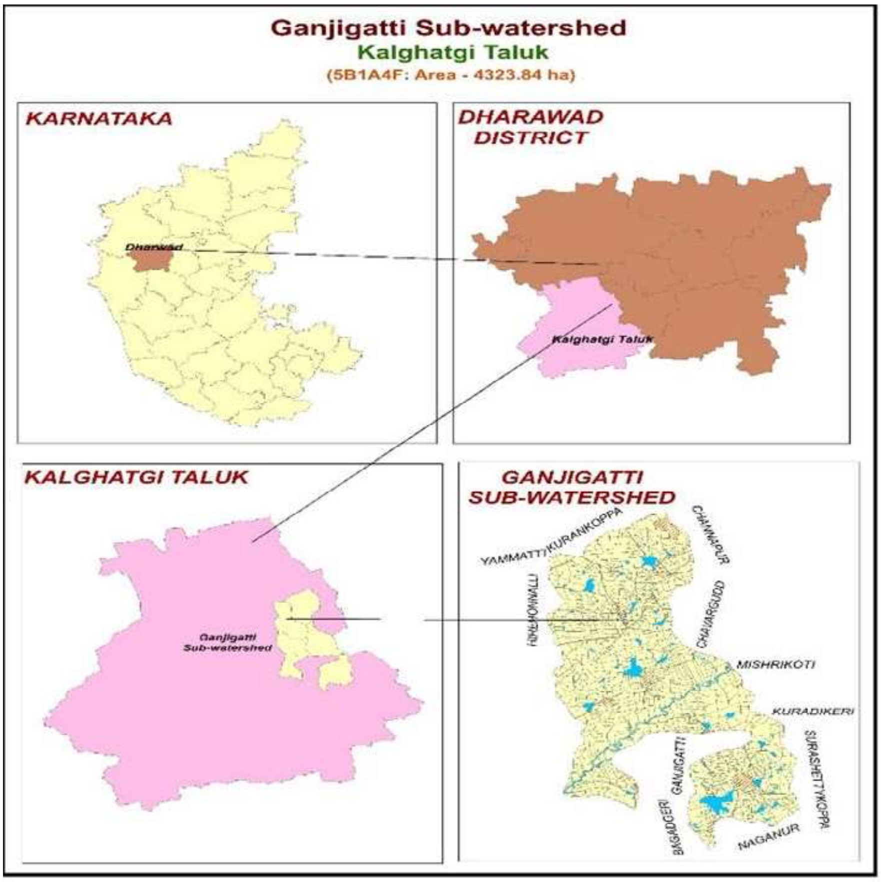

Fig 1. Location of the study area

Results and discussion

The soil properties of the study area were matched with the soil site suitability criteria for a few important cereal crops grown in north Karnataka. The soil suitability for major cereal crops is presented in Table 2.

3.1 Soil-site suitability evaluation for rice

Rice is primarily a tropical and subtropical crop. It is grown in a wide variety of climate-soil-hydrological regimes. It is a heat and water-loving plant. It requires a high temperature and an adequate water supply. Rice lands are classified according to water regimes into upland with no standing water,

Table 1. Soil-site characteristics of soil mapping units of Ganjigatti sub-watershed

