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Characterization and evaluation of land resources in Khapri village of Nagpur district, Maharashtra using high resolution satellite data and GIS

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Abstract : Characterization and evaluation of land resources in Khapri village of Nagpur district of Maharashtra were carried out using IRS-P6 LISS-IV and IRS-1D PAN sharpened LISS-III data and GIS coupled with field survey. Six major landforms *viz.* isolated hillocks (15-30% slope), plateau top (1-3% slope), escarpments (8-15% slope) pediment (3-8% slope), upland (1-3% slope) and valley plain (1-3% slope) were identified. The major land use/land cover identified were agriculture, degraded forest and wasteland with scrub. Eight soil series were tentatively identified and mapped as series and complex with phases on 1:12,500 scale based on landform-soil relationship. Soils of isolated hillock, escarpment, pediment and upland are very shallow (Lithic Ustorthents/Typic Ustorthents) whereas the soils of valley plain are very deep (Vertic Haplustepts/Typic Haplusterts). These soils were grouped into IIs, IIIs, IVs, IVes and VIes land capability sub-classes and good with poor to extremely poor soil productivity. The soil suitability analysis indicated that very shallow soils are marginally to not suitable and very deep soils of valley plain are moderately suitable for growing cotton, sorghum and soybean. Suitable conservation measures and interventions have been suggested to improve the productivity of these soils.

Additional key words : *Remote sensing, land capability, soil productivity, suitability for crops*

Introduction

Sustainable management of land resources is essential for food security, maintenance of environment and general well being of the people. Indiscriminate use of resources coupled with lack of management has, however, led to degradation echoing the concern of planners, researchers and farmers alike (Sharma 2006). It is essential to enhance the soil productivity to meet the future demand. Soil resource inventory through characterization of the resources provides an insight into the potentials and limitations (Manchanda *et al.* 2002). The information so generated is generally interpreted for grouping of soils for land capability, soil productivity and suitability for crops through evaluation procedures which helps the administrators and managers for agriculture and related developmental activities on sustainable basis.

With the technological advancements in remote sensing in terms of spatial, spectral, radiometric and temporal resolutions of different sensors and the

Fig. 1. IRS-P6 (Resourcesat-1) data (February 2004) of Khapri village, Nagpur with cadastral boundaries

availability of data in digital format, several studies have been initiated to characterize and map the soils at a larger scale (Srivastava and Saxena 2004; Solanke *et al.* 2005; Shukla *et al.* 2009). An attempt has been made to characterize, evaluate and map the land resources of Khapri village in Katol tehsil of Nagpur district using IRS-P6 (Resourcesat-1) LISS-IV and IRS-1D PAN sharpened LISS-III data and GIS.

Materials and Methods

Khapri village with an area of 567 ha falling in the Survey of India (SOI) toposheet No. 55K/12 is located between 21°7' to 21°9' N latitudes and 78°31' to 78°33' E longitudes in Katol tehsil of Nagpur district of Maharashtra. The major landforms identified are isolated hillocks, plateau top, escarpment, pediments, upland and valley plain evolved from Deccan basalt. The elevation of the area ranges from 460 to 620 m above mean sea level (MSL) and associated with moderately steeply sloping (15-30%), moderately sloping (8-15%), gently sloping (3-8%) and very gently sloping (1-3%) lands.

The soils have 'Ustic' and 'Hyperthermic' soil moisture and soil temperature regimes, respectively. The natural vegetation comprises a wide variety of dry deciduous mixed tree species, shrubs interspersed with grasses. Commonly occurring tree species are Teak (*Tectona grandis*), Babul (*Acacia spp.*), Palas (*Butea frondosa*), Charoli (*Buchananea latifolia*), Jujube (*Ziziphus jujuba*), etc. A large area of cultivated land is mainly under *kharif* crops such as cotton (*Gossypium spp.*), sorghum (*Sorghum bicolor*), soybean (*Glycine max*) and pigeonpea (*Cajanus cajan*). The dominant *rabi* crops of the area are wheat (*Triticum aestivum*) and gram (*Cicer arietinum*) generally raised on residual moisture/protective irrigation.

Digital data of IRS-P6 LISS-IV of February, 2004 (Fig. 1) and IRS-1D PAN sharpened LISS-III (November 2002) with a spatial resolution of 5.8 m was used and geocoded using Geomatica image processing software with reference to toposheet. The toposheet was used to prepare landform, slope maps and delineate the forest boundary for land use/land cover map. Cadastral map of the village available at 1:5000 scale was georeferenced with reference to satellite data and used for identification of field boundaries, location of profile studies and for traversing in the field. For preparation of land use/land cover map, the methodology followed for extraction of information from satellite data is essentially of standard visual interpretation based on tone, texture, pattern, shape and size (Lillesand and Kiefer 2002).

