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Evaluation of agricultural land resources for irrigation in the cotton growing Yavatmal district, Maharashtra, India

B. P. Bhaskar[1*], Jadish Prasad[1] and Gopal Tiwari[1]

[1]Division of Soil Resource Studies, ICAR-National Bureau of Soil Survey and Land Use Planning, Amravati road, Nagpur-440033 (Maharashtra), INDIA
[*]Corresponding author. E-mail: bhaskar_phaneendra@yahoo.co.in

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Abstract: The main objective of this study is to evaluate suitability of shrink-swell soils for surface irrigation system based upon a parametric evaluation system in low irrigation potential (7%) of cotton growing Yavatmal district, Maharashtra, India. The thirty three shrink-swell soil series on basaltic landforms were identified from reconnaissance soil survey on 1:50,000 scale and evaluated for surface irrigation methods using Geographic Information System (GIS). The standard weekwise rainfall data showed that the rainfall is less than 20% of total precipitation during September and December, the top A horizon reaches to wilting point and needs supplementary protective irrigation to cotton based cropping systems . It was estimated that ten soil mapping units (1.8 Mha and 13.89%) of shrink-swell soils on moderate slopes (5 to 8%) were evaluated as suitable for surface methods and calculated the irrigation intervals that vary from 8.61±1.35 days for cotton to 8.9±1.4 days for wheat and 10±1.64 days for sugar cane. The study emphasized the utility of soil resource maps helps to delineate the soils with large PAWC(>200mm) with slight yield advantage and will serve as benchmark sites to monitor the interrelationships of soil water dynamics with respect to climate and cotton yields.

Keywords: Land suitability evaluation, Parametric method, Soil series , Surface irrigation

INTRODUCTION

Maharashtra has an area of 307,780 km^2, of which 225,000 km^2 is cultivable. Twenty per cent of the cultivable area is served by irrigation infrastructure. Today, the irrigated infrastructure covers 4.5 million hectare (Mha), as compared with potentially irrigable area of 12.6 Mha (that includes ground water irrigation potential) (Chivate, 2010). The irrigation developed so far till June, 2005 is 0.874 Mha from state sector schemes and 0.304 Mha from local sector schemes (total 1.178 Mha). Irrigation potential created as a percent of gross sown area is only 19% for the region as a against 30% irrigation coverage for drought proofing. The soil resource inventories in Maharashtra have shown that 1.5% total geographical area (TGA) in command areas of Godavari, Ghod, Purna, Manar, Mula, Pravara, Nira and Krishna river basins was occupied by moderately to strongly saline/sodic soils (Challa *et al.*, 1995). The parameterric system was used to evaluate land suitability for both surface and drip irrigation in the Ben Slimane province, Morocco (Briza *et al.,* 2001 and Bazzani *et al.,* 2002) and in Senegal (Bienvenue *et al.,* 2003). Likewise, parametric system using GIS was used to determine suitable areas for different irrigation methods in arid parts of southern Ankara and reported that drip type of irrigation system is suitable for more than half of the study area due to soil and topographic limitations (Dengiz*,* 2006), whereas in north Molasani plain in Iran, it was reported that drainage and calcium carbonates are limiting factors for surface and drop methods (Albaji *et al.,* 2008 and 2014). Similar kind of excercises were reported in evaluating Vertisols and vertic intergrades of basaltic terrain in Jayakwadi command area revealed that these soils have fair to poor productivity with severe limitations of sodicity, low permeability and effective rooting depth for irrigation (Bhaskar *et al.,* 2002 & 2014b) and of sodicity, erosion, drainage, organic carbon and calcium carbonate in Mula command area of Ahmednagar (Kharche *et al.,* 2010). Henceforth, the objective this study is to evaluate and compare the suitability of Vertisols and vertic intergrades for gravity and drop irrigation methods in semiarid and drought prone cotton growing Yavatmal district in Maharashtra where irrigation potential is 6.8% of total cultivated area .

MATERIALS AND METHODS

Description of study area: Yavatmal in the eastern (Vidharbha) region of the Maharashtra state lies between 19^{0}26' to 20^{0}42'N Latitude and 77^{0}18' to 79^{0}98'E Longitude. This district covers 13,582 km^2 area (4.41% of the state) with a population of 20, 77,144 (2.63% of the state) and 43% of rural families

