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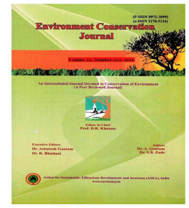

A novel soil quality assessment method for sustainable soil management and enhancing crop productivity in tribal areas of central India

Rajendiran, S.✉
Division of Environmental Soil Science, ICAR-Indian Institute of Soil Science (IISS), Bhopal (Madhya Pradesh), India

M.L. Dotaniya
Division of Environmental Soil Science, ICAR-IISS, Bhopal (Madhya Pradesh), India

M.Vassanda Coumar
Division of Environmental Soil Science, ICAR-IISS, Bhopal (Madhya Pradesh), India

S. Kundu
Division of Environmental Soil Science, ICAR-IISS, Bhopal (Madhya Pradesh), India

N.K. Sinha
Division of Soil Physics, ICAR-IISS, Bhopal (Madhya Pradesh), India

A.K. Tripathi
Division of Soil Biology, ICAR-IISS, Bhopal (Madhya Pradesh), India

S. Srivastava
Division of Soil Chemistry and Fertility, ICAR-IISS, Bhopal (Madhya Pradesh), India

J.K. Saha
Division of Environmental Soil Science, ICAR-IISS, Bhopal (Madhya Pradesh), India

A.K. Patra
ICAR-IISS, Bhopal (Madhya Pradesh), India

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ABSTRACT

Soil quality degradation is a major threat to any agricultural production system. Therefore periodical monitoring of soil quality status is inevitable for sustainable management of agricultural production systems. Though there are various methods available to assess the soil quality, simple and management oriented methods are necessary. The current investigation aimed to evaluate soil quality of tribal areas of central India adopting minimum dataset of 15 soil physical, chemical and biological parameters. A novel scoring technique was followed to score soil quality indicators based on its relation with crop yield, degree of variation and percent deficiency. Relative soil quality index (RSQI) was calculated and was correlated with crop productivity. Most of the soils in the region had poor soil quality (77.2% in Jhabua, 85.4% in Alirajpur and 67.2% in Dhar) with low crop yield. The major constraints of crop production in these areas were low soil organic carbon (<0.5%), available N (<280 kg ha^{-1}), S (<10 mg kg^{-1}), P (<10 kg ha^{-1}), Zn (<0.5 mg kg^{-1}), dehydogenase activity (10 µg TPF g^{-1} 24 h^{-1}) and soil depth (<1 m). Adopting sustainable management practices could improve soil quality and crop productivity. This new approach is simple and systematic; this principle can be easily adoptable to other locations, and principally focuses on management related and soil parameters that constraint to production and ecological functions.

Introduction

Declining soil quality in various agrarian systems has posed a remarkable challenge to enhancing crop productivity, economic growth, and healthy environment. The major causes of soil quality degradation are inappropriate land use and soil management, desertification, erosion, salinization,

Corresponding author E-mail: *Rajendiran.S@icar.gov.in*
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etc. (NAAS, 2012). Existing soil management technologies in India and other developing countries have been evolved with the objective of increasing and sustaining high agricultural productivity. However the ever increasing human and animal population demands more food from the limited available land resources. To meet food demand of increasing population forces to practice intensive cultivation to achieve higher productivity. Intensive cultivation practices lead to poor resources use efficiency and other environmental consequences. For instances, partial and total factor productivity of applied fertilizers across India are decreasing (NAAS, 2006). Further imbalance use of fertilizers causes mining of nutrients from soil and emergence of secondary and micronutrient deficiencies in the soils (Shukla andBehera, 2012). Excess application of particular nutrient causes nutrient imbalance and environmental or soil quality degradation (NAAS, 2012). On the other hand, the growing concerns on food quality, groundwater quality, greenhouse gases (GHG) emissions, climate change, soil biodiversity, etc., there is a pressing need for integration and reorientation of soil management practices to improve and sustain the production systems (NAAS, 2017). Therefore it is essential to periodically monitor soil quality status of different management systems to make necessary suitable measures for sustaining or enhancing crop productivity and maintaining ecological health over a longer period.

Several methods or approaches of soil quality assessment have been adopted by different authors across the world (Andrews *et al.*, 2004; Buenneman *et al.*, 2018) and in India (Singh, 2007; Kundu *et al.*, 2012; Vasu *et al.*, 2017; Mahajan, 2020). The various approaches are visual assessments, analytical and statistical techniques (Andrews *et al.*, 2004). Soil quality index (SQI) is largely accepted and considered the best tool for evaluation of soil quality degradation (Wang and Gong, 1998). However, there is no universally accepted dataset selection, scoring, and soil quality indexing method for different field conditions. Different soil quality indexing methods have been used by different researchers (Masto *et al.*, 2008; Andrews *et al.*, 2004). The widely used minimum dataset methods of soil quality indicators in previous studies are expert opinion and statisticaltools (e.g., regression, principal component analysis). The linear and non linear scoring techniques are adopted to transform the datasets into scores, but none of the previous studies have evaluated these techniques simultaneously (Masto *et al.*, 2008; Buennemann *et al.*, 2018). Limitations of previous studies are differences in SQI values among the various soil quality indexing methods (e.g., additive, weighted, and max-min objective functions) and differences in evaluating the methods using the same data simultaneously in a similar field conditions (Masto *et al.*, 2008).