The landforms, slope and land use/land cover variations are considered for depicting the soil variability and preparation of soil map. Twenty profiles covering all the physiographic units were exposed and studied for morphological properties (Soil Survey Division Staff 2000) and classified as per Soil Taxonomy (Soil Survey Staff 2003). Horizon-wise soil samples were collected from representative pedons and analysed for different physical and chemical properties following standard procedures (Black 1965; Jackson 1967). Soil samples were analyzed for DTPA-extractable Fe, Mn, Cu and Zn (Lindsay and Norvell 1978). The soils were grouped under different land capability sub-classes (Klingebiel and Montgomery 1961), land irrigability sub-classes (AIS&LUS 1971) and soil productivity classes (Riquier *et al.* 1970). The soil-site suitability for cotton, sorghum and soybean was worked out as per the methodology given in the FAO frame work on land evaluation (FAO 1976) modified by Sys *et al.* (1991). The soil-site requirements as suggested by NBSS&LUP (1994) have been used for evaluating the suitability of different mapping units for cotton, sorghum and soybean. ArcGIS software was used for digitization of field boundaries, spatial and attribute database generation and preparation of various thematic maps.

Results and Discussion

Present land use/land cover

Based on image characteristics, the major land use / land cover identified are cultivated land, degraded forest, wasteland with scrub and habitation (Fig. 2a). Cultivated land is again delineated into single and double crop with orange orchards based on temporal data. The extent of area under different land utilization types indicates that cultivated land occupies 76.2 per cent of the total geographical area (TGA) of which 47.2 per cent is under single crop. Double crop with orange orchards occupy 29.1 per cent of the cultivated area where assured/protective irrigation is available. Degraded forest and wasteland with scrub occupy 14.2 (80.6 ha.) and 1.3 per cent (7.3 ha.), respectively.

Slope

Four slope classes *viz.* very gently sloping (1-3%), gently sloping (3-8%), moderately sloping (8-15%) and moderately steeply sloping (15-30%) lands have been identified (Fig. 2b). The major area is under very gently sloping land (70.3% of TGA). Gently sloping, moderately sloping and moderately steeply sloping land occupy 13.8, 5.3 and 1.9 per cent of TGA, respectively.

Landform-soil relationship

Six major landforms, namely, isolated hillocks, plateau top, escarpment, pediment, upland and valley plain were identified and delineated (Fig. 2c). Moderately steeply sloping (15-30%) isolated hillocks occur at an elevation of 560 to 620 m above MSL and support degraded forest. The very gently sloping (1-3%) plateau top occurs at an elevation of 560-580 m above MSL supported by wasteland with scrub. The moderately steeply sloping escarpment (15-30%) under degraded forest occur at an elevation of 520 to 560 m above MSL. These areas are under severe erosion. The pediments are also erosional surfaces that occur at an elevation of 500 to 520 m above MSL. The pediments are further divided into upper and lower pediments based on slope. The gently sloping upper pediments (3-8%) are, in general, under degraded forest and single crop in patches, whereas, the very gently sloping (1-3%) lower pediments are under single crop. The very gently sloping (1-3%) uplands at an elevation of 480 to 500 m above MSL are under single crop. The very gently sloping valley plain at the lowest elevation (460 to 480 m above MSL) is mainly under double crop with orange orchards.

Eight soil series (Khapri-1, Khapri-2, Khapri-3, Khapri-4, Khapri-5, Khapri-6, Khapri-7 and Khapri-8) are tentatively identified and mapped as soil series and complex with phases at 1:12500 scale (Fig. 2d) after establishing landform-soil relationship (Table 1). The soils occurring on isolated hillock, plateau top and escarpment (Khapri-1) are very shallow, somewhat excessively drained, dark brown (10YR 3/3 M), sandy loam with severe erosion and qualify for Lithic