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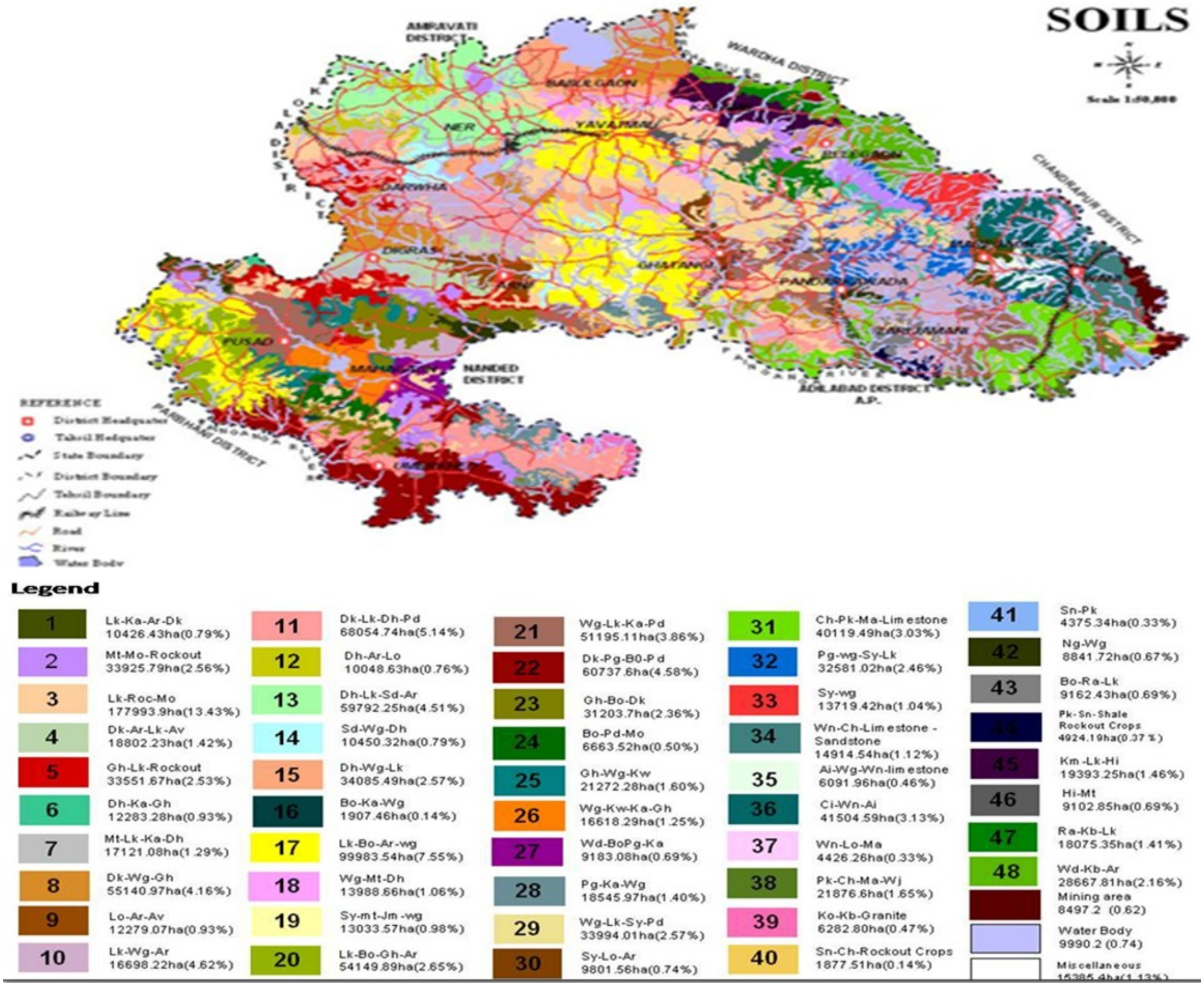

Fig.1. *Soil map of Yavatmal district with legend.*

live below poverty line. The total cultivated area is 8.84 lakh ha with double cropped area of 41,189 ha with low cropping intensity (101%) and low irrigation potential (7%). This district comes under Deccan Plateau, hot semi-arid eco-region of Western Maharashtra plateau and hot moist semi-arid eco-subregion (Mandal *et al.,* 2005). The mean annual rainfall ranges from 1125 mm in eastern parts of Wani to 962 mm in western parts of Darwha and 1180 mm in central portion of Yavatmal showing an increasing trend as one proceeds from West to East. Tehsil wise average rainy days and average rainfall (mm) is recorded as mean rainfall of 1180 mm with 62 average rainy days in Yavatmal tehsil (Northern side) to minimum of 587 mm of rainfall in Ner tehsil with 47 rainy days. The major crops are cotton (52% of total area) followed by Jowar (22%) and Redgram (6.6%) . The water balance diagram of Yavatmal shows that the black soils in the region are saturated with water and kept close to field capacity due to the 70 to 80% of monsoon rainfall concentrated from June to August. The standard weekwise rainfall data shows that the average amount of weekly rainfall is varied from 52.04mm in 24th week to 65.89 mm at 35th week with variation of 76.53 % to 93.5% of corresponding weeks. The mean rainy days are more or equal to 4 during 26th week to 33rd week with less than 50 per cent of variation. As the cotton crop calendar extends upto 45th week, there is reduction in amount of rainfall from 38th week from 32.77mm to 1.36mm at 43rd week (Bhaskar *et al*., 2014a). The dry stage is often with at least 15 days of dry spells after September 15th in the region. The rainfall is less than 20% of total precipitation during September and December which is in coincidence of rapid growth of cotton with flowering and boll development stages. During this period, the top A horizon reaches to wilting point and needs supplementary protective irrigation to cotton.

Land resource data: A Reconnaissance soil survey was carried out using 1:50000 scale toposheets of Survey of India (SOI) and Indian Remote Sensing (IRS)-P6 false colour composites satellite (11th April -10th