In spite of the above limitations, assessing SQI of different land use and soil management systems is important to locate the areas to be carefully managed for sustainable development. Previously the concept of SQI tool has been used and applied in different places following various approaches for assessing soil quality (Singh, 2007; Masto *et al.*, 2008; Kundu *et al.*, 2012; Vasu *et al.*, 2017). In this study also SQI concept was adopted with a novel scoring procedure for selected minimum dataset of indicators. The objective of the current investigation is to assess the soil quality status of tribal population dominated and most backward areas of central India using minimum set of indicators with simple novel scoring procedure. Further thus obtained SQI is correlated with productivity functions. The major soil parameters that constraint soil quality and crop productivity are also identified for suitable integrated land and soil management practices to sustain the agricultural systems in the region.

Material and Methods

Background of study area

Tribal population dominated and economically most backward Alirajpur, Jhabua and Dhar districts of Madhya Pradesh was selected for the investigation (Figure 1). The study area is situated in the Central Plateau and Hills Agro-Climatic Region. It comes under the Madhya Bharat plateau, western Malwa Plateau, eastern Gujarat plain Vindhya Satpura range and Narmada valley Agro-Ecological Region. The tribal population in Alirajpur and Jhabua districts is more than 80% of the total population, and more than 60% in case of Dhar. Larger section of population (more than 50%) in these districts lives in poverty. The major tribal groups in these districts are *Bhil* and *Bhilala*.

They largely depend on agriculture and allied activities for their livelihood. The major crops grown in these districts are maize (both in rainy and winter seasons), soybean, cotton, and black gram in rainy season; wheat and gram in winter. Some of the minor crops are black gram, groundnut, peas, sorghum, pigeon pea, chilli, garlic, potato, onion, tomato, and paddy. The soils of these regions are grouped under Entisols and more than 80% of the soils are shallow to medium deep soils (Velayutham *et al.*, 1999). Lands are highly drought-prone and degraded waste lands. Major agricultural and socio-economic related constraints are failure of rainfall and low water availability, severe land degradation and soil erosion, undulating topography, shallow soils, low soil water retention capacity, low crop productivity, mono-cropping, low soil fertility, landless labours or marginal land holdings, agricultural indebtedness, migration, etc.

Survey and soil sampling

Fifteen representative villages (Figure 1) were randomly selected from each developmental block of Jhabua and Alirajpur districts for soil sample collection. In each village, six soil samples were collected from the farmers field based on the socio-economic status particularly on the basis of land holdings (two samples each from marginal and small (< 2 ha), medium (2-5 ha) and large (>5 ha) famers). As these districts comprise of six blocks each, in total 540 geo-referenced surface soil (0-15 cm depth) samples were collected. In Dhar district, 10 villages from each block were selected and total 780 samples were collected across the 13 blocks in the district (Table 1, Figure 1). The soil sampling was done after harvest of *rabi* (winter season) crops in the months of March-June during 2013 in Jhabua, during 2014 in Alirajpur, and during 2015 in Dhar, respectively. During soil sampling soil depth was also measured by digging.

Estimation of relative yield

Yield data was also collected from the farmers during survey and soil sampling and had been used for relative yield calculations. As soil samples were collected from soybean, maize and wheat cultivated fields, equivalent wheat yields (EWY) were calculated for soybean and maize using following formulae:

$$\mathbf{EWY_{Soybean}(kg\ ha^{-1})} = \frac{\text{Yield of Soybean }(\text{kg ha}^{-1})\text{X Price of Soybean }(\text{Rs. kg}^{-1})}{\text{Price of Wheat }(\text{Rs. kg}^{-1})}$$

$$\mathbf{EWY_{Maize}(kg\ ha^{-1})} = \frac{\text{Yield of Maize }(\text{kg ha}^{-1})\text{X Price of Maize }(\text{Rs. kg}^{-1})}{\text{Price of Wheat }(\text{Rs. kg}^{-1})}$$

The following values were used for calculation that collected from the farmers during survey and sampling and the average prices of produces in the region: soybean- price Rs. 30 kg^{-1} and yield range was 7.5-18.5 q ha^{-1}; wheat- price Rs. 18 kg^{-1} and yield range was 19.5-32.0 q ha^{-1}; and maize- price Rs. 15 kg^{-1} and yield range was 15.0-26.0 q ha^{-1}. From the equivalent wheat yield, relative yield was calculated from the following equation as below:

$$\textbf{Relative yield } (\%) = \frac{\text{WEYof the location }(\text{kgha}^{-1})}{\text{Maximum WEY }(\text{kgha}^{-1})}\mathbf{x100}$$

Soil analysis

The collected soil samples were air dried and processed to pass through 2 mm sieve and analyzed for their physicochemical properties. Silt, and clay content; bulk density (water displacement method); organic carbon; dehydrogenase activity (DHA),pH and electrical conductivity (1:2.5 soil-water suspension); mineralizable N; available P; available K; available S; DTPA extractable Zn, Fe, Mn and Cu; and hot water soluble B of soils were analysed following standard procedures.