Table 1. Landform-soil relationship

Landforms	Slope (%)	Land use/land cover with image characteristics	Soil series / complex	Soil classification
Isolated hillock	15-30	Degraded forest with bluish green tone, coarse texture	Khapri-1	Loamy-skeletal, mixed hyperthermic Lithic Ustorthents
Escarpment	8-15	Degraded forest with bluish green tone, coarse texture	Khapri-1	Loamy-skeletal, mixed, hyperthermic Lithic Ustorthents
Plateau top	1-3	Wasteland with scrub with bluish green tone, medium texture	Khapri-1	Loamy-skeletal, mixed, hyperthermic Lithic Ustorthents
Upper pediment	3-8	Cultivation (single crop) with greenish blue tone, checker board pattern	Khapri-2	Clayey, smectitic, hyperthermic Typic Ustorthents
Upper pediment	3-8	Degraded forest with bluish green tone, coarse texture	Khapri-3	Clayey, smectitic, hyperthermic Typic Ustorthents
Lower pediment	1-3	Cultivation (single crop) with greenish blue tone, checker board pattern	Khapri-4 + Khapri-5	Khapri-4: Clayey, smectitic, hyperthermic (calcareous) Typic Ustorthents Khapri-5: Fine-loamy, mixed, hyperthermic Typic Ustorthents
Upland	1-3	Cultivation (single crop) with greenish blue tone, checker board pattern	Khapri-6	Clayey, smectitic, hyperthermic (calcareous) Typic Ustorthents
Valley plain	1-3	Cultivation (double crop) with orange orchards with red and dark blue mixed tone, checker board pattern.	Khapri-7 + Khapri-8	Khapri-7: Fine, smectitic, hyperthermic (calcareous) Vertic Haplustepts Khapir-8: Fine, smectitic, hyperthermic (calcareous) Typic Haplusterts

Ustorthents at subgroup level. Two soils (Khapri-2 and Khapri-3) are identified on upper pediments. The soils of Khapri-2 which are under cultivation are very shallow, somewhat excessively drained, dark brown (10 YR 3/3 M), clay loam with severe erosion and qualify for Typic Ustorthents whereas, the soils of Khapri-3 are very shallow, somewhat excessively drained, dark brown (7.5 YR 3/3 M), clay loam (Typic Ustorthents) with severe erosion.

Two soils (Khapri-4 and Khapri-5) are identified on lower pediment. The soils of Khapri-4 are shallow, well drained, very dark grayish brown (10 YR 3/2 M), sandy clay (Typic Ustorthents) with slight erosion whereas the soils of Khapri-5 are shallow, well drained, very dark grayish brown (10 YR 3/2 M), clay loam (Typic Ustorthents) with slight erosion. The soils of Khapri-6 (Typic Ustorthents) identified on upland are very shallow, well drained, brown (10 YR 4/3 M), calcareous, clay loam with moderate erosion. Two soils namely Khapri-7 and Khapri-8 are identified on very gently sloping valley plain. The soils of Khapri-7 are very deep, moderately well drained, very dark grayish brown (10 YR 3/2 M), clay (Vertic Haplustepts), calcareous with slight erosion whereas, the soils of Khapri-8 are very deep, moderately well

