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Assessment and management of soil sustainability of the soils of north-west gir madhuvanti topo sequence of south saurashtra region of Gujarat

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Abstract
Six representative pedons were evaluated for their soil sustainability and there constraints by scoring method of the soils of different land slope of north-west Gir Madhuvanti topo sequence of south Saurashtra region of Gujarat. The soils of hill slope belong to Lithic Ustorthents (P_1) were placed in sustainable class (S_2). The soils of upper piedmont belong to Lithic Ustorthents (P_2), lower piedmont belong to Vertic Haplusterts (P_3), plain area belong to Typic Haplusterts (P_4), depression area belong to Sodic Haplusterts (P_5) and upper coast belong to Fluventic Calciustepts (P_6) were placed in sustainable with high input class (S_3). In addition to this, the general mean score of weight factors of soil constraints were found in the order of Hill Slope (23) < Lower Piedmont (27) < Upper Piedmont (28) < Plain Area (30) = Depression Area (30) = Upper Coast (30). Indicators of soil sustainability, such as effective rooting depth (20-90 cm), bulk density (1.23-1.43 Mg m^{-3}), texture (clayey), structure (sub-angular blocky), available water capacity (14-27 cm m^{-1}), saturated hydraulic conductivity (0.00-0.18 cm hr^{-1}), pH (6.79-8.28), EC (0.28-3.08 dSm^{-1}), organic carbon (0.54-0.84 % of surface horizon) and SAR (0.78-4.02) were compared with the limits as proposed by Lal, (1994) [6] to understand the severity of constraints for sustainability.

Keyword: soil sustainability, land slopes, north-west Gir Madhuvanti topo sequence, soil indicators, Evaluation

Introduction
Growing populations demand an increase in the amount of food being produced, which in turn, puts pressure on the productivity and sustainability of soils. These would serve as baseline indicators for future planning and also determine the crop yield and response to the management practices adopted. This demands our focused attention to develop alternative land use options and identifying best possible area for a given crop for sustaining and optimizing the production. It necessitates the appropriate interpretation of soil data base in terms of their sustainability for different agricultural/ non-agricultural uses to rationalize land use. For the sustainable use of the natural resources, a detailed charter of land resources giving its potential and constraints becomes pre-requisite for planning.

Material and method
The study area (north-west Gir Madhuvanti topo sequence) was located between $21^0$13' to $21^0$25' N latitudes and $69^0$57' to $70^0$32' E longitudes encompassing parts of the Mendarda, Vanthli, and Keshod tehsils of Junagadh district and Porbandar tehsil of Porbandar district of south Saurashtra at an elevation ranged from 5 to 190 above mean sea level. IRS IA LISS II FCC imagery on 1:50,000 scale in conjunction with Survey of India topographical (SOI) map referred above on 1:50,000 scale were used to select various land slopes of north-west Gir Madhuvanti topo sequence of south Saurashtra region of Gujarat namely: hill slope (LS-1), upper piedmont (LS-2), lower piedmont (LS-3), plain area (LS-4), depression area (LS-5) and upper coast (LS-6) (Fig.-1). Horizon-wise soil samples collected from the typifying pedons were analysed for their physical and chemical characteristics following standard procedure and soils were classified according to Key to Soil Taxonomy (Anonymous, 2003) [2]. Evaluations of soil sustainability based on evaluating the constraints of soils by using scoring method, as outlined by Lal (1994) [6], *viz.*, S_1 = highly sustainable (< 20), S_2 = Sustainable (20-25),

S_3 = Sustainable with high input (25-30), S_4 = Sustainable with alternate land use (30-40) and S_5 = Unsustainable (> 40) (Table 1).

Result and discussion

Indicators for soil sustainability

Attributes of soil quality assessment have been outlined and described by USDA (1992) [13], Acton (1993) [1] and (Lal, 1994) [6]. The indicators observed based on morphological and laboratory studies of different land slopes of north-west Gir Madhuvanti topo sequence of south Saurashtra are presented in Table 2 and 3 with weighting score factors (Scoring).

(A) Effective rooting depth

Severe limitation of effective rooting depth observed in pedon P_1 and P_2 at hill slope and upper piedmont of north-west Gir Madhuvanti topo sequence as a result of petro calcic substratum and compacted basaltic material. The moderate limitation of effective rooting depth observed in pedon P_3, P_4 and P_5 and slight limitation P_6. A fact also corroborated by the findings of Sharma (2000) [10], Savalia (2005) [8], Patel (2010) [7] and Gandhi (2013) [4].