Nutrient index measurement

Nutrient index (NI) was calculated using the following equation as given by Parker *et al.* (1951)

$$\textbf{Nutrient index} = (\mathbf{1 \times N_1 + 2\ X\ N_2 + 3\ X\ N_3})/\mathbf{N}$$

Where, N_l = Number of soil samples in low category; N_m = Number of soil samples in medium category; N_h = Number of soil samples in high category; and N = Total number of soil samples.

The critical range followed for fixing low, medium and high in all the nutrients were as prescribed in Kundu *et al.* (2012). The medium ranges were 0.5-0.75% for OC, 280-560 kg ha^{-1} for N, 10-25 kg ha^{-1} for P, 120-280 kg ha^{-1} for K, 10-25 mg kg^{-1} for S, 0.6-1.2 mg kg^{-1} Zn, 4.5-9.0 mg kg^{-1} Fe, 0.2-0.4 mg kg^{-1} Cu, 2.0-4.0 mg kg^{-1} Mn, and 1.3-2.6 mg kg^{-1} B. Below and above these ranges, it was considered

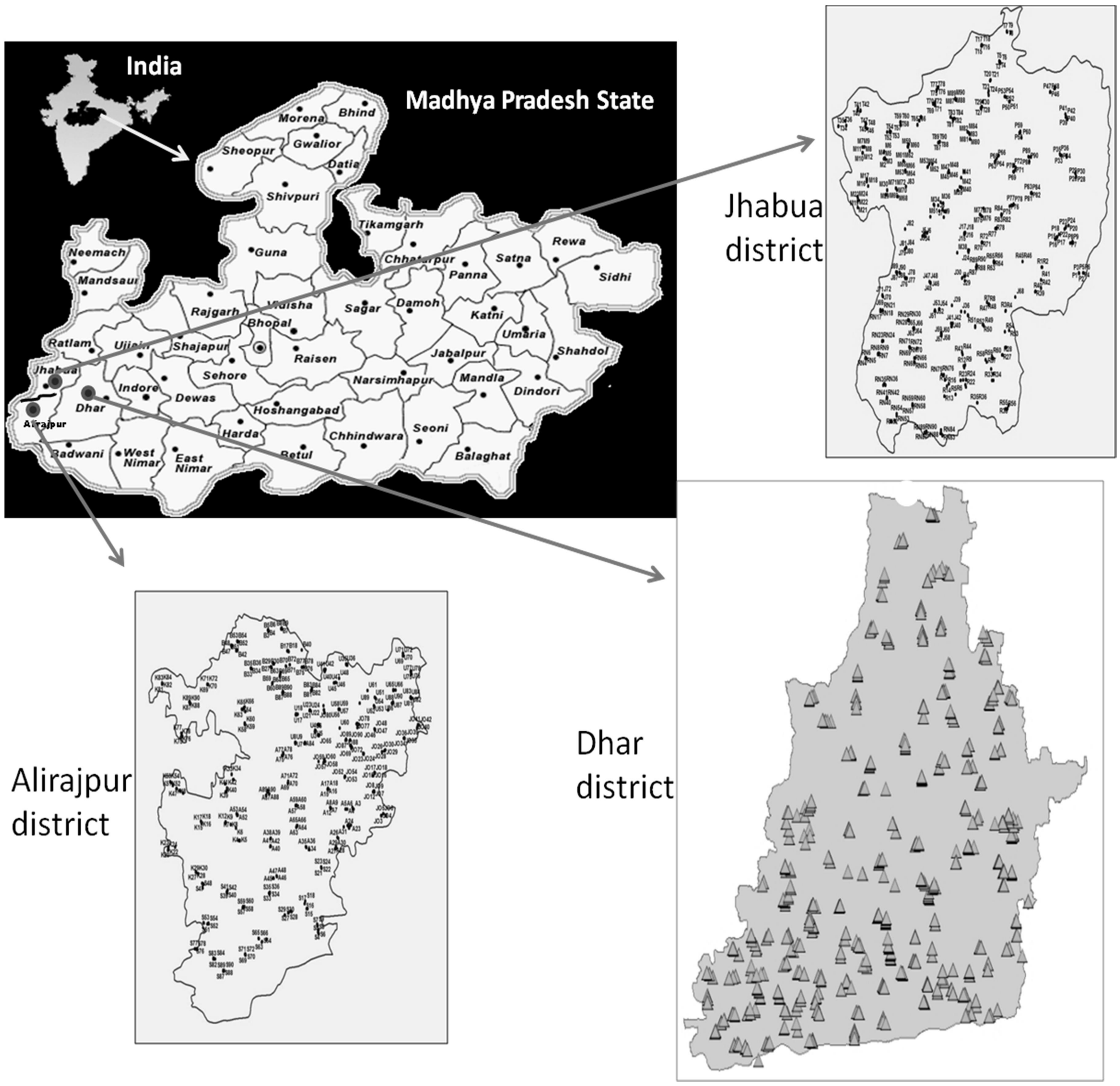

Figure 1: Study area with geo-tagged sampling points in Jhabua, Alirajpur, and Dhar districts.

low and high for respective nutrients. Based on the nutrient index value, the soils are categorized into three classes as follow: NI value less than 1.67 meant for low fertility status; 1.67-2.33 for medium fertility status; and more than 2.33 is for high fertility status.