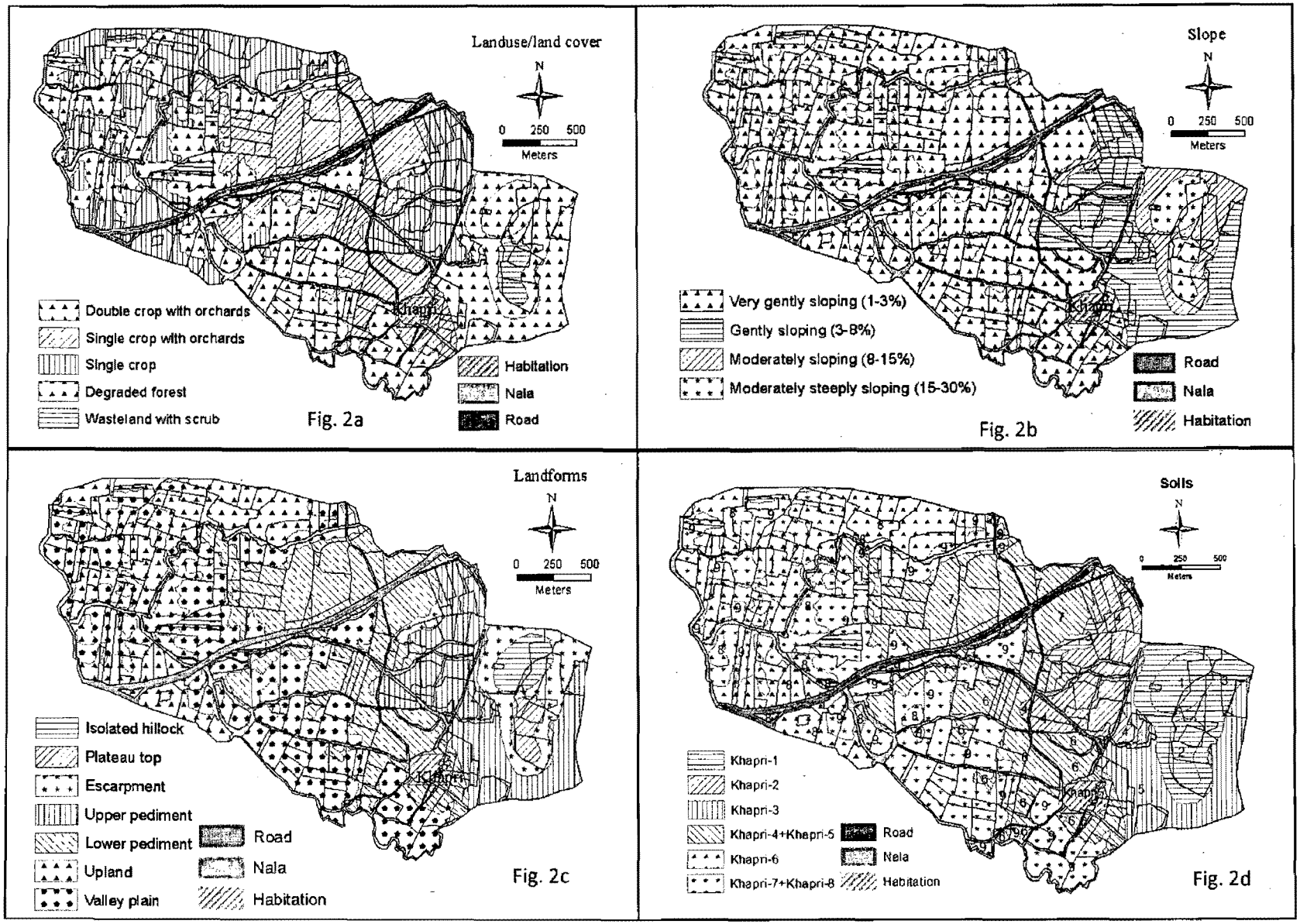

Fig. 2. Characterization of Land use/land cover (a), slope (b), landforms (c) and soils (d)