(B) Bulk density

The bulk density of soil is responsible for compaction, root growth and transpiration of water. The bulk density observed in the range between 1.23 and 1.43 Mg m^{-3}. Moderate limitation of bulk density was observed in pedon P_4 and P_5. The soils of the pedon P_1, P_2 and P_3 observed slight limitation and severe limitation of bulk density was observed in pedon P_6 (Savalia, 2005, Patel, 2010 and Gandhi, 2013) [8, 7, 4].

(C) Texture

Clay (c) texture in pedon P_3, P_4 and P_5 posed extreme limitation for permeability of soil. The clay loam texture was observed only in pedon P_2 posed moderate limitation, whereas silty clay loam (sicl) texture was observed only in pedon P_6 posed slight limitation for permeability. But the loam (l) texture was found in pedon P_1 posed no limitation for permeability of soil (Savalia, 2005, Patel, 2010 and Gandhi, 2013) [8, 7, 4].

(D) Structure

In general, the soil structure for all the soils were sub-angular blocky in surface and sub-surfaces offering slight limitation in their workability (Savalia, 2005, Patel, 2010 and Gandhi, 2013) [8, 7, 4].

(E) Available water capacity

The moderate degree of limitation was noted in pedon P_1, P_2 and P_4 with respect to AWC, whereas slight limitation observed in pedon P_3, P_5 and P_6. (Singh *et al,* 2008 and Savalia, 2005) [12, 8]

(F) Saturated hydraulic conductivity (Sat. H. C.)

The soils of pedon P_4 have severe limitation, whereas P_5 and P_6 have extreme limitation with respect to very slow hydraulic conductivity due to high smectite dominant minerals near the sea coast. In pedons P_1, P_2 and P_3 the problem was moderate (Savalia, 2005, Patel, 2010 and Gandhi, 2013) [8, 7, 4].

(G) pH

Extreme limitation recorded in pedon P_5 and P_6 with respect to pH. Severe limitation observed in pedon P_2, P_3 and P_4, while no limitation was found in Pedon P_1 due to hill slope area. High pH affects nutrient transformation, nutrient absorption as well as nutrient fixation and thus, become a limiting factor. The nutrient dynamics in the soil is affected through the imbalance in nutrient availability, which ultimately results in drastic reduction in soil productivity (Savalia, 2005) [8].

(H) EC

The soils of pedon P_6 have slight limitation with respect to EC, whereas pedon P_1 to P_5 have no limitations (Savalia, 2005; Patel, 2010 and Gandhi, 2013) [8, 7, 4].

(I) Organic carbon

The soils pedon P_1, P_2, P_3, P_4, P_5 and P_6 showed severe limitation on account of organic carbon content under situation of semi-arid (dry) condition. This indicates, low fertility status on the soils (Lal, 1994; DNRM, 2000; Sharma, 2000; Savalia, 2005; Patel, 2010 and Gandhi, 2013) [6, 3, 10, 8, 7, 4]. Problems of physical limitations of soils are generally related to reduction in organic carbon content (DNRM, 2000) [3].

(J) SAR

The SAR values observed < 10 in all the soils examined, thus gives an impression that the soils could be categorized with no limitation (Savalia, 2005, Patel, 2010 and Gandhi, 2013) [8, 7, 4].

Evaluation and management of soil sustainability

- **Hill slope**

The soils of pedon P_1 (Karsangadh) were in sustainable class (S_2) on account of extreme limitations in depth, severe limitation in organic carbon and moderate limitations like AWC and saturated hydraulic conductivity (Table - 3). These findings are corroborated with finding the Savalia *et al.* (2009) [9], Patel (2010) [7] and Gandhi (2013) [4].

Management

Soil conservation measures like graded narrow base terrace bunds or trenches and contour bunding should be adopted (Savalia *et al*., 2009) [9].

- **Upper piedmont**

The soils of pedon P_2 (Malanka) were sustainable with high input (S_3) on account of extreme limitations in depth, severe limitations like poor soil fertility (low O.C) and pH, moderate limitations like saturated hydraulic conductivity, AWC and texture (Table - 3).

Management

Agronomic practices of primary tillage, adequate plant population and following moisture conservation practices, use of drought tolerant crops and varieties, drip irrigation, Use of organic manures along with inorganic fertilizers should be adopted, Graded narrow base terrace bunds or trenches are recommended to increase soil depth/rooting volume, conservation tillage and forage-based crop rotations which reduce erosion and allow soil forming factors to maintain and rehabilitate top soil.