Soil quality indicators and a novel scoring procedure

In the present study, about 15 soil physical, chemical and biological parameters were selected as soil quality indicators based on the expert judgement (Kundu *et al.*, 2012). The score to each indicator was assigned following standard nonlinear scoring procedures (Andrews *et al.*, 2004). For soil depth, soil organic carbon, DHA and available nutrients, "more is better" function is used and the higher scores were assigned to the high values and vice versa (Table 2). In case of silt+clay, bulk density and pH optimum values are given higher scores and higher and lower values are assigned lower scores as per the expert judgement (Table 2) (Kundu *et al.*, 2012).

Each of the indicator was divided into four classes namely, Class – I, Class – II, Class – III, and Class - IV with an assigned score of 4, 3, 2, and 1, respectively (Table 2) (Kundu *et al.*, 2012). A new method was employed for assigning weight to soil quality indicators in the study.

Table 1: List of villages surveyed and sampled in each district: Jhabua district (N=540), Alirajpur district (N=540) and Dhar district (N=780) (N= Number of soil samples in each district)

District	Block	Villages
Jhabua	Jhabua	Anthervelia, Gundipada, Bamura Kalyanpur, Basodi, Parvatti, Umari, Semlia bada, Kardant Badi, Mojipada, Golachoti, Peeplipada, Bhampaliya, Khedi, Nagadia, Baudibadi
	Rama	Mahudipada, Fatepura, Mahuakeda, Para, Edi Choti, Daulat pura, Paledi, Rama, Mirgarandi, Jamukundi, Sadu, Kheda, Dokerbhani, Kalapan, Kagalco
	Meghnagar	Madarani, Chokwada, Mondli, Gwali, Rasodi, Agroll, Rajpura, Chotaguda, Thalawli, Japadhra, Umaradhara, Peepalkuta, Dedla, PanchPeepliya, Nagarpura
	Ranapur	Sothiyajalam, Poochadungri, Retaluniya, Budhasala, Kalapan, Khermal, Junagaun, Machiliya Jeer, Chuyi, Van, Padalva, Damni Samna, Khadkoyi, Chaparkunda, Morekundiya
	Petlawad	Bherupada, Daturia, Balasa, Pithadi, Amirgadh, Berbet, Saragi, Karwad, Bamnia, Dulakhedi, Kodali, Rupgadh, Mohancodi, Aisyakhedi, Anathkhedi
	Tandla	Semlia (Narela), Kukadipada, Parwada, Khawaza, Sagwa, Baiwasa, Harinaga, Bhimpuri, Morjhari, Daulatpura, Udaipuria, Kaidels, Bedanta, Kotda(Bheemkunda), Tandla
Alirajpur	Udaigarh	Sebad, Hardashpur, Temachi, Badaitara, Mota Umar, Dhamantha, Kana Kakad, Baudi Khurd, Baida, Jeeri choti, Sudi badi, Budagul Badi, Padu Badi, Chuliya, Koliya Barda
	Alirajpur	Machaliyapur, Kharkha, Ghatwari, Nanpur, Sejgoan, Ajanta, Somkua, Ali, Indi, Seja, Nirala, Khotiundva, Burdhan, Ambar, Indersingh Choki
	Bhabra	Sejavada, Dugar wani, Amankhuaa, Chotee karati, Babhra, Chote Pol, Badagano, Mahindra, Barjhar, Emlee Pochi, Mehda, Matana, Gerighati, Khijara, Behdwa
	Sondwa	Melgaon, Kulwat, Walpur, Bhurdiya, Sondawa, Ojadu, Ambi, Gundawat, Chakthala, Puwasa, Umrat, Chotikendra, Bagathgarh, Garajuwara, Mathuwada
	Kattiwada	Darkhedi, Sorwa, Kel, Adharkanch, Phulmal, Chandpur, Mordhi, Amba Debry, Palia Mahu, Amkhoot, Puniawad, Karelimawadi, Bada Kheda, Harodu, Harukheda
	Jobat	Salkhera, Khari, Nehtada, Dehdala, Severiya, Padwa, Ranjithgarh, Bilaza, Chhoti Khattali, Badi Hirapur, Sidhgaon, Kandha, Kalikether, Abgari, Rampura
Dhar	Dhar	Sahalpura, Kesur, Bijur, Nepavli, Jhamurkhedi, Baggedi, Gunavath, Jethpura, Billodh, Karadiya
	Nisharpur	Dahar, Nisarpur, Bhawariya, Susari, Ambada, Lohari, Nimbal, Dahod, Chikalda, Deshwalia
	Dahi	Dahi, Attasuma, Amlal, Badwariya, Phipheda, Arada, Karajwari, Chipwariya, Jamda, Daram rai
	Baagh	Padalya, Baagh, Gadvori, Chamjhar, Narwali, Tanda, Badda, Geta, Bhomari, Akada
	Gandwani	Avaltha, Jeerabath, Keshvi, Chikliya, Pipli, Gobarva, Gozthana, Kota, Jaamli, Balledi
	Manawar	Gulati, Kulvani, Shidhana, Lankur, Bagalya, Jetpur, Eagalwar, Edi, Morat, Devrah
	Tirla	Raipuriya, Chickliya, Damanda, Gumanpura, Sulkanpur, Dilwara, Khedi, Ukala, Kuva, Kidukiya Kallu
	Kukshi	Talanpur, Dolya, Girwaniya, Megra, Awali, Kapsi, Badugyar, Longsari, Umari, Kundara
	Umarban	Pipalma, Kuwat, Lumhera Burjuga, Jheerni, Beerampura, Rawatpura, Ramadhama, Kalaldha, Peepliya, Banpura
	Naalcha	Gumanpura, Karamthalai, Narsinghmal, Sarai, Badikiya, Simsimal, Bhilkhedi, Bachanpur, Siloda Kurd, Villodha Kurd
	Badnawar	Lillikhadi, Bhahatgarh, Kod, Bidwal, Koonone, Nagda, Murrarka, Paikunda, Multhan, Ghatghara
	Dharampuri	Rampura, Mundla, Kakadu dha, Sankota, Mehegoan, Lunerakurd, Gulati, Peepliya Kurd, Rupatta, Shirsodiya
	Sardarpur	Ralamandal, Barmandal, Labriya, Rajod, Jolana, Bola, Dulad, Dati, Bobavar, Ruparil