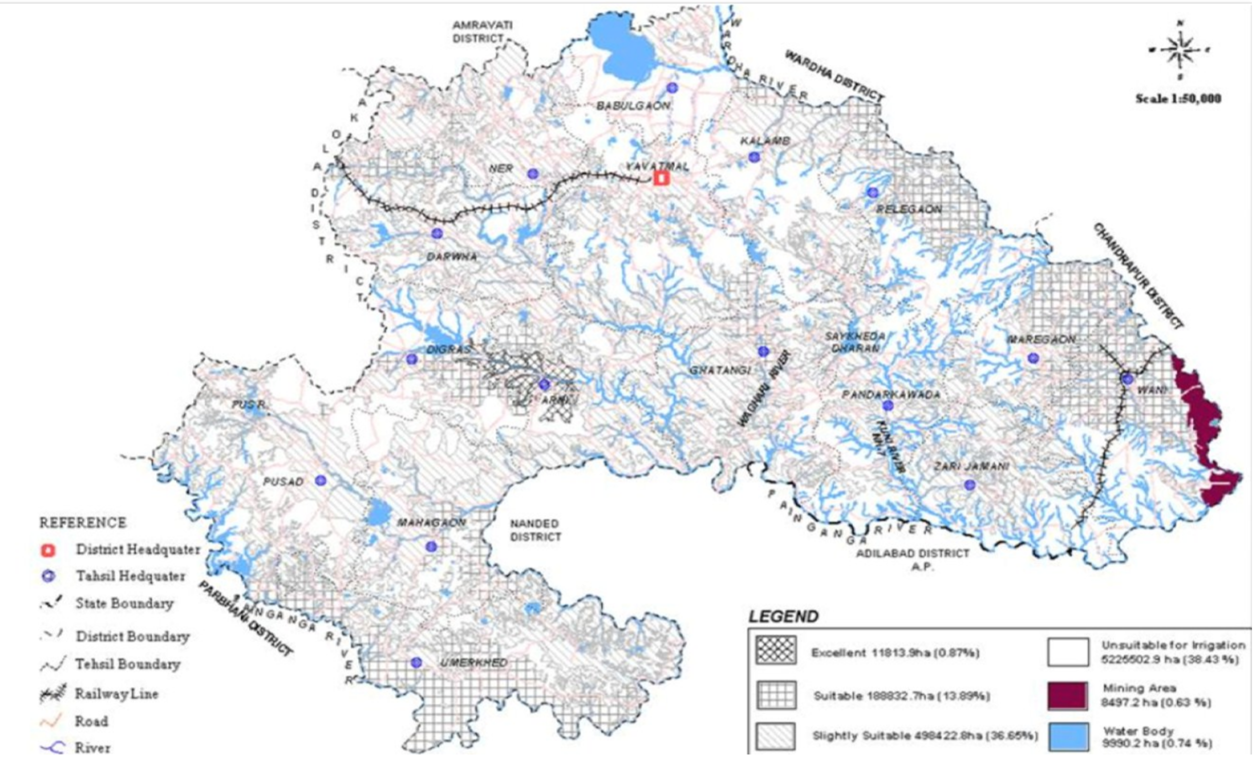

Fig. 2. *Agricultural land suitability for surface irrigation.*

May, 2006) as base maps for field as per the standard procedures (Martínez Beltrán, 1993). Fourteen landforms were identified such as hills and ridges in northern and central parts of Yavatmal (12.6% of total area), upper, middle and lower plateaus (398,240.4 ha and 29.34% of total area). Isolated hills/elongated hills mesa and butte, escarpments, upper and lower pediplains (17.74%) and gently to moderately sloping alluvial plains, very gently sloping to gently sloping plain, intervening valleys in south western parts (8.05%) and gullied stony gravelly wastelands (3.4%). A total of 1450 soil profiles were studied upto a depth of 2m or to lithic contact and recorded morphological properties as per Schoeneberger *et al.* (2002). The soil profiles were classified as per keys to soil taxonomy (Soil Survey Staff, 2014). Thirty three soil series were defined as per the criteria of Reddy (2006). The soil map of Yavatmal district in Geo-media environment was derived with 48 mapping units (Fig. 1).

Laboratory analysis: Horizon wise soil samples were collected and sieved air dry samples through 2 mm sieve for fine earth fraction. The routine and standard procedures were used for particle size analysis by international pipette method, bulk density by clod method, pH, Electrical conductivity (1:2.5 soil water ratio), organic carbon by wet digestion method, calcium carbonate by acid neutralization method, exchangeable bases with 1 *N* ammonium acetate extractable and cation exchange capacity (CEC) with ammonia distillation method (Jackson, 1973) and water retention at -33 kPa and -1500 kPa using pressure plate membrane apparatus (Richards,1954).

Land evaluation for irrigation: The steps followed in land evaluation for irrigation and in deriving thematic map of suitability zones for irrigation were as follows:

Step 1.Soil map with limiting symbol formula was used to define limitations of each series in the numerator and topography / drainage in the denominators.

Step 2. Development of capability index and soil units were rated by multiplying the proportion of each soil type by its respective soil rating.

Step.3.Decision rules were proposed for irrigation and derived priority areas suitable for irrigated agriculture using Geo-media.

Parametric evaluation: The parametric evaluation system from Sys *et al*. (1991 & 1993) was applied using standard granulometrical and physico-chemical characteristics of a soil profile. The different land characteristics that influence the soil suitability for irrigation are rated and a capability index for irrigation (Ci) is calculated according to the formula:

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

Where A= rating of soil texture,B= rating of soil depth,C: rating of $CaCO_3$ status,
D:salinity/alkalinity rating,E: drainage rating and F: slope rating.

The suitability of shrink – swell soils for irrigation were done by considering soil texture (weighted average to adepth of 100cm), soil depth(thickness and horizon sequences), calcium carbonate content (upto

150cm), salinity, drainage and slope(%). The rating scheme for suitability for irrigation is presented in table 1.

Rating soil mapping units: Soil units mapped as complexes were rated by multiplying the proportion of each soil type. The sum of total area of each soil series in the unit to get respective final soil rating (AAFRD, 2004). For example: Soil mapping unit Lo-Ar-Av.

Proportion of unit (%)	Capability index	Partial soil rating
35 (Loni series)	90	3150
35 (Arni series)	73	2555
30 (Arunavati series)	81	2430
Final soil rating		8135

The capability classes are defined according to the value of the capability (or suitability) index (Ci).

Capability index	Class	Definition	Symbol
>80	1	Excellent	S1
60-80	II	Suitable	S2
45-60	III	Slightly suitable	S3
30-45	IV	Almost unsuitable	N1
<30	V	Unsuitable	N2

Available depth of soil water: Available depth of water is calculated as per the formulae of Gardner *et al*. (1984)

$$d= \frac{Fc - PWP}{100}.BD.D$$

Where FC = field capacity (Water held at -33 kPa), PWP = permanent wilting point (water held at -1500 kPa), BD = bulk density (Mg m^{-3}), D = thickness of horizons.

For each series, these values were calculated, multiplied with proportion of series in each soil mapping unit and summation of series association was considered as final value for each mapping unit. These values were used for computing Irrigation interval as

$$\frac{Allowable\ soil\ water\ depletion}{Daily\ water\ use}$$

The allowable soil water depletion was 50% for wheat and cotton and 65% for sugarcane and daily water use was 0.6 $mmday^{-1}$ for wheat, 0.75 $mmday^{-1}$ for cotton and 0.95 $mmday^{-1}$ for sugar cane (Mohan and Arumugam, 1994).