- **Lower piedmont**

The soils of pedon P_3 (Mendarda) were sustainable with high input (S_3) on account of extreme limitations in this area like texture, severe limitation like poor soil fertility (low O.C) and pH and moderate limitations like, soil depth and saturated hydraulic conductivity (Table - 3).

Management

For increase soil organic matter, zero or minimum tillage, legume based and other crop rotation, cover crops and forage crops should be practiced, use of organic manures along with balanced fertilizers should be adopted, provision of drainage whenever required. Frequent inter culturing operations, use of recycling and organic waste should be adopted, application of weathered materials, gypsum and sand in furrow are found to be effective.

- **Plain area**

The soils of pedons P_4 (Tinmus) were sustainable with high input (S_3) on account of extreme limitations in plain area like texture, severe limitations like low saturated hydraulic conductivity, high pH, and poor soil fertility (low O.C.) and moderate limitations like bulk density, AWC and soil depth (Table - 3). These finding are in conformity with the finding of Savalia *et al*. (2009) [9], Patel (2010) [7] and Gandhi (2013) [4].

Management

Agronomic practices such as soil deep ploughing, special planting practices and irrigation management, mulching and rain water leaching and adoption of salt tolerant cultivars. For increasing organic matter, continuous cropping with well ranged crops, reduce, zero or minimum tillage, legume based and other crop rotations, cover crops and forage. Frequent inter culturing operations, constant monitoring of soils should be done while using saline waters for irrigation purpose. In saline soils, the entire root zone requires to be flushed for which availability of good quality water is essential.

- **Depression area**

The soils of pedon P_5 (Akhodar) were sustainable with high input (S_3) on account of extreme limitations in depression area like very low saturated hydraulic conductivity, texture, severe limitations like high pH, poor soil fertility (low O.C.) and moderate limitations like bulk density and soil depth (Table - 3). These finding are in conformity with the finding of Savalia *et al*. (2009) [9].

Management

Agronomic practices such as chiseling deep ploughing, special planting practices, irrigation management, mulching, rain water leaching and adoption of salt tolerant cultivars. For increasing organic matter, continuous cropping with well ranged crops, reduce, zero or minimum tillage, legume based and other crop rotations, cover crops and forage. Frequent inter culturing operations, application of *tanch* (murrum), gypsum and sand in furrow found effective. Gypsum, weathered material and sand in furrow should be applied to improve soil aeration. Constant monitoring of soils should be done while using saline waters for irrigation purpose. In saline soils, the entire root zone requires to be flushed for which availability of good quality water is essential, proper sub-surface drainage need to be ascertained. Lateral ditches can serve to drain the soils of excessive salts. For severely degraded soils, xerophytes, halophytic trees, shrubs and grasses should be grown (Giri *et al.*, 1999) [5].

- **Upper coast**

The soils of pedons P_6 (Madhavpur) were sustainable with high input class (S_3) on account of extreme limitations in area like very low saturated hydraulic conductivity and high pH, severe limitations like poor soil fertility (low O.C.) and high bulk density and moderate limitation like soil depth (Table - 3). These finding are in conformity with the finding of Savalia *et al*. (2009) [9].

Management

Agronomic practices such as chiseling deep ploughing, changing the land configuration by special planting practices, irrigation management, mulching, rain water leaching and adoption of salt tolerant cultivars. For increasing organic matter, continuous cropping with well ranged crops, reduces, zero or minimum tillage, legume based and other crop rotations, cover crops and forage should be adopted. Frequent inter culturing operations, application of *tanch* (murrum), gypsum and sand in furrow found effective. Gypsum, weathered material and sand in furrow should be applied to improve soil aeration. Constant monitoring of soils should be done while using saline waters for irrigation purpose. In saline soils, the entire root zone requires to be flushed for which availability of good quality water is essential. Proper sub-surface drainage need to be ascertained. Lateral ditches can serve to drain the soils of excessive salts. For severely degraded soils, xerophytic, halophytic trees, shrubs and grasses should be grown. *Acacia catchu, Azadirachta indica, Casuarina equisetifotia, Cynadon dactyton, Eucalyptus spp., Propsopis juliflora, Phoenix sylverstris, Rhizophora mucronata* should be grown (Giri *et al.*, 1999) [5].