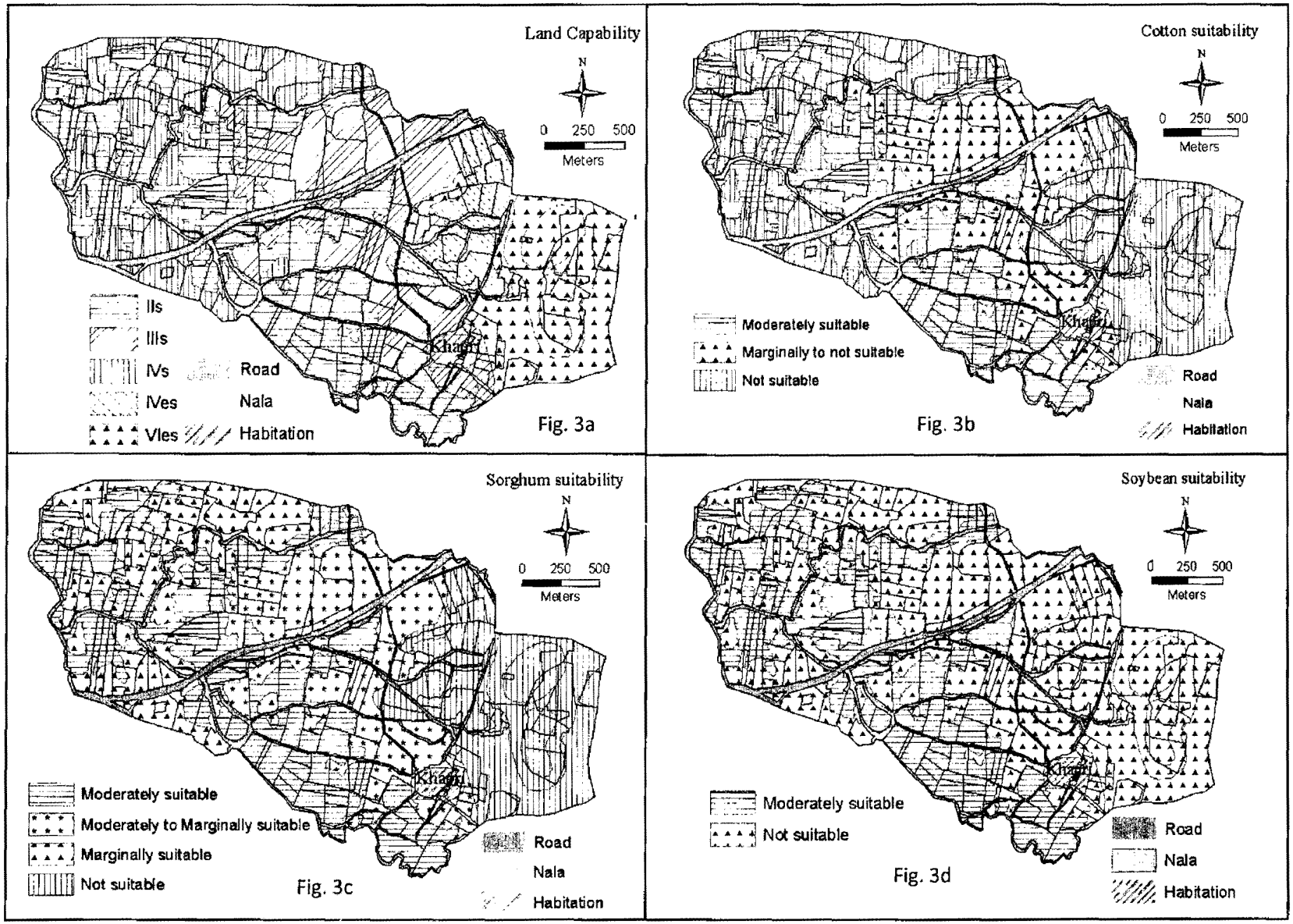

Fig. 3. Land evaluation maps for land capability (a), suitability for cotton (b), sorghum (c) and soybean (d)

Table 2. Soil map legend with series and phases

Phase Symbol	Series	Series and Phase	Phase description
1	Khapri-1	Kh-1cE4st2	Sandy loam, 15-30% slope, very severe erosion, moderate stoniness (15-35%)
2	Khapri-1	Kh-1cB4st2	Sandy loam, 1-3% slope, very severe erosion, moderate stoniness (15-35%)
3	Khapri-1	Kh-1cD4st2	Sandy loam, 8-15% slope, very severe erosion, moderate stoniness (15-35%)
4	Khapri-2	Kh-2fC3st2	Clay loam, 3-8% slope, severe erosion, moderate stoniness (15-35%)
5	Khapri-3	Kh-3fC3	Clay loam, 3-8% slope, severe erosion
6	Khapri-4+Khapri-5	(Kh-4+Kh-5) iB1	Sandy clay, 1-3% slope, slight erosion
7	Khapri-4+Khapri-5	(Kh-4+Kh-5) fB2	Clay loam, 1-3% slope, moderate erosion
8	Khapri-6	Kh-6fB2	Clay loam, 1-3% slope, moderate erosion
9	Khapri-7+Khapri-8	(Kh-7+Kh-8) mB1	Clay, 1-3% slope, slight erosion

drained, very dark grayish brown (10 YR 3/2 M), clayey (Typic Haplusterts), calcareous with slight erosion. The soil map legend with series and phases is presented in table 2.

Physical and chemical properties of soils

The data (Table 3) indicate that the clay content varied from 18.5 to 60.2 per cent. Higher clay content is noticed in soils of Khapri-7 and Khapri-8 developed on valley plain compared to the soils developed on other landforms. The higher clay content in soils of valley plain are associated with higher bulk density and water retention at 33 and 1500 kPa. The data (Table 4) related to chemical properties indicate that the soils of Kharpri-1, Khapri-2 and Khapri-3 are neutral in reaction; soils of Khapri-5 are slightly alkaline whereas the soils of Khapri-4, Khapri-6, Khapri-7 and Khapri-8 are moderately alkaline in reaction. The organic carbon (OC) content in these soils is low and ranged from 0.12 to 0.56 per cent. The soils of Khapri-4, Khapri-6, Khapri-7 and Khapri-8 are calcareous. In general, these soils are highly base saturated and in some cases, more than 100 per cent owing to presence of Ca-Zeolites (Pal *et al.* 2006) which steadily supply the bases.