RESULTS AND DISCUSSION

Brief description of soil series: The important morphological characteristics of these basaltic soils shows that the occurrence of well drained , dark grey and clay textured he shallow Lakhi and very shallow Gahuli series on hills and ridges (Table 2). These soils are associated with moderately deep Hirdi series having dark brown matrix, with distinct slickensides within 1m on upper plateaus and mildly alkaline shallow Jamwadi, strongly alkaline very deep Kalmab and moderately deep Katherwadi series on middle plateaus and moderately alkaline Koulambi series on lower plateaus. The Korta and Ralegaon soil series on isolated hills have dark brown to black subsurface layers (7.5 hue to 10YR hue) clay textured, moderately alkaline with prominent slickensided zones whereas mesas, butte and steep escarpments have very shallow, well drained Moho series and moderately deep Waghari series with dark grey, moderately alkaline, clay subsoils and cambic horizons . The upper and lower pediplains have dark greyish brown to dark brown matrix with slickensided zone within 1m in Apti and Saykheda series whereas alluvial plains of Penganga and Pus valleys have deep, moderately alkaline and calcium carbonate enriched slickensided zone in Arunavati, Chanoda, Loni, Pandhurna and Wani soil series. The gullied and stony gravelly waste unit has shallow to very shallow Moregaon, Pandharkawada and Wanjari series having dark yellowish brown (Wanjari) to brown (Pandharkawada) and very dark greyish brown (Moregaon) with mildly to moderately alkaline and clay textured cambic horizons.

Physical and chemical characteristics: The particle distribution data shows that Nagdhari (P22) and Waghari (P30) soils have clay less than 35% in soil control section (25-100cm) with fine loamy particle size whereas Loni (P17) and Saykheda (P27) series have fine silty particle size with silt content exceeding 40% (Table 3). The Apti (P3), Chanoda (P6), Dhanki (P8), Hirdi (P10), Lakhi (P18) and Penganga series (P25) have very fine particle size with clay more than 60% (Soil Survey Staff, 2014) but in other soils, the particle size is fine. These expansive clay soils have bulk density of 1.57 to 1.79 Mg m^{-3} causing root hindrance and aeration (Geus, 1973) and COLE value of 0.1 to 0.2 indicating very severe shrink swell hazard (Schafer *et al*, 1976). The high COLE values in these soils indicate dominance of montmorillonite controlling the degree of shrinkage. These soils have mean plant available water of 12.65% with 2.95% of standard deviation. The plant available water can be approximated with multiple regression equation with R^2 value of 0.294, and F value of 2.25.

Plant available water (%) = - 6.39 + 0.156 (sand) + 0.283 (silt %) + 0.189 (clay %) – 0.433(organic carbon, g kg^{-1}) – 0.022 (calcium carbonate, g kg^{-1}).

These soils are moderately to strongly alkaline with low salt concentration (Table 3). Sixty seven per cent of soils are low in organic carbon (less than 0.5) and remaining 33% soils are medium (0.5 to 0.75%). The calcium carbonate content less than 1% is observed in Dhanki series (P8) whereas as less than 6% in case of Chanoda (P6), Jamwadi (P11), Koulambi (P13), Katherwadi (P14), Korta (P15), Kharbi (P16), Loni

Table 1. Rating scheme for evaluating suitability of soils for surface irrigation.

(a) Rating of textural classes for surface and drip irrigation

Textural classes	Rating for surface irrigation					Rating for drip irrigation				
	Fine gravel (%)			Coarse gravel (%)		Fine gravel (%)			Coarse gravel (%)	
	<15	15–40	40–75	15–40	40–75	<15	15–40	40–75	15–40	40–75
CL	100	90	80	80	50	100	90	80	80	50
SiL	100	90	80	80	50	100	90	80	80	50
SCL	95	85	75	75	45	95	85	75	75	45
L	90	80	70	70	45	90	80	70	70	45
SiL	90	80	70	70	45	90	80	70	70	45
Si	90	80	70	70	45	90	80	70	70	45
SiC	85	95	80	80	40	85	95	80	80	40
C	85	95	80	80	40	85	95	80	80	40
SC	80	90	75	75	35	95	90	85	80	35
SL	75	65	60	60	35	95	85	80	75	35
LS	55	50	45	45	25	85	75	55	60	35
S	30	25	25	25	25	70	65	50	35	35

CL: Clay Loam SiL: Silty Loam SCL: Sandy Clay Loam L: Loam SiL: Silty Loam Si: Silty , SiC: Silty Clay C: Clay SC: Sandy Clay SL: Sandy Loam LS: Loamy Sand S: Sandy.

(b) Rating for soil depth, $CaCO_3$ and salinity classes for surface and drip irrigation systems

Soil depth (cm)	Surface	Drip	$CaCO_3$ (%)	Sur-face	Drip	Salinity Ec(dSm^{-1})	Surface		Drip	
							C, SiC, SiCL, S, SC	Other textures	C, SiC, SiCL, S, SC	Other textures
<20	25	35	<0.3	90	90	<4	100	100	100	100
20-50	60	70	0.3-10	95	95	4-8	90	95	95	95
50-80	80	90	10-25	100	95	8-16	80	50	85	50
80-100	90	100	25-50	90	80	16-30	70	30	75	35
>100	100	100	>50	80	70	>30	60	20	65	25

(c) Rating of drainage classes for surface and drip irrigation

Drainage classes	Rating for surface irrigation		Rating for drip irrigation	
	C, SiC, SiCL, S, SC Textures	Other textures	C, SiC, SiCL, S, SC textures	Other textures
Well drained	100	100	100	100
Moderately drained	80	90	100	100
Imperfectly drained	70	80	80	90
Poorly drained	60	65	70	80
Very poorly drained	40	65	50	65
Drainage status not known	70	80	70	80

(d) Rating of slope for irrigation.

Slope Classes (%)	Rating for surface irrigation		Rating for drip irrigatio	
	Non-terraced	Terraced	Non-terraced	terraced
0–1	100	100	100	100
1–3	95	95	100	100
3–5	90	95	100	100
5–8	80	90	90	100
8–16	70	80	80	90
16–30	50	65	60	75
>30	30	45	40	55

Table 2. Landforms and soils with selected morphological properties of Yavatmal district, Maharashtra.