Soil Phases	Wetness (w)	Physical condition of Soil (s)				Fertility (f)					Salinity/ alkalinity (n)		Erosion (e)
	Drainage	Texture	Depth (cm)	Stoniness	Gravel	$CaCO_3$ %	pH	OC (%)	CEC	BS (%)	EC (dS m^{-1})	ESP (%)	Slope %
AKTmB2R2	Moderately well	clay	79	Nil	<15%	3.21	7.18	0.48	59.33	72.52	0.28	1.48	1-3
ASRfB2	Well drained	clay loam	130	Nil	<15%	15.96	8.68	0.33	48.70	87.46	0.36	1.00	1-3
ASRfB2g1	Well drained	clay loam	130	Nil	15-35%	15.96	8.68	0.33	48.70	87.46	0.36	1.00	1-3
ASRmB2	Well drained	Clay	130	Nil	<15%	15.96	8.68	0.33	48.70	87.46	0.36	1.00	1-3
ASRmC3	Well drained	Clay	130	Nil	<15%	15.96	8.68	0.33	48.70	87.46	0.36	1.00	3-5
BGDhB2g1	Well drained	Sandy clay loam	20	Nil	15-35%	1.5	5.91	1.19	16.55	60.76	0.49	1.94	1-3
BGDhC3g2	Well drained	Sandy clay loam	20	Nil	35-60%	1.5	5.91	1.19	16.55	60.76	0.49	1.94	3-5
BGHfB2	Moderately well	Clay loam	90	Nil	<15%	7.35	7.33	0.6	23.64	85.7	0.3	2.19	1-3
BGHfB2g1	Moderately well	Clay loam	90	Nil	15-35%	7.35	7.33	0.6	23.64	85.7	0.3	2.19	1-3
BGHfB2g2	Moderately well	Clay loam	90	Nil	35-60%	7.35	7.33	0.6	23.64	85.7	0.3	2.19	1-3
BGHfC3	Moderately well	Clay loam	90	Nil	<15%	7.35	7.33	0.6	23.64	85.7	0.3	2.19	3-5
BGHfC3g1	Moderately well	Clay loam	90	Nil	15-35%	2.99	7.08	0.58	23.48	83.88	0.12	1.72	3-5
BGHfD3g2	Moderately well	Clay loam	90	Nil	35-60%	2.99	7.08	0.58	23.48	83.88	0.12	1.72	5-10
BGHhB2	Moderately well	Sandy clay loam	90	Nil	<15%	7.35	7.33	0.6	23.64	85.7	0.3	2.19	1-3
BGHhB2g1	Moderately well	Sandy clay loam	90	Nil	15-35%	7.35	7.33	0.6	23.64	85.7	0.3	2.19	1-3
BGHmB1g1St2	Moderately well	Clay	80	1-3	15-35%	3.5	6.83	0.83	43.84	77.7	0.18	0.53	1-3
BNKmB1	Well drained	Clay	35	Nil	<15%	2.81	7.23	0.53	28.34	69.91	0.22	2.42	1-3
BNKmB1g1	Well drained	Clay	35	Nil	15-35%	2.81	7.23	0.53	28.34	69.91	0.22	2.42	1-3
BNKmB2g1	Well drained	Clay	35	Nil	15-35%	2.81	7.23	0.53	28.34	69.91	0.22	2.42	1-3
BNKmC2g2	Well drained	Clay	35	Nil	35-60%	2.81	7.23	0.53	28.34	69.91	0.22	2.42	3-5
BTPmA1	Well drained	Clay	200	Nil	<15%	12.02	8.3	0.75	58.22	90.28	0.16	2.67	0-1
BTPmB2	Well drained	Clay	200	Nil	<15%	12.02	8.3	0.75	58.22	90.28	0.16	2.67	1-3
BTPmB2g1	Well drained	Clay	180	Nil	15-35%	13.28	7.82	0.45	37.39	89.51	0.36	2.63	1-3
GJGiB2	Moderately well	Sandy clay	55	Nil	<15%	3.76	7.22	0.66	22.68	71.53	0.22	1.48	1-3
GJGiB2g1	Moderately well	Sandy clay	55	Nil	15-35%	3.76	7.22	0.66	22.68	71.53	0.22	1.48	1-3
GJGiC3g1	Moderately well	Sandy clay	55	Nil	15-35%	3.76	7.22	0.66	22.68	71.53	0.22	1.48	3-5
HNLiC2g1	Moderately well	Sandy clay	67	Nil	15-35%	3.06	5.92	0.66	19.82	50.72	0.26	2.03	3-5
HNLiC2g2	Moderately well	Sandy clay	67	Nil	35-60%	3.06	5.92	0.66	19.82	50.72	0.26	2.03	3-5
HRGmB2	Moderately well	Clay	130	Nil	<15%	15.9	8.1	0.49	49.58	90.85	0.34	0.86	1-3
HRGmB2Ca	Moderately well	Clay	130	Nil	<15%	15.9	8.1	0.49	49.58	90.85	0.34	0.86	1-3
HRGmC3g1	Moderately well	Clay	130	Nil	15-35%	15.9	8.1	0.49	49.58	90.85	0.34	0.86	3-5
KDKhB2g1	Moderately well	Sandy clay loam	49	Nil	15-35%	2.89	6.42	0.53	59.33	72.52	0.16	0.84	1-3
KDKhC3g2	Moderately well	Sandy clay loam	49	Nil	35-60%	2.89	6.42	0.53	59.33	72.52	0.16	0.84	3-5
KDKhC3g3	Moderately well	Sandy clay loam	49	Nil	60-80%	2.89	6.42	0.53	59.33	72.52	0.16	0.84	3-5
KDKiB2	Well drained	Clay loam	35	Nil	<15%	2.53	6.84	0.76	23	69.1	0.22	1.87	1-3
KMDhC3g2	Well drained	Sandy clay loam	35	Nil	35-60%	0.91	5.36	0.73	11.15	49.67	0.1	1.82	3-5
KMDmB2	Well drained	Clay	35	Nil	<15%	0.91	5.36	0.73	11.15	49.67	0.1	1.82	1-3
KMDmB2g1	Well drained	Clay	35	Nil	15-35%	0.91	5.36	0.73	11.15	49.67	0.1	1.82	1-3
KRKfC2g1	Well drained	Clay loam	30	Nil	15-35%	2.65	5.61	0.58	20.03	68.16	0.09	2.07	3-5
KRKmC2g1	Well drained	Clay	40	Nil	15-35%	3.33	6.02	1.02	21.16	70.31	0.06	0.79	3-5
MLPdB1g1	Moderately well	loam	20	Nil	15-35%	1.35	5.83	0.58	23.62	49.72	0.11	2.22	1-3
MLPdC2g1	Moderately well	loam	20	Nil	15-35%	1.35	5.83	0.58	23.62	49.72	0.11	2.22	3-5

Contd…..

Soil Phases	Wetness (w)	Physical condition of Soil (s)					Fertility (f)				Salinity/ alkalinity (n)		Erosion (e)
	Drainage	Texture	Depth (cm)	Stoniness	Gravel	$CaCO_3$ %	pH	OC (%)	CEC	BS (%)	EC (dS m-1)	ESP (%)	Slope %
MLPdC2g2	Moderately well	loam	20	Nil	35-60%	1.35	5.83	0.58	23.62	49.72	0.11	2.22	3-5
MRKiB2	Moderately well	Sandy clay	28	Nil	<15%	3.21	7.18	0.48	26.49	64.29	0.28	1.48	1-3
MRKiB2g1	Moderately well	Sandy clay	28	Nil	15-35%	3.21	7.18	0.48	26.49	64.29	0.28	1.48	1-3
MVDfB2	Well drained	Clay loam	170	Nil	<15%	4.66	6.62	0.52	23.96	84.18	0.2	2.07	1-3
MVDfB2g1	Well drained	Clay loam	170	Nil	15-35%	4.66	6.62	0.52	23.96	84.18	0.2	2.07	1-3
MVDfD3	Well drained	Clay loam	170	Nil	<15%	4.66	6.62	0.52	23.96	84.18	0.2	2.07	5-10
RMNiC3g2	Well drained	Sandy clay	120	Nil	35-60%	3.2	8.28	0.64	17.35	90.34	0.18	4.65	3-5
RMNiD3g2	Well drained	Sandy clay	120	Nil	35-60%	3.2	8.28	0.64	17.35	90.34	0.18	4.65	5-10
SDKhB2	Moderately well	Sandy clay loam	39	Nil	<15%	3.81	6.45	0.56	27.41	69.55	0.16	0.81	1-3
SDKhB2g1	Moderately well	Sandy clay loam	39	Nil	15-35%	3.81	6.45	0.56	27.41	69.55	0.16	0.81	1-3
SDKiB2g1	Moderately well	Sandy clay	46	Nil	15-35%	3.85	6.68	0.72	19.92	87.4	0.14	2.61	1-3
SDKiC3g1	Moderately well	Sandy clay	46	Nil	15-35%	3.85	6.68	0.72	19.92	87.4	0.14	2.61	3-5
SGLmB1	Moderately well	Clay	180	Nil	<15%	15.05	8.13	0.45	53.97	92.99	0.21	1.36	1-3
SGLmB1g1	Moderately well	Clay	180	Nil	15-35%	15.05	8.13	0.45	53.97	92.99	0.21	1.36	1-3
SSKcD3g2	Moderately well	Sandy loam	30	Nil	35-60%	1.25	5.49	0.47	6.18	69.69	0.28	2.56	5-10
SSKcE3g2	Moderately well	Sandy loam	30	Nil	35-60%	1.25	5.49	0.47	6.18	69.69	0.28	2.56	10-15
SSKhC3g1	Moderately well	Sandy clay loam	30	Nil	15-35%	1.25	5.49	0.47	6.18	69.69	0.28	2.56	3-5
UGKmB2	Moderately well	Clay	65	Nil	<15%	3.05	7.13	0.64	29.03	58.28	0.24	1.81	1-3
YSJhB2g2	Moderately well	Sandy clay loam	30	Nil	35-60%	0.45	5.55	0.64	14.54	40.22	0.12	1.86	1-3