Table 2: Soil quality indicators with their classes and scores for the evaluation of soil quality (Adopted and modified from Kundu et al., 2012)

Soil quality indicators	Class I	Class II	Class III	Class IV
Physical indicators				
Depth (m)	>2	1-2	0.5-1	<0.5
Silt+Clay (%)	30-40	20-30/40-50	10-20/50-60	<10/>60
Bulk density (Mg m^{-3})	1.3-1.4	1.3-1.2/1.4-1.5	1.2-1.1/1.5-1.6	<1.1/>1.6
Biological indicators				
Organic carbon (%)	>1	1-0.75	0.75-0.5	<0.5
DHA (µg TPF g^{-1} 24 h^{-1})	>20	20-15	15-10	<10
Chemical indicators				
pH	6.5- 7.5	6.5- 6/7.5-8	6- 5.5/8-8.5	<5.5 />8.5
Mineralizable N (kg ha^{-1})	>560	560-420	420-280	<280
Available. P (kg ha^{-1})	>25	15-25	15-10	<10
Available K (kg ha^{-1})	>280	280-200	200-120	<120
Available S (mg kg^{-1})	>25	25-15	15-10	<10
DTPA- Zn (mg kg^{-1})	>2.0	2.0-1.0	1.0-0.5	<0.5
DTPA- (mg kg^{-1})	>10.0	10-5.5	5.5-2.5	<2.5
DTPA-Mn (mg kg^{-1})	>10.0	10.0-4.0	4.0-2.0	<2.0
DTPA-Cu (mg kg^{-1})	>2.0	2.0-0.5	0.5-0.2	<0.2
Hot water soluble B (mg kg^{-1})	>1.5	1.5-0.7	0.7-0.3	<0.3
Score	4	3	2	1

Table 3: Criteria for giving weight to different indicators- A new approach

Weight	% distribution of deficiency	Correlation with yield	Co-efficient of variation (%)
5	>80	>0.50	>80
4	60-80	0.4-0.5	60-80
3	40-60	0.3-0.4	40-60
2	20-40	0.2-0.3	20-40
1	10-20	0.1-0.2	10-20
0	<10	<0.1	<10

Weight to each indicator was given based on the following criteria: (1) relation with crop yield (correlation co-efficient), (2) coefficient of variation (extent of variation in a specific region), and (3) percentage distribution of deficiency (Table 3). The total weight to each indicator was derived from the sum of weights obtained based on the above three criteria. The final weight of each indicator was considered by converting sum of all the indicators weight to 100 scale range (Table 5).

Soil quality index calculation

The soil quality index (SQI) was calculated by the following equation given by Wang and Gong (1998).

$$\mathbf{SQI} = \sum(\mathbf{W_i} \times \mathbf{I_i})$$

Where, Wi was the weight of the indicator and Ii was the marks/score of the indicator class. Thus, summing up of all the 15 indicators provided the SQI value for a particular soil of the farmer's field. In order to judge the SQI value of any site against the theoretical maximum value of SQI (i.e. 400), the concept of relative soil quality index (RSQI) was used (Singh, 2007). The RSQI was calculated as below:

$$\mathbf{RSQI} = \frac{\mathbf{SQI_{sample}}}{\mathbf{SQI_{max}}} \times \mathbf{100}$$

Where, SQI_{sample} was the SQI calculated for particular sample and SQI_{max} was the maximum SQI value. Based on the RSQI value, soils of tribal areas were grouped under different categories as described by Singh (2007) (Table 6) and the linear relationship was also established between yield and RSQI following regression statistical model (Figure 2).

Results and Discussion

Physicochemical properties of soil

Most of the soils in the region were sandy loam in texture as 53.7% and 38.2% in Alirajpur and Jhabua, respectively; whereas in Dhar, clay (30.8% soils) and sandy loam (27.4%) were the major soil textures. The other soil textures found in the region were sandy clay loam, clay, loam, clay loam and sandy clay (Table 4). Majority of soils are neutral to alkaline pH with normal electrical conductivity (<1.0 dS m^{-1}) (data not included). Soil fertility status of these districts was depicted in Table 4. The nutrient index values ranged for organic carbon (OC), available nutrients N, P, K, S, Zn, Fe, Cu, Mn and B were 1.36-1.56, 1.14-1.17, 1.63-1.84, 2.50-2.77, 1.23-1.39, 2.06-2.17, 2.55-2.81, 2.92-3.00, 2.97-3.00, and 2.22-2.68, respectively. Based on the nutrient index (NI), the soils of these districts were grouped into low fertility category for OC, available N, and available S. In case of available P, Alirajpur and Jhabua soils had low and Dhar soils had medium fertility status. DTPA extractable-Zn in the soils of all the three districts was in the medium fertility range. These soils were high in available K, DTPA extractable Fe, Cu, andMn, and hot water soluble B (Table 4).

