Asian Journal of Soil Science and Plant Nutrition

Volume 10, Issue 3, Page 519-532, 2024; Article no.AJSSPN.122103
ISSN: 2456-9682

Assessment of Soil Nutrient Dynamics in Sugarcane Cultivation Areas of Navsari District: Implications for Sustainable Agriculture

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Authors' contributions

This work was carried out in collaboration among all authors. Authors BJK and VJZ designed the study, Author BJK performed the analysis, wrote the protocol and wrote the first draft of the manuscript. Author BJK managed the analysis of the study. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ajsspn/2024/v10i3364

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/122103

Original Research Article

Received: 21/06/2024
Accepted: 24/08/2024
Published: 28/08/2024

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Cite as: *Keniya, B. J., V. J. Zinzala, R. R. Sisodiya, and A. V. Patel. 2024. "Assessment of Soil Nutrient Dynamics in Sugarcane Cultivation Areas of Navsari District: Implications for Sustainable Agriculture". Asian Journal of Soil Science and Plant Nutrition 10 (3):519-32. https://doi.org/10.9734/ajsspn/2024/v10i3364.*

ABSTRACT

Sentinel 2 satellite data from the year 2021 were acquired from the Copernicus site to identify the sugarcane producing area in the Navsari district. Hybrid classification approach *i.e.,* supervised and unsupervised with ground truth data were applied using ERDAS IMAGINE software. After image classification, 2.5 km x 2.5 km grid was prepared in Q-GIS software which along with classified sugarcane area were overlapped for site identification. Then, random soil surface and sub-surface samples were collected with reference from grid of intensive sugarcane growing area. The available nitrogen, phosphorus, potassium, DTPA-Fe, DTPA-Mn, DTPA-Zn and DTPA-Cu of surface soil ranged from 132.19 to 428.65 kg ha^{-1}, 18.48 to 107.32 kg ha^{-1}, 202.34 to 359.39 kg ha^{-1}, 0.97 to 29.90 ppm, 1.10 to 29.63 ppm, 0.20 to 6.89 ppm and 1.02 to 11.69 ppm while sub-surface soil varied from 101.91 to 388.62 kg ha^{-1}, 10.16 to 99.57 kg ha^{-1}, 138.66 to 323.35 kg ha^{-1}, 0.35 to 24.97 ppm, 0.20 to 29.08 ppm, 0.05 to 3.64 ppm and 0.21 to 8.07 ppm respectively. The soils of sugarcane growing area of Navsari district showed low OC, available N and S while other nutrients were normal in range for sugarcane cultivation.

Keywords: Surface soil, sub-surface soil; nutrients; available nitrogen (N); phosphorus (P_2O_5); potassium (K_2O); DTPA (Diethylene Triamine Penta Acetic Acid)- iron (Fe); manganese (Mn); zinc (Zn); copper (Cu).

1. INTRODUCTION

The declining scenario in agricultural land and the growing food demand needs attention to optimized use of soil resources. The systematic soil survey provides an understanding of the nature and type of soil, its limitations, potential and sustainability for different land uses. The evaluation of characteristics and classification of soil provides information on the various morphological, physical, chemical and mineralogical properties of the soil [1]. These properties show complexity, spatial and temporal variety across the landscape and are very important for developing an effective land-use system for sustainable increase of agricultural production [2].

Sugarcane (*Saccharum officinarum*) is a vital crop that serves as a primary source of sugar and bioenergy production globally. Sugarcane is a widely cultivated crop in India and also an important cash crop of South Gujarat. India is the second largest producer of sugarcane contributing 306 million tons production and occupies about 4.4 million ha area [3]. In the agricultural and industrial economy of the country, it plays a crucial role. India is one of the biggest sugar producers and close competition with Brazil for its first place. Sugarcane is cultivated in 222,960 hectares in Gujarat [4].