lowland with 5–50 cm standing water and deep water with >50 cm standing water (Naidu *et al.,* 2006). Low temperatures (13-21°C) at early growth stages, namely seedling, tillering, panicle initiation and anthesis, are most detrimental to obtaining high grain yields. High temperatures (35-40 °C) during the vegetative growth stage can result in reduced tillering. The average temperature required throughout the life cycle of the crop ranges from 21°C to 35°C. The average water requirement of rice crop ranges from 1110 to 1250 mm. Rice can be grown in a wide range of soil reactions (pH 4.5–8.0). The various factors that influence rice yield are texture, infiltration and permeability rate of the soil, which have a great influence on the selection of this crop. As it requires standing water, a structure less soil with high clay and silt content is required after puddling.

Based on the criteria and degree of limitation, the soil-site suitability of soil mapping units for rice has been worked out. The overall suitability class for rice (Table 2) showed that mapping units such AKTmB2R2, BGHfB2, BGHfB2g1, BGHfB2g2, BGHhB2, BGHhB2g1, BGHmB1g1St2, GJGiB2, GJGiB2g1, HRGmB2, HRGmB2Ca, SGLmB1, SGLmB1g1 and UGKmB2 are moderately suitable (S2) due to limitations with climate, drainage (moderately well), soil texture, depth and topography. Where as, mapping units namely ASRfB2, ASRfB2g1, ASRmB2, ASRmC3, BGHfC3, BGHfC3g1, BNKmB1, BNKmB1g1, BNKmB2g1, BNKmC2g2, BTPmA1, BTPmB2, BTPmB2g1, GJGiC3g1, HNLiC2g1, HNLiC2g2, HRGmC3g1, KDKhB2g1, KDKhC3g2, KDKhC3g3, KDKiB2, KMDhC3g2, KMDmB2, KMDmB2g1, KRKfC2g1, KRKmC2g1, MRKiB2, MRKiB2g1, MVDfB2, MVDfB2g1, RMNiC3g2, SDKhB2, SDKhB2g1, SDKiB2g1, SSKhC3g1 and YSJhB2g2 showed severe limitations of soil depth, well drainage, soil texture, $CaCO_3$ content and topography, which leads to marginal suitability (S3) for rice. The mapping units BGDhB2g1, BGDhC3g2, BGHfD3g2, MLPdB1g1, MLPdC2g1, MLPdC2g2, MVDfD3, RMNiD3g2, SDKiC3g1, SSKcD3g2 and SSKcE3g2 are not suitable (N) for growing rice crop, but the mapping units differ in degree and kind of limitations among them.

Rice crop on 717 ha (16.59% of TGA) (Fig 2) of sub-watershed area is moderately suitable (S2cwse) with limitations of climate (c), wetness (w), soil physical characteristics (s) and

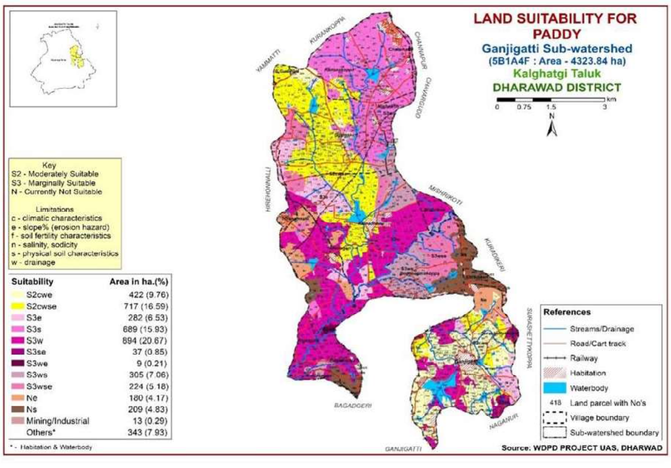

Fig. 2. Soil-site suitability map for rice crop in Ganjigatti sub-watershed

Table 2. Soil-site suitability classification of mapping units for major cereal crops