The soil quality indicators selected in this study were simple and easily quantifiable parameters. Majority of them particularly soil organic carbon, microbial activity, soil depth and available nutrients were used and recommended as important soil quality indicators from the previous studies (Kundu *et al.*, 2012; Srinivasarao *et al.*, 2013; Buennemann *et al.*, 2018; Mahajan *et al.*, 2020). In this study also, soil organic carbon, DHA, available N, S, P and Zn, and soil depth had more weight and affected the soil quality and crop production largely in the region. In this method, it is found that, in Jhabua, SOC was largely influenced the crop yield followed by available N, DHA and available S, P, soil depth and Zn than soil bulk density, pH, available K and silt+clay content (Table 5). In Alirajpur, organic carbon and available P were largely affected the crop yield followed by available S, soil depth, N, DHA, clay+silt, Zn in the sequence (Table 5). In Dhar, available N was the most influencing indicator followed by OC, Zn, S, P and soil depth (Table 5). This trend was different from other two districts in the study. The soils in the study area had shallow depth and were prone to erosion because of undulating topography and poor management practices. Major soil texture found in these districts were sandy loam that reported to be poor in water and nutrient holding capacity and conducive to loss of applied fertilizers by leaching process than other textural classes such as loam, clay loam, sandy clay loam, clay, etc. (Hillel, 2003). Further fertility status of the soil was also low particularly in case of OC, N, S, P and Zn. The low soil organic carbon in these soils were because of higher temperatures and poor management practices such as inadequate and imbalanced supply of manures and fertilizers, poor soil and water conservation practices, mono-cropping for a longer period. Similar results were reported by Lal (2004). Inadequate supply of fertilizer nutrients and intensive crop cultivation also led to the deficiency of many numbers of available nutrients in the soils of study area. All the indicators used in the study were not only focused on the production function and also other ecological functions of the soils as addressed in previous studies (Baveye *et al.*, 2016; Buennemann *et al.*, 2018).

Soil quality distribution and crop yield

The RSQI estimated for the study area by following new approach and soil quality distribution in the study area under different classes/categories were presented in Table 6. The soil quality of the study area was largely under poor quality category followed by moderately poor and medium category. The soil samples under poor soil quality status were 77.22% for Jhabua, 85.37% for Alirajpur, and 67.18% for Dhar, respectively. In Jhabua, only poor to medium quality soils were found and no good and very good quality soils were found. Among the three districts soil quality was comparatively better in Dhar followed by Jhabua and Alirajpur.However none of the soils in these districts had very good quality (Table 6). The linear regression relationship was established between RSQI and RY in respective districts. They were RY=1.66xRSQI-29.3 (R^2=0.44) for Jhabua; RY=1.34xRSQI-12.1 (R^2=0.48) for Alirajpur; and RY=0.90xRSQI+9.67 (R^2=0.27) for Dhar, respectively (Figure 2). This showed that there was significant positive correlation exists between RSQI calculated through new approach and the RYs of study area. Further, the soil quality indicators used for deriving SQI

Table 4:Soil physico-chemical properties and fertility status of the region

Texture	Percent of soil samples			pH (range)	Class	Percent of soil samples			Parameters	Jhabua		Alirajpur		Dhar	
	Jhabua	Alirajpur	Dhar			Jhabua	Alirajpur	Dhar		NI	Remarks	NI	Remarks	NI	Remarks
Sandy loam	38.2	53.7	27.4	5.0-6.0	Moderately acidic	6.67	3.89	3.21	Organic carbon	1.49	Low	1.36	Low	1.56	Low
Sandy clay loam	16.4	22.2	18.6	6.0-6.5	Slightly acidic	13.2	6.81	6.03	Mineralizable-N	1.14	Low	1.14	Low	1.17	Low
Clay	27.2	11.6	30.8	6.5-7.5	Neutral	55.0	32.0	37.1	Available P	1.65	Low	1.63	Low	1.84	Medium
Loam	9.11	7.2	12.4	7.5-8.0	Slightly alkaline	19.1	33.4	28.7	Available K	2.77	High	2.50	High	2.69	High
Clay loam	5.45	5.3	9.52	8.0-8.5	Moderately alkaline	5.37	23.9	24.6	Available S	1.23	Low	1.29	Low	1.39	Low
Sandy clay	3.64	-	1.28	>8.5	Highly alkaline	0.93	-	0.36	DTPA- Zn	2.17	Medium	2.06	Medium	2.11	Medium
Total	100	100	100		Total	100	100	100	DTPA- Mn	2.99	High	2.97	High	3.00	High
ND- Not determined									DTPA- Cu	3.00	High	2.93	High	2.92	High
NA- Not applicable									DTPA- Fe	2.81	High	2.74	High	2.55	High
NI-Nutrient Index									Hot water soluble- B	2.68	High	2.22	Medium	ND	NA