Navsari district in the vibrant state of Gujarat, India, stands as a pivotal region for sugarcane cultivation, contributing significantly to the nation's sugar and agro-industry. Navsari district comes under south Gujarat heavy rainfall agro-climatic zone. Navsari district consist of six talukas. These talukas are Navsari, Khergam, Jalalpore, Chikhli, Vansada and Gandevi. Sugarcane was cultivated in Navsari district in 15,194 ha in 2019-20 which slightly reduced to 15,026 ha in 2020-21 with production of 9.68 lakh MT and 9.58 lakh MT respectively [4].

2. MATERIALS AND METHODS

The study was conducted in Navsari district of south Gujarat during the year 2022-2023. Monsoon generally commences from the second fortnight of June and retreats by middle of September to end of September with an average annual rainfall of 1767.3 mm. The data indicated that the maximum temperature ranged between 26.4 to 39.5 ˚C while the minimum temperature ranged between 10.9 to 27.7 ˚C during the experiment season December-2021 to February-2023 respectively. The maximum relative humidity was between 68 and 98% while the minimum relative humidity was between 20% and 97% during the experiment season December-2021 to February-2023 while bright sunshine hours day^{-1} was between 0.0 to 10.2 hours.

The study area *i.e.,* Navsari district has clayey soil. According to the data collected from the Department of Agricultural Meteorology, N. M. College of Agriculture, Navsari Agricultural University, Navsari, over the last 20 years, from 2004 to 2023, the mean annual rainfall in the study area is recorded at 1861 mm. This area receives rainfall which is sufficient for sugarcane crops. In the event of a prolonged dry spell, protective irrigations may be required, which can be provided through canals or bore wells where feasible. The mean value of the monthly minimum temperature ranges from 13.59 °C in January to 26.43 °C in May, with an overall mean value of 20.41 °C. Conversely, for the maximum temperature, the mean value ranges from 28.24 °C in August to 35.62 °C in April, with an overall mean value of 31.52 °C. Morning relative humidity data showed a range from 74.92 percent in November to 88.61 percent in September. Evening relative humidity also varied across months, ranging from 34.78 percent in March to 79.07 percent in July. The mean of monthly sunshine hours ranged from 2.63 hours in July to 9.57 hours in May, with an annual mean value of 6.81 hours. This indicates that there is adequate sunlight reaching the plants for the photosynthesis process. The study area falls under the heavy rainfall zone of south Gujarat. During the months of July and August, the maximum rainfall occurs, resulting in lower hours of sunshine. The annual average wind velocity is comparatively low (4.71 km hr^{-1}). It is ranging from 2.41 km hr^{-1} during November to 8.17 km hr^{-1} during June. The soil of Gandevi and Vansda taluka are delineated within the *Inceptisols* order, specifically *Typic Haplustepts* subgroup. However, soil of Chikhli taluka are categorized under the *Entisols* order, typified by the *Typic Ustorthents* subgroup, while the soils of Navsari, Khergam and Jalalpore taluka are classified under the *Vertisols* order, within the *Typic Haplusterts* subgroup. The study area has ustic soil moisture regime and hyperthermic soil temperature regime.

Sentinel 2 satellite data from the year 2021 were acquired from the Copernicus site to identify the sugarcane producing area in the Navsari district. Hybrid classification approach *i.e.,* supervised and unsupervised with ground truth data were applied using ERDAS IMAGINE software. After image classification, 2.5 km X 2.5 km grid was prepared in Q-GIS software. Classified sugarcane area and 2.5 X 2.5 km grid were overlapped for site identification. Then, random soil samples were collected with reference from grid of intensive sugarcane growing area. From each grid soil samples were collected at a depth of 0-22.5 and 22.5-45 cm by adopting standard procedure [5]. The latitude and longitude were also recorded for each sample point with the help of portable Global Positioning System (GPS). 179 surface and 179 subsurface soil samples were collected from all over Navsari district of sugarcane growing area. Out of 179 grids from which soil samples were collected, 19, 24, 40, 41, 16 and 39 grids were from Gandevi, Jalalpore, Navsari, Vansda, Khergam and Chikhli taluka respectively.