Soil Phases	Rice	Wheat	Maize	Sorghum	Pearl millet
AKTmB2R2	S2cwe	S2cs	S2ws	S2c	S2cws
ASRfB2	S3w	S2c	S1	S2cs	S3s
ASRfB2g1	S3w	S2c	S1	S2cs	S3s
ASRmB2	S3w	S2cs	S2s	S2cs	S3s
ASRmC3	S3we	S2cse	S2se	S2cse	S3s
BGDhB2g1	Ns	Ns	Ns	Ns	Ns
BGDhC3g2	Ns	Ns	Ns	Ns	Ns
BGHfB2	S2cwe	S2c	S2w	S2c	S2cws
BGHfB2g1	S2cwe	S2c	S2w	S2c	S2cws
BGHfB2g2	S2cwe	S2c	S2w	S2c	S2cws
BGHfC3	S3e	S2ce	S2we	S2ce	2cwse
BGHfC3g1	S3e	S2ce	S2we	S2ce	S2cwe
BGHfD3g2	Ne	S3e	S3e	S2ce	S3e
BGHhB2	S2cwse	S2c	S2w	S2c	S2cws
BGHhB2g1	S2cwse	S2c	S2w	S2c	S2cws
BGHmB1g1St2	S2cwe	S2cs	S2w	S2c	S2cw
BNKmB1	S3ws	S3s	S3s	S3s	S3s
BNKmB1g1	S3ws	S3s	S3s	S3s	S3s
BNKmB2g1	S3ws	S3s	S3s	S3s	S3s
BNKmC2g2	S3wse	S3s	S3s	S3s	S3s
BTPmA1	S3w	S2cs	S2s	S2c	S3s
BTPmB2	S3w	S2cs	S2s	S2cs	S3s
BTPmB2g1	S3w	S2cs	S2s	S2cs	S3s
GJGiB2	S2cwse	S2cs	S2ws	S2cs	S2cws
GJGiB2g1	S2cwse	S2cs	S2ws	S2cs	S2cws
GJGiC3g1	S3e	S2cse	S2wse	S2cse	2cwse
HNLiC2g1	S3e	S2cse	S2wse	S2cse	2cwse
HNLiC2g2	S3e	S2cse	S2wse	S2cse	2cwse
HRGmB2	S2cwse	S2cs	S2ws	S2cs	S3s
HRGmB2Ca	S2cwse	S2cs	S2ws	S2cs	S3s
HRGmC3g1	S3e	S2cse	S2wse	S2cse	S3s
KDKhB2g1	S3s	S3s	S3s	S3s	S3s
KDKhC3g2	S3s	S3s	S3s	S3s	S3s
KDKhC3g3	S3s	S3s	S3s	S3s	S3s
KDKiB2	S3ws	S3s	S3s	S3s	S3s
KMDhC3g2	S3wse	S3s	S3s	S3s	S3s
KMDmB2	S3ws	S3s	S3s	S3s	S3s
KMDmB2g1	S3ws	S3s	S3s	S3s	S3s
KRKfC2g1	S3wse	S3s	S3s	S3s	S3s
KRKmC2g1	S3wse	S3s	S3s	S3s	S3s
MLPdB1g1	Ns	Ns	Ns	Ns	Ns
MLPdC2g1	Ns	Ns	Ns	Ns	Ns
MLPdC2g2	Ns	Ns	Ns	Ns	Ns
MRKiB2	S3s	S3s	S3s	Ns	S3s
MRKiB2g1	S3s	S3s	S3s	Ns	S3s
MVDfB2	S3w	S2c	S1	S2c	S2c
MVDfB2g1	S3w	S2c	S1	S2c	S2c
MVDfD3	Ne	S3e	S3e	S2ce	S3e
RMNiC3g2	S3w	S2cse	S2se	S2ce	S2cse
RMNiD3g2	Ne	S3e	S3e	S2ce	S3e
SDKhB2	S3s	S3s	S3s	S3s	S3s
SDKhB2g1	S3s	S3s	S3s	S3s	S3s
SDKiB2g1	S3s	S3s	S3s	S3s	S3s
SDKiC3g1	Ne	S3s	S3s	S3s	S3s
SGLmB1	S2cwse	S2cs	S2ws	S2cs	S3s
SGLmB1g1	S2cwse	S2cs	S2ws	S2cs	S3s
SSKcD3g2	Ne	S3se	S3s	S3s	S3s
SSKcE3g2	Ne	Ne	Ne	S3se	Ne
SSKhC3g1	S3se	S3s	S3s	S3s	S3s
UGKmB2	S2cwse	S2cs	S2ws	S2cs	S2cws
YSJhB2g2	S3s	S3s	S3s	S3s	S3s

slope (e), followed by 422 ha (9.76% of TGA) area that is moderately suitable (S2cws) with limitations of climate (c), wetness (w) and soil physical characteristics (s). As per analysis in the GIS platform, rice crop representing 894 ha (20.67% of TGA) of sub-watershed area is marginally suitable (S3w) with limitations of wetness (w), followed by 689 ha (15.93% of TGA) area is marginally suitable (S3s) with limitations of soil physical characteristics (s), 305 ha (7.06% of TGA) area is marginally suitable (S3ws) with limitations of soil wetness (w) and physical characteristics (s), 224 ha (5.18% of TGA) area is marginally suitable (S3wse) with limitations of soil wetness (w), physical characteristics (s) and topography, 37 ha (0.85% of TGA) area is marginally suitable (S3se) with limitations of soilphysical characteristics (s) and topography (e), and 9 ha (0.21% of TGA) area is marginally suitable (S3we) with limitations of soil wetness (w) and topography. However, rice crop accounts for 209 ha (4.83% of TGA) of sub-watershed area that is not suitable (Ns) with very severe limitations of soil depth and texture (s), followed by 180 ha (4.17% of TGA) of area that is not suitable (Ne) with very severe limitations of slope% (e).The result revealed that factors like rainfall, temperature, depth, slope, erosion, texture and drainage were the major constraints that influenced the growth and productivity of paddy in the study area. Similar results were reported by Singha and Swain (2016); Bera *et al.* (2017); Zothansiami *et al.* (2017); Gogoi *et al.* (2018).

3.2 Soil-site suitability evaluation for wheat

Wheat is the world's number-one cereal crop. It is an annual crop and a very important winter crop, contributing about 32 per cent of the total food grain production in India. The most suitable temperature for germination and growth is 20-25°C. Well-distributed rainfall of 500–700 mm is conducive to proper growth. The average length of the growing period required was >150 days. Wheat is best adapted to well-drained loam to silt clay loam soils.The suitability of soil phases of Ganjigatti sub-watershed for growing wheat indicated that all the mapping units were categorized into moderately, marginally suitable and currently not suitable, having moderate to very severe limitations of climate, soil physical properties and land form characteristics. The areas of moderately (S2), marginally (S3) and currently not suitable class (N) for wheat were 2324 (53.75% of TGA), 1429 (33.05% of TGA) and 215 ha (4.97% of TGA), respectively (Fig 3).