Table 5: New approach of giving weight to soil quality indicators for evaluating soil quality

Soil quality indi-cator	Jhabua					Alirajpur					Dhar				
	% defici-ency	CV (%)	Corre-lation with yield	*Wei-ght	Con-verted 100 scale	% defici-ency	CV (%)	Corre-lation with yield	*Wei-ght	Con-verted 100 scale	% defici-ency	CV (%)	Corre-lation with yield	*Wei-ght	Con-verted 100 scale
Depth	80.23(5)	41.3(3)	0.195(1)	9	8.82	84.05(5)	34.28(2)	0.445(4)	11	10.2	56.71(3)	41.3(3)	0.22(2)	8	8.33
Silt+Clay	68.84(4)	31.11(2)	0.088(0)	6	5.87	78.90(4)	15.24(1)	0.232(2)	7	6.48	42.21(3)	26.31(2)	0.18(1)	6	6.25
BD	20.42(2)	3.67(0)	0.041(0)	2	1.96	34.91(2)	8.24(0)	0.125(1)	3	2.78	23.59(2)	7.06(0)	0.14(1)	3	3.13
OC	88.60(5)	36.02(2)	0.552(5)	12	11.8	91.94(5)	36.55(2)	0.537(5)	12	11.1	87.43(5)	33.69(2)	0.38(3)	10	10.4
DHA	65.42(4)	21.32(2)	0.412(4)	10	9.80	65.15(4)	19.12(1)	0.429(4)	9	8.33	65.42(4)	24.64(2)	0.27(2)	8	8.33
pH	12.42(1)	9.63(0)	0.075(0)	1	0.98	17.18(1)	11.57(1)	0.182(1)	3	2.78	28.08(2)	8.88(0)	0.28(2)	4	4.16
N	100.0(5)	23.52(2)	0.459(4)	11	10.8	99.43(5)	33.32(2)	0.345(3)	10	9.26	100(5)	44.85(3)	0.37(3)	11	11.5
P	58.7(3)	65.14(4)	0.294(2)	9	8.82	61.20(4)	66.22(4)	0.461(4)	12	11.1	62.43(4)	52.54(3)	0.16(1)	8	8.33
K	12.12(1)	24.32(2)	0.083(0)	3	2.95	22.87(2)	38.96(2)	0.170(1)	5	4.63	10.77(1)	34.43(2)	0.10(1)	4	4.16
S	91.25(5)	34.17(2)	0.356(3)	10	9.80	86.3(5)	49.80(3)	0.396(3)	11	10.2	84.10(5)	57.72(3)	0.14(1)	9	9.38
Zn	45.70(3)	32.06(2)	0.317(3)	8	7.85	37.86(2)	77.88(4)	0.178(1)	7	6.48	57.05(3)	79.02(4)	0.29(2)	10	10.4
Fe	5.27(0)	57.21(3)	0.205(2)	5	4.89	5.70(0)	55.79(3)	0.013(0)	3	2.78	10.38(1)	59.49(3)	0.19(1)	5	5.21
Mn	1.30(0)	53.68(3)	0.118(1)	4	3.92	3.1(0)	66.90(4)	0.045(0)	4	3.70	0(0)	60.65(4)	0.16(1)	3	3.13
Cu	8.92(0)	87.63(5)	0.101(1)	6	5.87	6.7(0)	86.38(5)	0.027(0)	5	4.63	6.41(0)	98.05(5)	0.21(2)	7	7.29
B	26.8(2)	32.10(2)	0.272(2)	6	5.87	44.2(3)	50.21(3)	0.024(0)	6	5.55	-	-	-	-	-
Total	-	-	-	102	100	-	-	-	108	100	-	-	-	96	100

Note: value in the parenthesis is weight under each criterion; *weight of each indicator obtained by sum of weights under all three criteri

adopting new approach were accounted only 44%, 48%, and 27% of production functions in Jhabua, Alirajpur and Dhar, respectively. Soil quality of the tribal area of central India was found to be poor. None of the soils in the region had very good quality. The poor soil fertility and soil quality of the study area might be due low soil organic carbon, inappropriate land use and soil management, excessive nutrient mining, deficiency of available nutrients, soil erosion, poor microbial activity, etc. (Velayutham *et al.*, 1999). The similar results of soil quality degradation in other parts of India had been described by many workers (Srinivasarao *et al.*, 2013; Mahajan *et al.*, 2020). Further there was a high positive relationship existed between SQIs calculated adopting new method and RYs. The new approach adopted for SQI calculation was highly suitable and reflected the actual status of soil quality and crop productivity of study area. Soil factors that largely influenced the crop productivity in the region are organic carbon, available N, S, P, Zn, dehydogenase activity (DHA) and soil depth. Similar results of influence of organic matter, microbial acitivities and available nutrients on crop yield were reported by other researchers (Masto *et al.*, 2008, Kundu *et al.*, 2012; Vasu *et al.*, 2017; Mahajan *et al.*, 2020). Moreover, the SQI calculated had accounted 27-48% of productivity functions in the region (Figure 2). This showed that the other factors apart from the soil quality indicators used in the study influenced the crop production functions. They could be climate, topography, rainfall pattern, water availability, cultivars used, pest and diseases, etc. (Nayak *et al.*, 2019). These were beyond the scope of the current investigation.