Soil fertility

In general, the soils of Khapri village are low (153.6-262.0 kg ha^{-1}) in available nitrogen; very low (8.9-13.4 kg ha^{-1}) in soils of Khapri-1, Khapri-2, Khapri-3, Khapri-4, Khapri-5 and Khapri-6 to low (20.1-29.1 kg ha^{-1}) in soils of Khapri-7 and Khapri-8 in available phosphorus and low (134.9 kg ha^{-1}) in soils of Khapri-1, medium to high (219.07-347.8 kg ha^{-1}) in soils of Khapri-2, Khapri-3, Khapri-4, Khapri-5 and Khapri-6 to very high (427.0-2022 kg ha^{-1}) (Khapri-7 and Khapri-8) in available potassium. Similar results were reported by Saxena (2009) in soils of basaltic terrain of Nagpur district. The DTPA-extractable micronutrient cations (Fe, Mn, Cu and Zn) of the soils (Table 4) indicates that DTPA-Fe ranged from 0.48 to 2.45 mg kg^{-1} in surface soils and found to be lower than the critical level of 4.5 mg kg^{-1} (Lindsay and Norvell 1978). The DTPA-Mn ranged from 0.77 to 4.16 mg kg^{-1} in surface soils and all the soils except the soils of Khapri-2 and Khapri-3 are which were deficient against the critical level of 3 mg kg^{-1} (Takkar *et al.* 1989). The DTPA-Cu varied from 0.28 to 0.77 mg kg^{-1} in surface soils and was found to be sufficient against the critical limit of 0.2 mg kg^{-1} (Katyal and Randhawa 1983). The DTPA-Zn varied from 0.12 to

Table 3. Physical properties of soils

Horizon	Depth (cm)	Sand 2-0.05 (mm) (%)	Silt 0.05-0.002 (mm) (%)	Clay <0.002 (mm) (%)	BD (Mgm^{-3})	Water retention (%) 33 kPa	1500 kPa	AWC
Pedon 1 (Khapri-1 series) : Loamy-skeletal, mixed, hyperthermic Lithic Ustorthents (Moderately sloping escarpment)								
Ap	0-8	52.4	29.1	18.5	1.22	18.7	15.6	3.1
Pedon 2 (Khapri-2 series) : Clayey, smectitic, hyperthermic Typic Ustorthents (Gently sloping upper pediment)								
Ap	0-18	38.0	22.9	39.1	1.16	32.0	26.9	5.1
Pedon 3 (Khapri-3 series) : Clayey, smectitic, hyperthermic Typic Ustorthents (Gently sloping upper pediment)								
A	0-7	43.2	19.1	37.7	1.20	26.6	15.5	11.1
Pedon 4 (Khapri-4 series) : Clayey, smectitic, hyperthermic (calcareous) Typic Ustorthents (Very gently sloping lower pediment)								
Ap	0-14	46.1	16.4	37.5	1.15	29.2	16.4	12.8
AC	14-33	51.5	10.4	38.1	1.25	25.6	14.7	10.9
Pedon 5 (Khapri-5 series) : Fine-loamy, mixed, hyperthermic Typic Ustorthents (Very gently sloping lower pediment)								
Ap	0-15	43.0	25.0	32.0	1.14	28.3	15.7	12.6
AC	15-28	44.0	22.1	33.9	1.25	27.0	15.3	11.7
Pedon 6 (Khapri-6 series) : Clayey, smectitic, hyperthermic (calcareous) Typic Ustorthents (Very gently sloping upland)								
Ap	0-16	39.0	24.6	36.4	2.11	32.6	20.1	12.5
Pedon 7 (Khapri-7 series) : Fine, smectitic, hyperthermic (calcareous) Vertic Haplustepts (Very gently sloping valley plain)								
Ap	0-23	50.5	5.0	44.5	1.29	26.6	15.2	11.4
Bw1	23-48	45.6	7.8	46.6	1.40	27.1	14.8	12.3
Bw2	48-76	25.4	18.1	56.5	1.48	40.3	27.2	13.1
Bw3	76-112	26.0	16.7	57.3	1.62	44.2	30.0	14.2
Bw4	112-150	24.6	14.8	59.6	1.74	41.2	27.4	13.8
Pedon 8 (Khapri-8 series) : Fine, smectitic, hyperthermic (calcareous) Typic Haplusterts (Very gently sloping valley plain)								
Ap	0-19	21.8	28.2	50.0	1.52	39.9	27.0	12.9
Bw	19-48	16.7	31.4	51.9	1.63	39.0	25.7	13.3
Bss1k	48-84	12.5	31.7	55.8	1.82	36.6	23.1	13.5
Bss2k	84-117	11.7	29.8	58.4	1.89	37.0	24.5	12.5
Bss3k	117-150	14.7	25.1	60.2	2.14	38.7	24.7	14.0

0.52 mg kg^{-1} in surface soils and the soils are deficient in Zn against critical level of 0.6 mg kg^{-1} (Sharma *et al.* 1996). The micronutrient contents, in general, decreased with depth. The micronutrient preparations of Fe, Mn and Zn need to be supplemented for healthy growth and higher yield of the crops.