The soil site suitability class S2 was subdivided into subclasses of S2c, S2ce, S2cs and S2cse based on the type of limitations. The mapping units under the subclass S2c are ASRfB2, ASRfB2g1, BGHfB2, BGHfB2g1, BGHfB2g2, BGHhB2, BGHhB2g1, BTPmA1, BTPmB2, BTPmB2g1, GJGiB2, GJGiB2g1, MVDfB2 and MVDfB2g1, moderately suitable for cultivation of wheat with moderate limitations of climatic factors such as rainfall, temperature and LGP; subclass S2ce (BGHfC3, BGHfC3g1) is moderately suitable for cultivation with moderate limitations of climatic factors such as rainfall, temperature and LGP and soil topography factors such as slope%; the mapping units under the subclass S2cs are AKTmB2R2, ASRmB2, BGHmB1g1St2, HRGmB2, HRGmB2Ca, SGLmB1, SGLmB1g1 and UGKmB2, moderately suitable for cultivation with moderate

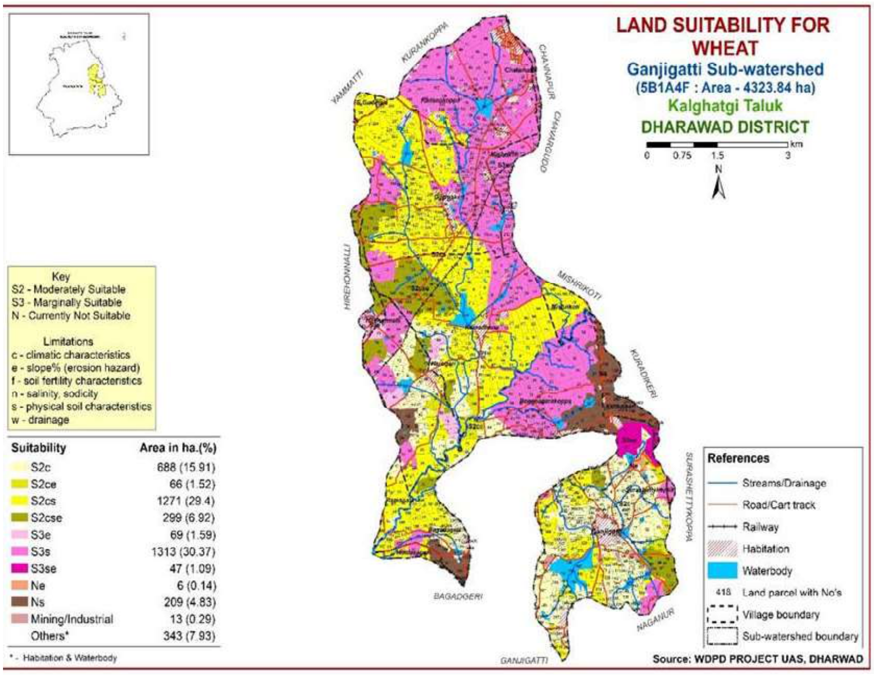

Fig. 3. Soil-site suitability map for wheat crop in Ganjigatti sub-watershed

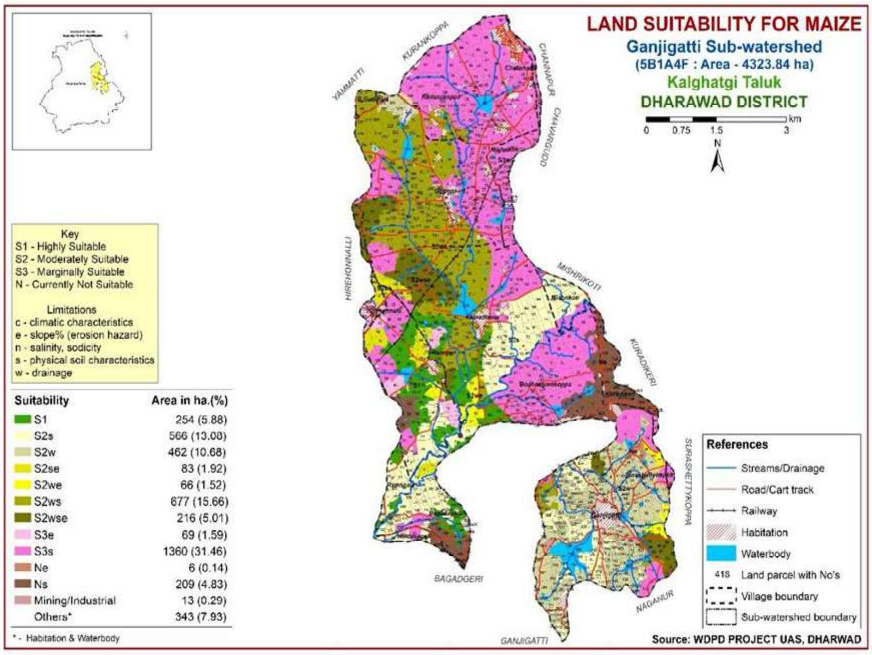

Fig. 4. Soil-site suitability map for maize crop in Ganjigatti sub-watershed

limitations of climatic factors and soil physical factors such as texture and depth; and whereas mapping units namely ASRmC3, GJGiC3g1, HNLiC2g1, HNLiC2g2, HRGmC3g1 and RMNiC3g2, are classified under subclass S2cse which is moderately suitable for cultivation of wheat with moderate limitations of climatic factors, soil physical factors and slope%. The area of S2c, S2ce, S2cs and S2cse sub-classes for wheat was 688 (15.91% of TGA), 66 (1.52% of TGA), 1271 (29.4% of TGA) and 299 ha (6.92% of TGA), respectively. Based on the types of limitations, the soil site suitability class S3 was subdivided into subclasses S3e, S3s and S3se. The subclass S3e mapping units include BGHfD3g2, MVDfD3 and RMNiD3g2, which are marginally suitable for cultivation of wheat with severe limitations of slope per cent; subclass S3s mapping units include BNKmB1, BNKmB1g1, BNKmB2g1, BNKmC2g2, KDKhB2g1, KDKhC3g2, KDKhC3g3, KDKiB2, KMDhC3g2, KMDmB2, KMDmB2g1, KRKfC2g1, KRKmC2g1, MRKiB2, MRKiB2g1, SDKhB2, SDKhB2g1, SDKiB2g1, SDKiC3g1, SSKhC3g1 and YSJhB2g2, which are marginally suitable for cultivation of wheat with severe limitations of soil physical factors such as texture and depth; and subclass S3se (SSKcD3g2) is marginally suitable for cultivation of wheat with severe limitations of soil physical factors and slope per cent. The area under the S3e, S3s and S3se suitability sub-classes of wheat was 69 (1.59% of TGA), 1313 (30.37% of TGA) and 47 ha (1.09% of TGA), respectively. The sub-classes Ne (SSKcE3g2) and Ns (BGDhB2g1, BGDhC3g2, MLPdB1g1, MLPdC2g1 and MLPdC2g2) are currently not suitable for wheat cultivation due to limitations in slope percent and soil physical factors such as depth and texture. The area under the Ne and Ns suitability sub-classes of wheat was 6 (0.14% of TGA) and 209 ha (4.83% of TGA), respectively. Similar results were also reported by Tripathi *et al.* (2006); Kumar *et al.* (2009 a and b) in the landforms of north Karnataka.