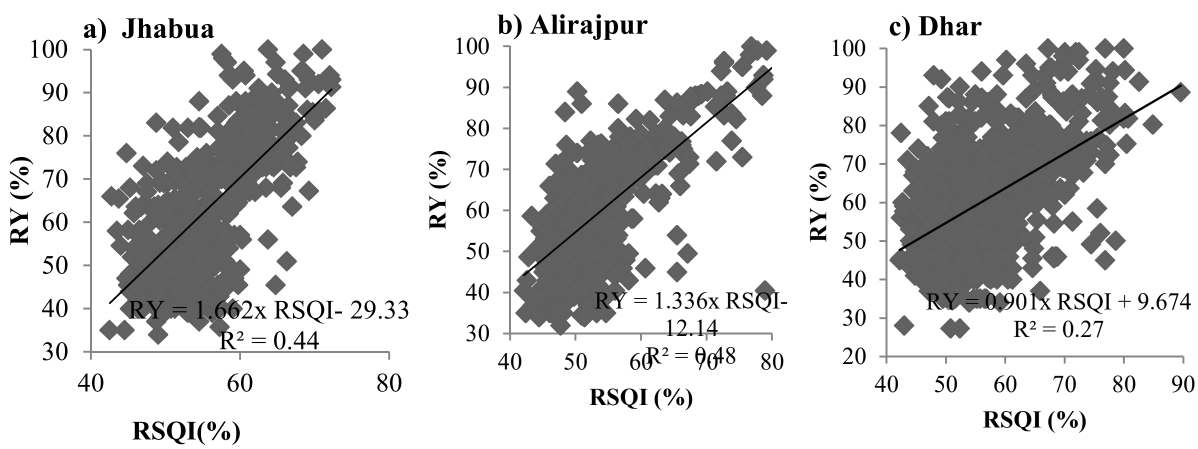

Figure 2: Interrelationship between relative soil quality index (RSQI) and relative yield (RY) in a) Jhabua; b) Alirajpur; and c) Dhar districts

Table 6: Classes/Category of soil quality based on relative soil quality index (RSQI) and soil quality status of study area (Adopted from Singh, 2007)

RSQI (%)	Classes	Category	Jhabua (% distribution)	Alirajpur (% distribution)	Dhar (% distribution)
>90	I	Very Good	Nil	Nil	Nil
80-90	II	Good	Nil	0.19	0.90
70-80	III	Medium	1.48	4.44	9.23
60-70	IV	Moderately Poor	21.30	10.00	22.69
<60	V	Poor	77.22	85.37	67.18

Significance of new approach of soil quality assessment

Soil quality assessment through the new approach reflected the actual status of soil in the study area. For example, in Alirajpur and Jhabua district, the percentage of poor quality soils was 85.37% and 77.22%; whereas in Dhar district, the percenaget of poor quality soils were 67.18%. This reflected in the average crop productivity of the districts. The mean crop productivity of Dhar district was higher than that of Jhabua district. Moreover, the new approach was more accurate and systematic. Weight to each indicator was given on the basis of its relation with crop yield, variation and high percent of deficiency/lower class. In previous studies, expert judgement and statistical technique (Principal component analysis, PCA) were mainly used for indexing soil quality (Singh 2007, Kundu *et al.*, 2012; Vasu *et al.*, 2017; Mahajan *etal.*, 2020). However the SQI values varied for different methods for same field conditions reported by the same authors (Andrews *et al.*, 2004). Further, Vasu *et al.* (2017) had demonstrated that expert opinion method was better than PCA method in relation to production functions. Simply depending on statistical techniques based on the generated data might not reflect the actual picture of the field conditions, therefore experts intervention required to judge or select the soil quality indicators. Expert opinion method though well reflected the production functions of study area, might not give much attention towards other ecological functions (Baveye *et al.*, 2016; Bounnemann *et al.*, 2018; Nayak *et al.*, 2019). In the new approach, the method employed not only focus on production function; it was inclusive of other ecological functions of soil. For example, equal preferences/weight was given to percent variation and deficiency of soil parameters in the region apart from crop yield relationship. Also it focused soil threats in the area for selecting suitable land use and soil use management to sustain major ecological functions of soil (Brussaard, 2012). In total the new approach was very simple; systematic; principally management oriented; focused on soil threats; gave equal importance to major ecological services of soils.

Conclusion

To sum up, most of the soils in the region are deficient in soil organic carbon and many mineral nutrients. Moreover the new approach of soil quality indexing has revealed that soil qualities in the study area are poor and highly degraded. The major soil threats in the region are decline soil organic matter, soil erosion, chemical degradation (nutrient deficiency and mining), loss of biodiversity, etc. which affect the various soil functions or processes and soil based ecosystem services. The novel soil quality assessment approach is very simple and systematic than other approaches such as statistical models. The principle can be further adopted in other regions for the similar purposes. This approach is principally management related and focuses mainly on soil parameters that constraint production and ecological functions. Practicing sustainable land use and soil management to alleviate the identified soil constraints can improve soil quality, crop productivity and other soil ecological services in the region.

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