Land forms	Area		Soil series	Thickness of horizon (cm)		Matrix color (moist)* of horizon		Texture **of horizon		Other features
	(ha)	(%)		A	B	A	B	A	B	
Hills and ridges	170970	**12.6**	Gahuli	17	-	10YR3/3	-	gc	-	Very thin ochric horizons with lithic contact below 50cm
			Lakhi	26	-	10YR3/3	-	c	-	Moderately alkaline, dark brown ochric horizons
Upper plateaus	64712	**4.8**	Hirdi	12	63	7.5YR3/2	7.5YR3/2	c	c	Slickensides within 1m with neutral reaction
Middle plateaus	236055	**17.4**	Jamwadi-	20	20	10YR3/2	10YR3/1	c	gc	Mildly alkaline thin and hard cambic horizons
			Kalamb	20	94	10YR4/2	10YR3/2	c	c	Moderately alkaline slickensided zone
			Katherwadi	12	84	10YR3/2	10YR3/2	c	c	Strongly alkaline sodic slickensided zones within 1m
Lower plateaus	97472	**7.2**	Koulambi	20	69	10YR3/1	10YR3/2	c	c/l	Moderately alkaline cambic horizons
Isolated hills	92440	**6.8**	Korta-	20	30	7.5YR3/1	7.5YR3/1	c	c	Slightly alkaline, very hard cambic horizons
			Ralegoan	19	131	10YR3/2	10YR3/2	zc	zc	Moderately alkaline slickensided zones within 50cm
Measa and Butte	85696	**6.3**	Moho	7-	-	7.5YR3/2	-	cl	-	Neutral, thin, ochric layer
			Waghari	19	29	10YR3/2	10YR3/2	c	c	Moderately alkaline with pressure faces in cambic horizons
Escarpments	62716	**4.6**	Met	20	-	5YR3/2	-	c	-	Moderately alkaline, lithic contact within 50cm
Upper pediplains	175599	**12.9**	Borgoan	16	51	2.5Y5/2	2.5Y3/1	zc	zc	High value, clay increase, low chroma
			Dhanora ,	13	17	10YR3/2	10YR3/2	c	zc	Thin cambic horizon
			Kharbi	20	110	10YR3/2	10YR3/1	c	c	Moderately alkaline, slickensided zones
Lower pediplains	214729	**15.8**	Apti-	13	57	10YR4/2	10YR3/2	c	c	Pressure faces and slickensides within 1m
			Saykheda	15	69	10YR3/3	10YR3/4	c	zc	Moderately alkaline slickensided zones
			Selodi	12	138	10YR4/2	10YR3/2	zc	c	Strongly alkaline, slickensided zones, strongly effervescent
Gently to Moderately sloping plains	45827	**3.4**	Arni	18	76	10YR3/2	10YR3/2	zcl	zcl	Cambic with pressure faces and slickensides
			Chikhalgoan	13	82	10YR4/2	10YR3/2	cl	zc	Pressure faces and slickensides within 1m
			Penganga	15	65	10YR3/2	10YR3/2	zc	c	Moderately alkaline, slickensided zones with in 1m
Very gently to Gently sloping alluvial plains	15659	**1.2**	Arunavati	19	76	10YR4/3	10YR5/4	cl	gcl	Gravelly calcium carbonate enriched
			Chanoda-	13	137	10YR4/2	10YR3/1	zc	c	Cambic/slickensided zone with low chroma
			Loni	15	135	10YR5/4	10YR4/4	zcl	zcl	Moderately alkaline, thick slicken sided zone
			Pandhurna	13	137	10YR4/3	10YR3/3	l	cl	Moderately alkaline with coarse angular aggregates
			Wani	12	128	10YR3/2	10YR3/1	c	c	Moderately alkaline with slickensided zones
Intervening valleys	47864	**3.5**	Dhanki	15	155	10YR3/2	10YR3/3	c	c	Moderately alkaline, slickensided zones
			Nagdhari	13	127	10YR6/4	10YR3/4	zcl	zcl	Moderately alkaline, sodic, prismatic aggregates
			Wanodi	15	137	10YR3/2	10YR3/2	c	c	Moderately alkaline with slickensided zones
			Sindola	12	40	10YR3/2	10YR3/1	zc	zc	Moderatle alkaline, cambic horizons
Gullied and Stony gravelly waste lands	47253	**3.2**	Maregaon	15	27	10YR3/2	10YR3/2	c	c	Moderately alkaline, cambic horizons
			Pandharkawada	11	-	10YR4/3	-	c	-	Neutral brown, ochric horizons
			Wanjari	13	27	10YR3/6	10YR3/4	c	c	Mildly alkaline , developed over limestone

** c=clay, zcl=silty clay loam, l=loam, zc =silty clay, gcl=gravelly clay loam, cl=clay loam, * = Munsell soil color notation

Table 3. Physical and chemical characteristics of soils of Yavatmal district, Maharashtra.