3.3 Soil-site suitability evaluation for maize

Maize is one of the most important cereals of the world. Maize crop requires an annual rainfall of 900-1000 mm, soil depth of more than 75 cm with sandy clay loam to clay loam texture, free of salinity, alkalinity and well drained soils. The most suitable temperature for germination is 21°C and for growth 32°C. Maize is very sensitive to stagnant water particularly during its early stages of growth. Maize is best adopted to well drained sandy loam to clay loam soils.The suitability of soil phases in the Ganjigatti sub-watershed for growing maize indicated that all the mapping units were highly suitable to currently not suitable (N), having none to slight, moderate, severe and very severe limitations of soil drainage, soil physical properties and limitations of land form characteristics. Areas of highly (S1), moderately (S2), marginally (S3) and currently not suitable (N) classes for maize were 254 (5.88% of TGA), 2071 (47.85% of TGA), 1429 (33.04% of TGA) and 215 ha (4.97% of TGA), respectively (Fig 4).

The mapping units, namely ASRfB2, ASRfB2g1, MVDfB2 and MVDfB2g1 are classified under soil site suitability class S1, which is highly suitable for maize cultivation without or with slight limitations. The soil site suitability class S2 is moderately suitable for maize cultivation with moderate limitations in soil drainage, soil physical factors and slope percentage. The S2 class was subdivided into S2s, S2se, S2w, S2we, S2ws and S2wse based on the types of limitations present. The mapping units under the subclass S2s are ASRmB2, BTPmA1, BTPmB2 and BTPmB2g1, moderately suitable for cultivation of maize with moderate limitations of soil physical factors such as texture, depth and stoniness; subclass S2se (ASRmC3 and RMNiC3g2) is moderately suitable for cultivation with moderate limitations of soil physical factors such as texture, depth and stoniness, and soil topography factors such as slope%; the mapping units under subclass S2w are BGHfB2, BGHfB2g1, BGHfB2g2, BGHhB2, BGHhB2g1 and BGHmB1g1St2, moderately suitable for cultivation due to moderate drainage conditions of the area; subclass S2we (BGHfC3 and BGHfC3g1) is moderately suitable for cultivation with moderate limitations of soil drainage and soil slope%; subclass S2ws mapping units include AKTmB2R2, GJGiB2, GJGiB2g1, HRGmB2, HRGmB2Ca, SGLmB1, SGLmB1g1 and UGKmB2, which are moderately suitable for cultivation with moderate limitations of soil physical factors such as texture, depth and stoniness, and soil drainage; and whereas mapping units namely GJGiC3g1, HNLiC2g1, HNLiC2g2 and HRGmC3g1, are classified under subclass S2wse, which are moderately suitable for cultivation of maize with moderate limitations of soil drainage, soil physical factors and slope%. The area of S2s, S2se, S2w, S2we, S2ws and S2wse sub-classes for maize was 566 (13.08% of TGA), 83 (1.92% of TGA), 462 (10.68% of TGA), 66 (1.52% of TGA), 677 (15.68) and 217 ha (5.00% of TGA), respectively.

Based on the types of limitations, the soil site suitability class S3 was subdivided into subclasses S3e and S3s. Subclass S3e is marginally suitable for cultivation of maize with severe limitations of slope per cent, which includes BGHfD3g2, MVDfD3 and RMNiD3g2; and mapping units under subclass S3s are BNKmB1, BNKmB1g1, BNKmB2g1, BNKmC2g2, KDKhB2g1, KDKhC3g2, KDKhC3g3, KDKiB2, KMDhC3g2, KMDmB2, KMDmB2g1, KRKfC2g1, KRKmC2g1, MRKiB2, MRKiB2g1, SDKhB2, SDKhB2g1, SDKiB2g1, SDKiC3g1, SSKcD3g2, SSKhC3g1 and YSJhB2g2, marginally suitable for cultivation with severe limitations of soil physical factors such as texture, depth and stoniness. The area under the S3e and S3s suitability sub-classes of maize was 69 (1.59% of TGA) and 1360 (31.45% of TGA), respectively. The sub-classes Ne (SSKcE3g2) and Ns (BGDhB2g1, BGDhC3g2, MLPdB1g1, MLPdC2g1 and MLPdC2g2) are currently not suitable for maize cultivation due to limitations in slope percent and soil physical factors such as depth and texture. The area under the Ne and Ns suitability sub-classes of maize was 6 (0.14% of TGA) and 209 ha (4.83% of TGA), respectively.Similar results were reported by Tripathi *et al.* (2006) in a micro-watershed of Kiar-Nagali, and the results are also supported by moderate limitations of texture, depth, and drainage have also been reported by Manojkumar (2011) in Bastawad micro-watershed of Northern transition zone of Karnataka and Manjunatha Chari (2015) in Chikmageri micro watershed in Karnataka.

3.4 Soil-site suitability evaluation for sorghum

Sorghum is referred to as the “camel” among crops as it can withstand drought greatly (Naidu *et al.,* 2006). It is one of the four major food crops of the world and millions of people in Africa and Asia depend of sorghum as staple food (FAO, 2008). In India, sorghum ranks third in the major food grain crops. It provides carbohydrates to 250 million people residing in the semi-arid zones of peninsular and central India. Sorghum crop requires an annual rainfall of >650 mm, soil depth of more than 75 cm with sandy clay loam to clay loam texture, free of salinity, alkalinity and well drained soils. The most suitable temperature for germination and growth 26^{o}C to 30^{o}C.The suitability of soil phases in the Ganjigatti sub-watershed for growing sorghum indicated that all the mapping units were with moderately, marginally suitable and currently not suitable category, having moderate to very severe limitations of climate, soil physical properties and land form characteristics. The areas of moderately (S2), marginally (S3) and currently not suitable classes (N) for sorghum were 2394 (55.34% of TGA), 1048 (24.23% of TGA) and 528 ha (12.20% of TGA), respectively (Fig 5).