Land capability and soil productivity

The soils are grouped under IIs, IIIs, IVs, IVes and VIes land capability sub-classes (Fig. 3a). The lands under IIs are good cultivable lands with minor soil problems due to fine texture. The lands under sub-class IIIs are moderately good cultivable lands with moderate soil problems due to depth, whereas, the lands under sub-classes IVs and IVes are fairly good cultivable lands with fair limitations due to soil depth (IVs) and slope, erosion and soil depth (IVes). The village also has non-arable lands (VIes) with limitations of moderate to strong slopes, erosion and soil depth. The soil series evaluated for soil

Table 4. Chemical properties of soils

Horizon	Depth (cm)	pH (1:2.5)	EC (dSm^{-1})	O.C. (%)	$CaCO_3$ (%)	CEC (cmol $(p+)kg^{-1}$)	B S (%)	Available micronutrients Fe	Mn	Cu	Zn
								($mg\ kg^{-1}$)			
Pedon 1 (Khapri-1 series) : Loamy-skeletal, mixed, hyperthermic Lithic Ustorthents (Moderately sloping escarpment)											
Ap	0-8	7.1	0.04	0.3	0.0	31.0	81.9	1.19	0.77	0.39	0.12
Pedon 2 (Khapri-2 series) : Clayey, smectitic hyperthermic Typic Ustorthents (Gently sloping upper pediment)											
Ap	0-18	6.9	0.08	0.63	0.74	46.8	103.2	2.22	3.79	0.77	0.50
Pedon 3 (Khapri-3 series) : Clayey, smectitic, hyperthermic Typic Ustorthents (Gently sloping upper pediment)											
A	0-7	6.6	0.05	0.68	0.61	37.4	93.5	2.45	4.16	1.01	0.52
Pedon 4 (Khapri-4 series) : Clayey, smectitic, hyperthermic (calcareous) Typic Ustorthents (Very gently sloping lower pediment)											
Ap	0-14	8.0	0.09	0.31	11.32	41.2	111.4	0.76	1.62	0.28	0.19
AC	14-33	8.1	0.08	0.28	10.27	37.3	129.7	0.61	0.82	0.22	0.16
Pedon 5 (Khapri-5 series) : Fine-loamy, mixed, hyperthermic Typic Ustorthents (Very gently sloping lower pediment)											
Ap	0-15	7.5	0.09	0.34	0.42	46.2	102.3	1.23	1.95	0.37	0.26
AC	15-28	7.7	0.08	0.12	0.77	49.8	99.9	0.91	0.80	0.23	0.15
Pedon 6 (Khapri-6 series) : Clayey, smectitic, hyperthermic (calcareous) Typic Ustorthents (Very gently sloping upland)											
Ap	0-16	8.1	0.09	0.70	6.05	47.5	105.4	0.50	1.41	0.33	0.19
Pedon 7 (Khapri-7 series) : Fine, smectitic, hyperthermic (calcareous) Vertic Haplustepts (Very gently sloping valley plain)											
Ap	0-23	8.0	0.09	0.36	4.99	38.0	110.7	0.72	1.36	0.44	0.28
Bw1	23-48	8.1	0.08	0.13	5.92	37.5	118.1	0.71	0.52	0.35	0.20
Bw2	48-76	8.1	0.07	0.23	9.48	52.3	115.6	0.69	0.56	0.39	0.18
Bw3	76-112	8.2	0.10	0.31	15.26	61.2	103.1	0.65	0.58	0.34	0.17
Bw4	112-150	8.2	0.09	0.13	10.52	53.6	102.7	0.59	0.47	0.24	0.16
Pedon 8 (Khapri-8 series) : Fine, smectitic, hyperthermic (calcareous) Typic Haplusterts (Very gently sloping valley plain)											
Ap	0-19	8.2	0.15	0.92	18.03	35.6	107.8	0.48	1.10	0.47	0.27
Bw1	19-48	8.2	0.13	0.56	12.17	39.5	151.3	0.48	0.54	0.38	0.15
Bw2	48-84	8.4	0.12	0.35	22.69	42.3	118.9	0.41	0.35	0.23	0.12
Bw3	84-117	8.5	0.15	0.21	18.08	47.8	124.2	0.27	0.20	0.11	0.12
Bw4	117-150	8.6	0.26	0.12	20.39	48.4	128.8	0.42	0.13	0.11	0.13

productivity (Table 5) indicates that the soils of Khapri-7 and Khapri-8 are good in productivity with moderate limitations of soil moisture and drainage. The soils of Khapri-2, Khapri-3, Khapri-4, Khapri-5 and Khapri-6 are poor in productivity due to severe limitations of effective soil depth and soil moisture whereas, the soils of Khapri-1 are extremely poor to nil in productivity with very severe limitations of effective soil depth, soil moisture and organic matter.