Soil series	Particle size distribution (<2 mm)			Bulk density ($Mg\ m^{-3}$)	PAWC (%)	ASW ($cm\ m^{-1}$)	COLE	pH	Organic carbon ($g\ kg^{-1}$)	$CaCO_3$ ($g\ kg^{-1}$)	CEC ($cmol\ kg^{-1}$)	Available		DTPA extractable	
	Sand	Silt	clay									N	P_2O_5	Fe	Zn
												……..……(mg kg⁻¹)………			
Arunavati	49	32.7	18.3	1.57	12.0	18.1	0.10	8.5	3.9	125.5	38.0	34.1	0.5	6.6	0.7
Arni	13	49.8	37.2	1.79	20.4	34.5	0.22	8.7	3.9	-	51.4	28.3	1.7	5.0	0.9
Apti	3.2	30.2	66.6	1.74	10.1	12.2	0.19	8.8	2.9	145.5	53.0	58.4	0.8	7.3	0.7
Borgaon	12	39.4	48.6	1.62	10.3	11.2	0.19	8.4	5.1	69.4	54.4	46.7	0.7	5.6	0.8
Chikhalgaon	24.8	39.0	36.2	1.61	12.6	23.7	0.15	8.4	3.2	65.0	40.1	35.2	0.5	6.4	0.9
Chanoda	2.8	28.7	68.5	1.83	15.8	42.9	0.21	8.1	1.4	40.2	67.1	39.7	0.9	7.0	0.8
Dhanora	6.1	41.3	52.6	1.69	10.16	5.1	0.19	8.1	6.5	64.5	70.0	31.2	0.7	4.9	1.1
Dhanki	1.3	34.3	64.4	1.72	11.9	34.7	0.23	8.1	4.6	7.1	70.1	40.4	0.1	7.2	1.0
Gahuli	10.2	39.5	50.3	1.48	11.1	2.8	0.15	8.0	2.5	5.6	61.7	-	-	7.4	0.4
Hirdi	2.6	31.4	66.0	1.71	15.5	22.6	0.18	6.9	5.8	-	53.4	-	-	7.6	0.7
Jamwadi	13.1	38.2	48.7	1.79	10.9	7.8	0.21	7.6	7.4	42.8	72.6	55.9	1.6	4.2	1.5
Kalamb	3.2	41.2	55.6	1.64	14.8	38.6	0.18	8.1	2.7	-	59.5	-	-	1.2	0.2
Koulambi	19.9	39.0	41.1	1.69	10.6	15.8	0.21	8.2	4.2	106.5	61.5	51.5	1.3	7.4	1.0
Katherwadi	11.6	34.4	54.0	1.74	17.0	28.4	0.20	8.9	4.1	-	56.5	52.6	0.6	7.3	0.8
Korta	23.1	24.0	52.9	1.79	10.1	8.9	0.24	8.0	2.8	38.1	62.5	46.7	0.5	5.4	1.1
Kharbi	11.8	30.0	59.2	1.74	16.3	36.5	0.21	8.1	3.2	-	60.8	37.5	2.8	5.3	0.9
Loni	12.7	49.0	32.3	1.57	16.2	40.9	0.18	7.9	1.0	8.4	46.0	28.3	1.0	6.4	0.8
Lakhi	5.4	28.0	67.0	1.70	11.6	5.1	0.20	8.4	2.6	16.5	66.9	-	1.5	7.9	0.7
Met	20.4	33.1	46.5	1.65	11.8	3.9	0.18	6.6	5.7	-	52.2	78.4	4.7	8.0	1.5
Moho	20.9	31.0	48.1	1.56	11.6	8.0	0.17	7.2	1.3	3.5	57.3	63.1	0.7	9.3	1.1
Maregaon	7.5	33.2	59.3	1.71	16.1	11.6	0.19	8.1	6.6	21.9	63.4	52.4	1.2	6.4	0.7
Nagdhari	10.7	40.0	49.3	1.69	9.4	27.9	0.11	8.3	0.8	-	46.8	-	-	1.1	0.4
Pandhurna	26.4	33.4	40.1	1.57	13.6	31.9	0.22	8.2	4.7	87.7	51.3	42.5	0.7	5.8	0.8
Pandharkawada	29.4	18.2	52.4	1.52	11.7	1.9	0.15	7.5	3.6	4.1	62.6	-	-	7.5	0.7
Penganga	1.5	34.4	64.1	1.79	11.2	18.9	0.21	8.3	5.3	63.9	50.8	37.9	0.5	5.5	0.9
Ralegaon	9.9	44.6	45.5	1.70	12.6	18.3	0.17	8.2	4.8	-	54.4	-	-	0.7	0.7
Saykheda	28.0	42.7	29.3	1.58	8.6	20.5	0.15	8.4	4.5	112.5	49.5	44.6	0.5	6.4	0.8
Selodi	4.3	35.5	59.2	1.77	14.7	39.2	0.19	8.9	2.6	112.6	66.7	42.7	0.5	7.1	0.9
Sindola	5.7	41.3	53.0	1.69	15.9	14.1	0.17	7.7	4.1	-	53.0	-	-	1.5	0.3
Waghari	27.6	36.4	36.0	1.61	8.6	6.7	0.20	8.3	6.9	94.6	67.1	56.0	1.1	6.0	0.8
Wanodi	4.3	38.4	57.3	1.68	12.2	31.0	0.20	8.3	1.6	-	41.2	25.8	0.4	4.7	0.4
Wani	18.8	33.6	48.4	1.70	15.5	36.7	0.21	8.3	2.9	75.5	56.7	31.0	0.5	6.2	0.8
Wanjari	20.3	38.1	41.7	1.55	7.2	4.5	0.16	7.8	6.6	61.6	46.9	80.4	0.1	7.4	0.6

Table 4. Land capability and suitability for irrigation systems in Yavatmal district.

Land capability class for irrigation	Soil series association	Capability index for irrigation		Area		Limitations		
		Gravity	Drop	(ha)	(%)	Soil	Topography	Drainage
Excellent (I)	Lo-Ar-Av(9)	81	83	11813.9	0.87	4zHz	Aa3E1	W101F1
Suitable(II)	Dk - Ar -Lk- Av (4)	52	57	17389.4	1.28	4gV(f)-A1	Aa1E1	W101F1
	Dh-Ar-Lo (12)	56	63	9553.7	0.71	Cb2E3	W101F1	
	Dk-Pg-Bo-Pd(22)	55	63	56172.7	4.13	4gV(f)-A1	Aa1E1	W101F1
	Wd-Bo-Pg-Ka (27)	52	61	8492.9	0.62	4gV(f)	Ba2E2	
	Sy -Lo-Ar (30)	68	71	8804.6	0.65	4gV(g)	Bb1E1	W101F1
	Wn-Ch-(34)	49	53	13793.6	1.02	4gV(f)	Bb2E2	W101F1
	Ai-Wg – Wn (35)	47	54	5634.1	0.41	4gV(f)1-ZA2	Cc2E2	W101F2
	Ci- Wn –Ai (36)	52	67	38385.1	2.82	4gV(f)1-HA1	Cb2E1	W101F2
	Wn-Lo –Ma (37)	56	53	4093.6	0.3	4gV(f)	Bb2E2	W101F1
	Wd-Kb-Ar (48)	53	54	26513	1.95	4gV(f)	Bb2E2	W101F1
				188832.7	13.89	4gV(f)	Ba2E2	
Slightly suitable(III)	Lk-Ka-Ar –Dk (1)	47	48	9361.3	0.69	3zVz-3Z	Ee2E3	
	Dk-Lk-Dh-Pd (11)	47	49	62781	4.62	4gV(f)-A1	Aa1E1	
	Dh- LK-Sd –Ar (13)	49	53	55298.4	4.08	Cb2E3	W101F1	
	Sd-Wg-Dh (14)	49	50	9665	0.71	4gV(f)-A2	Ba1E2	W101F1
	Bo-Ka-Wg (16)	44	51	1764.1	0.13	4gV(f)2-HA1	Bb2E1	W101F2
	Lk-Bo-Ar-Dk (17)	44	46	71759	5.28	2zVz-3Z	Ed2E2	
	Bo-Pd-Mo (24)	47	58	6162.7	0.45	4gV(f)2-HA1	Bb2E1	W101F2
	Sy –Wg (33)	45	47	12507.4	0.92	3gH(g)-2S	Cb2E2	W101F1
	Bo-Ra-Lk (43)	44	51	8473.8	0.62	4gV(f)2-HA1	Bb2E1	W101F2
	Km-Lk-Hi (45)	49	34	17935.7	1.32	3GVZ1-ZA1	Ba2E2	W101F2
	Ra-Kb-Lk (47)	47	42	17299.5	1.27	3gVg-1S	Cb2E2	