The soil site suitability class S2 was subdivided into subclasses of S2c, S2ce, S2cs and S2cse based on the type of limitations. The mapping units AKTmB2R2, BGHfB2, BGHfB2g1, BGHfB2g2, BGHhB2, BGHhB2g1, BGHmB1g1St2, BTPmA1, MVDfB2 and MVDfB2g1 are classified under the subclass S2c

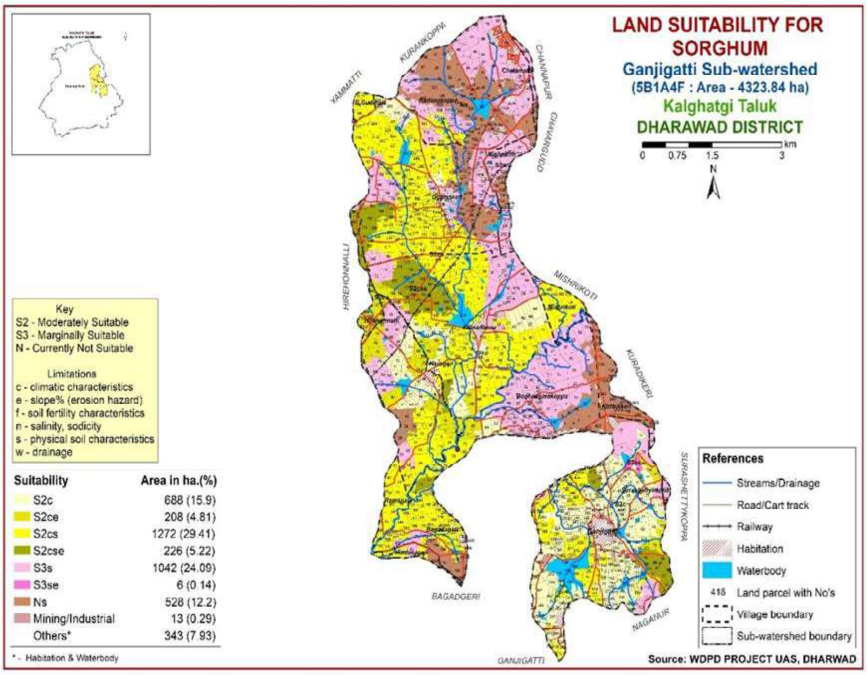

Fig. 5. Soil-site suitability map for sorghum crop in Ganjigatti sub-watershed

is moderately suitable for cultivation of sorghum with moderate limitations of climatic factors such as mean annual temperature; the mapping units under subclass S2ce are BGHfC3, BGHfC3g1, BGHfD3g2, MVDfD3, RMNiC3g2 and RMNiD3g2, moderately suitable for cultivation with moderate limitations of mean annual temperature and soil topography factors such as slope%; subclass S2cs, mapping units include ASRfB2, ASRfB2g1, ASRmB2, BTPmB2, BTPmB2g1, GJGiB2, GJGiB2g1, HRGmB2, HRGmB2Ca, SGLmB1, SGLmB1g1 and UGKmB2, which are moderately suitable for cultivation with moderate limitations of climatic factors and soil physical factors such as texture, depth and $CaCO_3$ content; and subclass S2cse (ASRmC3, GJGiC3g1, HNLiC2g1, HNLiC2g2 and HRGmC3g1) is moderately suitable for cultivation of sorghum with moderate limitations of climatic factors, soil physical factors and slope%. The area of S2c, S2ce, S2cs and S2cse sub-classes for sorghum was 688 (15.91% of TGA), 208 (4.81% of TGA), 1272 (29.41% of TGA) and 226 ha (5.22% of TGA), respectively.

Based on the types of limitations, the soil site suitability class S3 was subdivided into subclasses S3s and S3se. Subclass S3s includes the mapping units BNKmB1, BNKmB1g1, BNKmB2g1, BNKmC2g2, KDKhB2g1, KDKhC3g2, KDKhC3g3, KDKiB2, KMDhC3g2, KMDmB2, KMDmB2g1, KRKfC2g1, KRKmC2g1, SDKhB2, SDKhB2g1, SDKiB2g1, SDKiC3g1, SSKcD3g2, SSKhC3g1 and YSJhB2g2, which are marginally suitable for cultivation with severe limitations of soil physical factors such as texture, $CaCO_3$ content and depth, and subclass S3se (SSKcE3g2) is marginally suitable for cultivation of sorghum with severe limitations of soil physical factors and slope percent. The area under the S3s and S3se suitability sub-classes of sorghum was 1042 (24.09% of TGA) and 6 ha (0.14% of TGA), respectively. The mapping units BGDhB2g1, BGDhC3g2, MLPdB1g1, MLPdC2g1, MLPdC2g2, MRKiB2 and MRKiB2g1 were included under sub-class Ns, which are currently not suitable for sorghum cultivation due to limitations in soil depth. The area under the Ns suitability sub-classes of sorghum was 528 (12.2% of TGA).The results lined with Gabhane *et al.* (2006), Ravikumar *et al.* (2009); Manojkumar (2011), Anilkumar *et al.* (2019); Chikkaramappa *et al.*(2020); D Souza and Patil (2021).

3.5 Soil-site suitability evaluation for pearlmillet

Pearlmillet is an important small millet grown in India. Pearlmillet crops require an annual rainfall of 500–750 mm, a soil depth of more than 75 cm, sandy clay loam to clay loam texture, soils free of salinity and alkalinity, and well-drained soils. The most suitable temperature for germination and growth is 28 °C to 32 °C.The suitability of soil phases in the Ganjigatti sub-watershed for growing pearlmillet indicated that all the mapping units were moderately, marginally suitable and currently not suitable, having moderate to very severe limitations of climate, soil physical properties and land form characteristics. The areas of moderately (S2), marginally (S3) and currently not suitable (N) classes for pearlmillet were 1093 (25.27% of TGA), 2661 (61.53% of TGA) and 215 ha (4.97% of TGA), respectively (Figure 6).