Suitability of soils for crops

The suitability of soils for cotton (Fig. 3b) indicates that Khapri-1, Khapri-2, Khapri-3, Khapri-5 and Khapri-6 are not suitable due to very severe limitations of soil depth, slope and erosion. The soils of Khapri-4 are marginally suitable with limitations of soil depth and OC. The soils of Khapri-7 and Khapri-8 are moderately suitable due to moderate limitations of OC and $CaCO_3$, respectively. The suitability of soils

Table 5. Productivity index (rating class with assigned values) and productivity classes of soils

Soil Series	Soil Moisture (H)	Drainage (D)	Effective soil depth (P)	Texture/ structure (T)	Base saturation (N)	Soluble salts (S)	Organic matter (O)	Nature of clay (A)	Mineral reserves (M)	Productivity index	Productivity class
Kh-1	H3a (50)	D4 (100)	P2 (20)	T6b (90)	N5 (100)	S1 (100)	O1 (85)	A2 (95)	M2C (95)	6.9	Extremely Poor
Kh-2	H3a (50)	D4 (100)	P2 (20)	T6b (90)	N5 (100)	S1 (100)	O2 (90)	A3 (100)	M2C (95)	7.7	Poor
Kh-3	H3a(50)	D4 (100)	P2 (20)	T6b (90)	N5 (100)	S1 (100)	O2 (90)	A2 (95)	M2C (95)	7.3	Poor
Kh-4	H3a (50)	D4 (100)	P2 (20)	T6b (90)	N5 (100)	S1 (100)	O1 (85)	A2 (95)	M3C (100)	7.3	Poor
Kh-5	H3a (50)	D4 (100)	P2 (20)	T6b (90)	N5 (100)	S1 (100)	O1 (85)	A3 (100)	M2C (95)	7.3	Poor
Kh-6	H3a (50)	D4 (100)	P2 (20)	T6b (90)	N5 (100)	S1 (100)	O2 (90)	A3 (100)	M2C (95)	7.7	Poor
Kh-7	H4a (80)	D3a (90)	P6 (100)	T5b (80)	N5 (100)	S1 (100)	O2 (90)	A3 (100)	M2C (95)	49.3	Good
Kh-8	H4a (80)	D3a (90)	P6 (100)	T5b (80)	N5 (100)	S1 (100)	O2 (90)	A3 (100)	M2C (95)	49.3	Good

for sorghum (Fig. 3c) indicates that the soils of Khapri-1, Khapri-2, Khapri-3 are not suitable owing to very severe limitations of slope, erosion and severe limitations of soil depth. The soils of Khapri-5 and Khapri-6 are marginally suitable due to severe limitation of soil depth. The soils of Khapri-4, Khapri-7 and Khapri-8 are moderately suitable with moderate limitation of soil pH (Khapri-7 and Khapri-8) and soil depth (Khapri-4). The suitability of soils for soybean (Fig. 3d) indicates that the soils of Khapri-1, Khapri-2 Khapri-3, Khapri-4, Khapri-5 and Khapri-6 are not suitable due to very severe limitation of slope and soil depth (Khapri-1, Khapri-2 and Khapri-3) and soil depth (Khapri-4, Khapri-5 and Khapri-6). The soils of Khapri-7 and Khapri-8 are moderately suitable due to moderate limitation of soil pH and texture.

Suggested interventions

The gently sloping plateau top, moderately sloping escarpment, moderately steeply sloping isolated hillock and gently sloping upper pediments with extremely shallow to very shallow soils under degraded forest and wasteland with scrub are exposed to soil erosion due to lack of vegetative cover and therefore need afforestation with fast growing multi purpose trees (MPTs). The amount of litter addition through these interventions may provide a major source of soil organic matter (Raizada and Mandal 2007) and also offset the soil erosion (Hester *et al.* 1997). Mechanical measures like continuous contour trenches are to be taken up to conserve water and also to protect the soils. The very gently sloping lower pediments and uplands with shallow soils, which are under single crop, need to be protected through proper field bunding and mulching to reduce run-off and conserve moisture. Agroforestry and agri-horticultural interventions with suitable species may be needed. The very gently sloping valley plain with very deep clay soils under double crop supporting orange orchards with assured irrigation may be put under intensive cultivation with vegetables and floriculture with suitable provision for drainage.

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