Table 5. Available soil water (ASW) , irrigation intervals and fertility capability of each irrigable soil mapping unit of Yavatmal district.

Soil series / Suitability class	ASW ($cm\ m^{-1}$)	Irrigation interval (days)			FCC (Fertility capability class)	Area	
		Wheat	Cotton	Sugar cane		(ha)	(%)
Excellent (I)							
Lo-Ar-Av (9)	27.3	11.4	10.9	13.0	CCdvb-LLdvb (clayey, dry, ustic, vertic calcareous soils associated with loamy top soils deficient in nitrogen, phosphorus and zinc.	11813.9	0.87
Suitable (II)							
Dk - Ar -Lk- AV (4)	23.9	9.9	9.6	11.3	CCdvb-LLdvbn (clayey type vertic, ustic, calcareous soils associated with loamy with hard root restricting layers and sodium enriched clay soils with high shrink-swell potentials. These soils are generally deficient in nitrogen, phosphorus, iron and zinc.	188832.7	13.89
Dh-Ar-Lo (12)	25.4	10.6	10.2	12.1			
Dk-Pg-Bo-Pd (22)	21.6	8.1	7.8	9.3			
Wd-Bo-Pg-Ka (27)	22.6	9.4	9.1	10.7			
Sy -Lo-A r(30)	21.7	9.1	8.7	10.3			
Wn-Ch-(34)	24.5	8.7	8.4	9.9			
Ai-Wg – Wn (35)	18.2	7.1	6.8	8.0			
Ci- Wn –Ai (36)	21.5	8.2	7.9	9.4			
Wn-Lo –Ma (37)	26.3	9.5	9.1	7.8			
Wd-Kb-Ar (48)	26.0	10.8	10.4	12.3			
Slightly suitable (III)							
Lk-Ka-Ar –Dk (1)	26.5	11.1	11.0	12.6	CRdb-CCdvb (Clayey with more than 35% gravels , hard root restricting layers within 50 cm, dry, ustic on severely eroded plateau tops and escarpments and on stony gullied pediplains. These soils are associated with clayey, dry, ustic , vertic, calcareous soils occurring on gently sloping plains of Pus, Wardha and Penganga valleys).	274744.3	20.22
Dk-LK-Dh-Pd (11)	19.6	8.2	7.8	9.3			
Sd-Wg-Dh (14)	19.7	8.2	7.9	9.3			
Bo-Ka-Wg (16)	20.0	8.3	8.1	9.5			
Lk-Bo-Ar-Dk (17)	22.6	9.4	9.1	10.7			
Bo-Pd-Mo (24)	18.4	7.7	7.4	8.7			
Sy –Wg (33)	13.6	5.7	5.5	6.5			
Sn-Ch-Roc (40)	23.4	9.8	9.2	11.1			
Bo-Ra-Lk (43)	18.8	7.8	7.5	8.8			
Km-Lk-Hi (45)	20.1	8.4	8.1	9.5			
Ra-Kb-Lk (47)	23.2	9.7	9.3	10.9			
Mean ±Sd	22±3.4	8.9±1.37	8.61±1.35	10.0±1.64			
Cv(%)	15.22	15.37	15.69	16.31		475390.9	34.98

(P17), Moho (P20), Nagdhari (P22), Penganga (P25), Ralegaon (P26), Sindola (P29) and other soils, the $CaCO_3$ content is in between 5 to 10%. The weighted mean of calcium carbonate is 125.48 g kg^{-1} for Arunavati (P1), 122.4 g kg^{-1} for Saykheda (P27), 94.6 g kg^{-1} for Waghari (P30) and 75.46 g kg^{-1} for Wani (P32).

These soils are deficient in available nitrogen with mean of 33.17 mg kg^{-1} and phosphorus with mean of 0.74 mg kg^{-1} (Table 3). This observation is in agreement with the earlier reports of fertility status of black soils in India (Rao *et al.*, 1997). The DTPA extractable iron shows below critical limit < 4 mg kg^{-1} in Kalamb (P12), Nagdhari (P22), Pandhurna (23), Ralegaon (P26) and Sindola soils (P29) where as in other soils, DTPA extractable iron is medium (4 to 6 mg kg^{-1}). The DTPA extractable Zn is 0.2 mg kg^{-1} (P12) to 1.5 mg kg $^{-1}$ (P11). The Zn contents below critical limit (<1 mg kg^{-1}) is recorded in Gahuli (P9), Kalamb (P12), Nagdhari (P22), Ralegaon (P26), Sindola (P29) and Wanodi (P31) but in other soils, zinc was medium (Benton Jones, 2001).