The soil site suitability class S2 is moderately suitable for pearlmillet cultivation with moderate limitations in climate factors, soil drainage, soil physical factors and slope%. The S2 class was subdivided into S2c, S2cw, S2cse, S2cwe, S2cws and S2cwse based on the types of limitations present. Sub class S2c (MVDfB2 and MVDfB2g1) is moderately suitable for cultivation of pearlmillet with moderate limitations of climatic factor such mean annual temperature; subclass S2cw (BGHmB1g1St2) is moderately suitable for cultivation with moderate limitations of climatic factors and soil drainage; subclass S2cse (RMNiC3g2) is moderately suitable for cultivation with moderate limitations of mean annual temperature, soil physical factors such as texture, depth and $CaCO_3$ content and slope per cent; subclass S2cwe (BGHfC3g1) is moderately suitable for cultivation with moderate limitations of mean annual temperature, soil drainage and soil sloppiness; the mapping units AKTmB2R2, BGHfB2, BGHfB2g1, BGHfB2g2, BGHhB2, BGHhB2g1, GJGiB2, GJGiB2g1 and UGKmB2, classified under subclass S2cws, which are moderately suitable for cultivation with moderate limitations of mean annual temperature, soil physical factors such as texture, depth and $CaCO_3$ content, and soil drainage; and whereas mapping units namely BGHfC3, GJGiC3g1, HNLiC2g1 and HNLiC2g2, are classified under subclass S2cwse, which are moderately suitable for cultivation of pearlmillet with moderate limitations of mean annual temperature, soil drainage, soil physical factors and slope%. The area of S2c, S2cw, S2cse, S2cwe, S2cws and S2cwse sub-classes for pearlmillet was 175 (4.04% of TGA), 28 (0.66% of TGA), 74 (1.70% of TGA), 14 (0.32% of TGA), 545 (12.61) and 257 ha (5.94% of TGA), respectively.

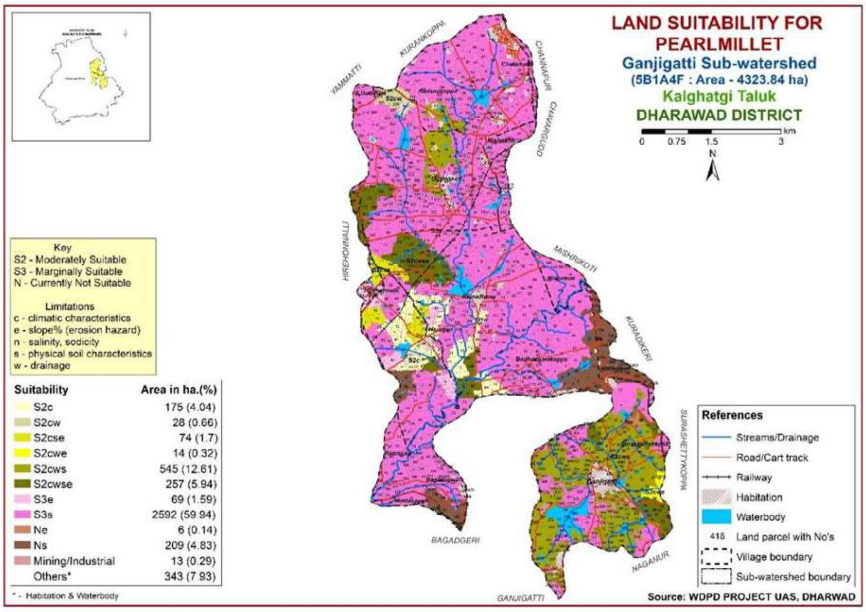

Fig. 6. Soil-site suitability map for pearlmillet crop in Ganjigatti sub-watershed

Based on the types of limitations, the soil site suitability class S3 was subdivided into subclasses S3e and S3s. Subclass S3e (BGHfD3g2, MVDfD3 and RMNiD3g2) is marginally suitable for pearl millet cultivation due to severe limitations of sloppiness, where as subclass S3s includes the mapping units ASRfB2, ASRfB2g1, ASRmB2, ASRmC3, BNKmB1, BNKmB1g1, BNKmB2g1, BNKmC2g2, BTPmA1, BTPmB2, BTPmB2g1, HRGmB2, HRGmB2Ca, HRGmC3g1, KDKhB2g1, KDKhC3g2, KDKhC3g3, KDKiB2, KMDhC3g2, KMDmB2, KMDmB2g1, KRKfC2g1, KRKmC2g1, MRKiB2, MRKiB2g1, SDKhB2, SDKhB2g1, SDKiB2g1, SDKiC3g1, SGLmB1, SGLmB1g1, SSKcD3g2, SSKhC3g1 and YSJhB2g2, which are marginally suitable for cultivation of sorghum due to severe limitations of soil physical factors such as texture, depth and $CaCO_3$ content. The area under the S3e and S3s suitability sub-classes of maize was 69 (1.59% of TGA) and 2592 (59.94% of TGA), respectively. The sub-classes Ne (SSKcE3g2) and Ns (BGDhB2g1, BGDhC3g2, MLPdB1g1, MLPdC2g1 and MLPdC2g2) are currently not suitable for pearlmillet cultivation due to limitations in slope percent and soil depth. The area under the Ne and Ns suitability sub-classes of pearlmillet was 6 (0.14% of TGA) and 209 ha (4.83% of TGA), respectively. Similar results lined with Madhusudan (2019) and D Souza and Patil (2021).

Conclusion

The soils in the Ganjigatti sub-watershed were found to be suitable for growing rice, wheat, maize, sorghum, and pearlmillet, albeit to varying degrees. Majority of soil mapping units are moderately (S2) and marginally suitable (S3) for cultivation due to moderate to severe limitations in climate, soil, drainage and slope per cent. Thesoil series BGD and MLP were currently not suitable due to very severe limitation of soil depth. The main limitations in all the soil mapping units found to be shallow soil depth, slope, texture, $CaCO_3$ content and climatic factors. However, the degree of these limitations in all these soil series varies from slight to very severe. In order to map specific soil resource limits for sustainable production of these crops in the study area, the results of this research could serve as a foundational data set. In order to improve lucrative land use planning decision support for sustainable crop production in the research area, the combination of remote sensing and GIS techniques might be envisioned as a commendable resource sustainable way to modelling the growth of these crops.

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