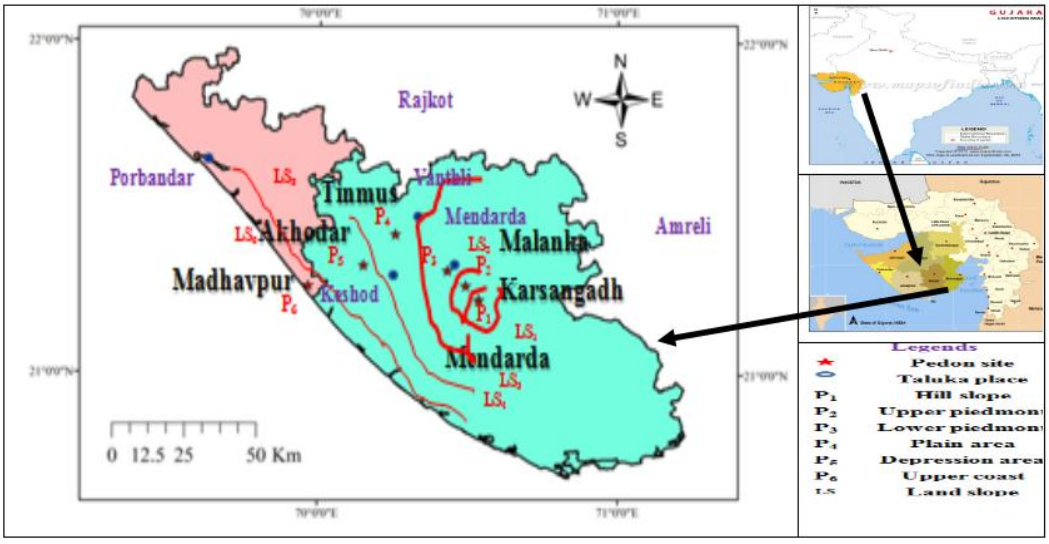

Fig 1: Site of pedons of north-west Gir Madhuvanti toposequence in South Saurashtra

Table 1: Critical levels of key indicators for soil constraints evaluation and soil sustainability according to Lal (1994)

Limitations	Weigh-ting factors	Effective rooting depths (cm)	Bulk density (Mg/m^3)	Consistency	Texture	Available water capacity (cm/m)	Structure	Sat. hydraulic conductive-ity (cm hr^{-1})	pH	EC (dSm^{-1})	Org. C. (%)	ESP	SAR
None	1	> 150	< 1.2	Loose	Loam	> 30	Strong sub angular blocky to crumb	> 2.0	6.0-7.0	< 3	5-10	< 15	< 10
Slight	2	100-150	1.2-1.3	Very friable	Silt-loam, silt, silty clay loam	20-30	Sub angular blocky	0.2-2.0	7.0-7.4	3-5	3-5	15-30	10-12
Moderate	3	50-100	1.3-1.4	Friable	Clay loam, sandy loam	8-20	Moderate sub angular blocky	0.02-0.2	7.4-7.8	5-7	1-3	30-50	12-15
Severe	4	25-50	1.4-1.5	Hard	Silty clay, loamy sand	2-8	Weak sub angular blocky	0.002-0.02	7.8-8.2	7-10	0.5-1.0	50-70	15-20
Extreme	5	< 25	> 1.5	Hard to extremely hard	Clay, sand	< 2	Massive or single grain	< 0.002	> 8.2	> 10	< 0.5	> 70	> 20

Table 2: Soil sustainability indicators and constraints analysis of the soils of north-west Gir Madhuvanti toposequence of south Saurashtra

Sr. No.	Properties	Pedon of north-west Gir Madhuvanti toposequence					
		P_1	P_2	P_3	P_4	P_5	P_6
1	2	3	4	5	6	7	8
1	Effective rooting depth (cm)	20(5)	20 (5)	54 (3)	74 (3)	87 (3)	90 (3)
2	B.D. ($Mg\ m^{-3}$)	1.23 (2)	1.28 (2)	1.24 (2)	1.33 (3)	1.34 (3)	1.43 (4)
3	Texture	l (1)	cl (3)	c (5)	c (5)	c (5)	sicl (2)
4	Structure	sbk(2)	sbk (2)	sbk (2)	sbk (2)	sbk (2)	sbk (2)
5	AWC/profile ($cm\ m^{-1}$)	14 (3)	16 (3)	27 (2)	19 (3)	21(2)	22 (2)
6	Sat. H.C. ($cm\ hr^{-1}$)	0.18 (3)	0.08 (3)	0.12 (3)	0.01 (4)	0.00 (5)	0.00 (5)
7	pH(1:2.5)	6.79 (1)	7.90 (4)	8.04(4)	8.13 (4)	8.20 (4)	8.28 (5)
8	EC (dSm^{-1})	0.28 (1)	0.35 (1)	0.91 (1)	1.66 (1)	2.17 (1)	3.08(2)
9	Organic carbon (%) (surface horizon)	0.84 (4)	0.81 (4)	0.72 (4)	0.69 (4)	0.60 (4)	0.54 (4)
10	SAR	0.78 (1)	0.85 (1)	2.35 (1)	3.39 (1)	3.59 (1)	4.02 (1)
	Total	23	28	27	30	30	30
	Sustainability	S_2	S_3	S_3	S_3	S_3	S_3