Land capability and suitability for irrigation: The limiting factors that lower suitability of basaltic clay soils for irrigation in the study area are mainly the slope, depth of soil, alkalinity, drainage and $CaCO_3$ content. The land capability index (LCI) is computed for judging the suitability for irrigation (Table 4) and defined soil-topography - drainage limitations with standard symbols for irrigable soil mapping unit in Yavatmal district. The excellent soil for irrigation covers 0.87% with soil associations of Loni series (LCI of 90), Arni series (LCI of 73) and Arunavati series (LCI of 81). These soils have moderate to slow subsoil permeability, medium to heavy top soil texture, deep with unweathered hard rock / calcareous material with slight alkalinity problem, moderate to strong microrelief variations and moderate erosion status. This unit is evaluated as suitable for surface irrigation systems. The excellent soils for irrigation are mostly concentrated in Digras and Arni tehsils of Pus valley under Arunavati river (Fig. 2).

Ten soil mapping units (4, 12, 22, 27, 30, 34, 35, 36, 37 and 48) are evaluated as suitable for irrigation covering 188,832.7 ha (13.89%). These units have 12 series associations viz., Arni, Apti, Chikalgaon, Chanoda, Dhanki, Kalam, Kolambi, Kharbi, Nagdhari, Pandhurna, Wanodi and Wani with moderate to slow subsoil permeability, 15 to 40% subsoil stoniness, heavy to very heavy top soil texture, deep with unweathered hard rock / calcareous material with slight salinity and alkalinity problem over gently sloping to sloping transversal slopes of 5 to 8% and slight to moderate water erosion status. The morphological homogeneity in shrink-swell features of these soil mapping units except slope that trigger the application rate of irrigation water and causes nutrients, soil and water loss by runoff process. These results are in agreement with the findings of Mohammad *et al.* (2010). The slightly suitable soils for irrigation include 11 soil mapping units for irrigation covering 20.22% of area (274,744.3 ha). These units have dominant soil associations of Borgaon, Dhanora, Katherwadi, Penganga, Ralegaon, Saykheda and Selodi having moderate to slow subsoil permeability and severe stoniness over 5 to 8% slopes with moderate to severe erosion.

Available soil water, irrigation intervals and fertility capability for irrigable units: The mean available soil water content of 22 soil units is 22 ± 3.4 cm m^{-1} with coefficient of variation of 15.22% (Table 5). For these soil units, the irrigation intervals vary from 8.61 ± 1.35 days for cotton to 8.9 ± 1.4 days for wheat and 10 ± 1.64 days for sugar cane. The area under excellent units is estimated as 0.87% with 13.89% of suitable and 20.22% under slightly suitable units for irrigation. The excellent mapping unit (Lo-Ar-Av) have available soil water of 27.3 cm m^{-1} whereas 10 suitable mapping units have mean of 23.17cm m^{-1} ± 2.53 cm m^{-1} and in 11 slightly suitable units have mean of 20.53 ± 3.36 cm m^{-1}. The crop coefficient (kc) of cotton with growth cycle of 190 days to be 0.46, 0.70, 1.01 and 0.39 at four different stages (Mohan and Arumugam 1994). are used to compute mean irrigation intervals which is varying from 8.8 days for cotton to 9.1 days for wheat and 10.11 days for sugarcane in case of suitable units but 8.2 days for cotton to 9.71 days for sugarcane in slightly suitable units. These computed values for irrigation intervals are in agreement with the earlier findings of shrink-swell soils in Jayakwadi irrigation project (Bhaskar *et al.*, 2002). It was reported that cotton field was sampled on each of 2, 5 and 10 days after an irrigation. It was observed that air-filled porosity was < 10% below 20 cm after five days of irrigation whereas it did not attain value less than 10% of air filled porosity at a depth of 40cm even after 10days (McGarry and Chan, 1984). They reported that the vertisols must have 10% air-filled pores as a critical value for plant root respiration beneath 20 cm after 5 days of irrigation and to 40 cm for 10 days.

The fertility capability classification (Sanchez *et al.*, 2003). shows that calcareous loamy top vertic soil association in excellent units are deficient in nitrogen, phosphorus and zinc where as hard root restricting and sodium enriched sub soils in case of suitable and of stony to gravelly root restricting vertic soil associations on gullied escarpments and clayey, calcareous soils in Pus and Wardha valleys under slightly suitable units (Table 5). The moderately deep clays have few limitations but shallow soils are unsuitable for all forms of irrigated cropping due to several limitations including wetness, soil depth, rockiness and water erosion hazard. The importance of climate for cotton based systems in Maharashtra is critically analyzed and reported that the rainfall of 250 to 325 mm from squaring to peak flowering stage was found to be critical (Mandal *et al.*, 2005). Hence the climate of Yavatmal for cotton is moderately suitable with short dry spells at critical stages of cotton during September to October. This region experiences 12 to 20 normal dry weeks followed by 3 to 8 weeks of wet weeks from 35 years of daily rainfall data using standard precipitation index (Bhaskar *et al.*, 2011 & 2014b). The success of rainfed cotton needs better understanding of the effects of plant available water (PAWC), amount and variability of seasonal rains and mean crop yield analysis over basaltic landscapes in the region. The cotton cropping strategies in the region where 14 % of area is suitable for irrigation needs to address the relational data sets of PAWC –climate – yield analysis under rainfed conditions so as to record the probability of achieving high yields and chance of avoiding monetory losses due to prolonged dry spells during cropping period. The soil resource maps helps to delineate the soils with large PAWC (>200mm) with slight yield advantage during dry periods because these soils never attain to maximum soil water storage capacity. The delineated soil mapping units will serve as benchmark sites to monitor the interrelationships of soil water dynamics with respect to climate and cotton yields.

Conclusion

The soil resource evaluation for irrigation in debt driven and drought prone cotton growing Yavamal district showed that the suitable land for irrigation is only 15% of total cultivated area. The parametric evaluation further showed 13.89% of irrigable area on moderate slopes (5 to 8%) are evaluated as suitable for surface methods whereas 20.22% of irrigable land is slightly suitable for drop irrigation with limitations of moderate to slow subsoil permeability, severe stoniness over 5 to 8% slopes and moderate to severe erosion. The irrigation frequencies of irrigable mapping units varied from 8.8 days for cotton to 9.1 days for wheat and 10.11 days for sugarcane. The study would be helpful in designing crop calendar under irrigated tract as per soil water retention characteristics and water availability and to identify the suitable zones for diversified cropping systems that is economically benefit to the farmers of Vidharbha region.

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