sbk: Sub-angular blocky figure, figures in parenthesis indicates weighting factors.
1= None 2=Slight 3= Moderate 4= Severe 5=Extreme
c- Clay, l- Loam, sicl- Silty clay loam, cl- Clay loam, Sat. H.C. = Saturated Hydraulic Conductivity,
S_1- Highly sustainable (< 20), S_2-Sustainable (20-25), S_3- Sustainable with high input (25-30), S_4- Sustainable with alternate land use (30-40)

Table 3: Soil constraints summation of weighting factors for relevant properties of the soils of north-west Gir Madhuvanti toposequence of south Saurashtra

Pedon / toposequence	Soil constraints					Soil sustainability class
	Extreme (5)	Severe (4)	Moderate (3)	Slight (2)	None (1)	
1	2	3	4	5	6	7
Pedon-1 Hill slope (Karsangadh), MSL : 190 m, $21^0$13' N latitudes, $70^0$32' E longitude, Lithic Ustorthents						
P_1	Depth	Organic carbon	AWC, Sat. H.C.	B.D., Structure	Texture, pH, EC, SAR	S_2 (23)
Pedon-2 Upper piedmont (Malanka), MSL :155 m, $21^0$16' N latitudes, $70^0$29' E longitude, Lithic Ustorthents						
P_2	Depth	pH, Organic carbon	Texture, AWC, Sat. H.C.	B.D., Structure	EC, SAR	S_3 (28)
Pedon-3 Lower piedmont (Mendarda), MSL : 92 m, $21^0$18' N latitudes, $70^0$25' E longitude, Vertic Haplusterts						
P_3	Texture	pH, Organic carbon	Depth, Sat. H.C.	B.D., AWC, Structure	EC, SAR	S_3 (27)
Pedon-4 Plain area (Tinmus), MSL : 27 m, $21^0$25' N latitudes, $70^0$15' E longitude, Typic Haplusterts						
P_4	Texture	Sat. H.C., pH, Organic carbon	Depth, B.D., AWC	Structure	EC, SAR	S_3 (30)
Pedon-5 Depression area (Akhodar), MSL : 13 m, $21^0$19' N latitudes, $70^0$08' E longitude, Sodic Haplusterts						
P_5	Sat. H.C., Texture	Organic carbon, pH	B.D., Depth	Structure, AWC	EC, SAR	S_3 (30)
Pedon-6 Upper coast (Madhavpur), MSL : 5 m, $21^0$16 N latitudes, $69^0$57' E longitude, Fluventic Calciustepts						
P_6	Sat. H.C., pH	B.D., Organic carbon	Depth	Texture, AWC, Structure, EC	SAR	S_3 (30)

S_1- Highly sustainable (<20), S_2-Sustainable (20-25), S_3- Sustainable with high input (25-30), S_4- Sustainable with alternate land use (30-40)
Sat. H.C. = Saturated Hydraulic Conductivity, SAR = Sodium Adsorption Ratio, AWC = Available Water Capacity

Conclusion

It may be summarized that in general soils of different land slope of north-west Gir Madhuvanti toposequence of south Saurashtra region of Gujarat are sustainable with high input class (S_3) (Weighted factors - 28) on account of major soil limitations like poor soil fertility (low O.C.), high pH as well as bulk density, low saturated hydraulic conductivity as well as restricted soil depth and fine texture. The management strategies of the soils of different land slopes, therefore, should be in accordance to the constraints and should be economically viable like as tillage, moisture conservation practices, tolerant crops and varieties, drip irrigation, organic

manures along with inorganic fertilizers, use of gypsum, graded narrow base terrace bunds or trenches *etc*.

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