Soil available nitrogen was determined by using the alkaline potassium permanganate method [6]. For this, 20 gram soil was taken in 800 ml distillation flask with 100 ml 0.32% $KMnO_4$, few glass beads, paraffin liquid and lastly add 100 ml 2.5% NaOH before switching on the heater while in 250 ml beaker take 25 ml 4% boric acid containing mixed indicator which was to be placed under receiver tube of the distillation apparatus. Continue distillation until 150 ml of distillate was collected which is to be titrate with 0.05 N H_2SO_4. Soil available phosphorus was determined by following the spectrometric (Extraction with 0.5 M $NaHCO_3$, pH 8.5) method [7]. For this, 5 gram soil was taken in 250 ml plastic bottle with 0.5 M 100 ml $NaHCO_3$, 1 spoon charcoal before shaking it for 30 minute on mechanical shaker. Filter the same with Whatman No. 42 filter paper and take 5 ml aliquot in 25 ml volumetric flask with 5 ml ammonium molybdate, 1ml working $SnCl_2$ and make volume to 25 ml of which spectrophotometer reading at 660 nm wavelength was taken for calculation of available P_2O_5. Soil available potassium was determined by following flame photometric (Extraction with 1N NH_4OAc) method [8]. For this, 5 gram soil was taken in 150 ml plastic bottle with 25 ml neutral normal ammonium acetate before shaking it for 30 minute on mechanical shaker. Filter the same with Whatman No. 1 filter paper and take flame photometer reading for calculation of available K_2O. DTPA-extractable Fe, Mn, Zn Cu, were determined from soil samples by using atomic absorption spectrophotometer method as suggested by Lindsay and Norvell, [9]. For this, 10 gram soil was taken in 100 ml plastic bottle with 20 ml DTPA extractant before shaking it for 2 hours on mechanical shaker. Filter the same with Whatman No. 42 filter paper and take atomic absorption spectrophotometer reading for calculation of micronutrients. The ratings of the soil nutrients are given in Tables 1 and 2.

The observed and collected data of soil parameters are subject to descriptive statistics by Panse and Sukhatme, (1967) and results were discussed accordingly. The mean is the result of sum of all items in the series divided by the number of items.

3. RESULTS AND DISCUSSION

3.1 Available Nitrogen (N)

In surface soil of Vansda taluka available nitrogen ranged between 132.19-428.65 kg ha^{-1} which was maximum, followed by 141.17-409.14 kg ha^{-1} in Navsari taluka, 158.73-359.84 kg ha^{-1} in Khergam taluka, 141.46-403.45 kg ha^{-1} in Jalalpore taluka, 137.14-391.83 kg ha^{-1} in Chikhli Taluka and 152.27-354.62 kg ha^{-1} in Gandevi taluka. However, the available nitrogen content was highest in Vansda taluka with mean value in sub-surface soil samples being 197.14 kg ha^{-1} followed by Navsari (186.92 kg ha^{-1}), Khergam (182.27 kg ha^{-1}), Gandevi (176.80 kg ha^{-1}), Chikhli (164.15 kg ha^{-1}) and Jalalpore (159.78 kg ha^{-1}) taluka. The available nitrogen of surface and sub-surface soil samples were low to medium.

The concentration of nitrogen decrease with the increase in depth might be due to the decreasing trend of soil organic carbon with depth. The similar result was also reported by Choudhary et al. (2019) in soils of Navsari district, Gujarat. The low nitrogen content could be attributed to soil management, varied application of FYM and fertilizer to previous crops. Another reason for low nitrogen content was clay mineral content into soil which decreases the availability of nitrogen due to fixation and volatilization losses. Similar result was reported by Patil et al. [10] in soils of Dindur sub-watershed of Karnataka.

3.2 Available Phosphorus (P_2O_5)

The available phosphorus of the surface soil samples ranged from 18.48 kg ha^{-1} observed in Moti Bhamti village of Vansda taluka to 107.32 kg ha^{-1} observed in Kothamadi village of Jalalpore taluka with an average of 70.56 kg ha^{-1} while available phosphorus of the sub-surface soil samples varied from 10.16 kg ha^{-1} observed in Sukhabari village of Vansda taluka to 99.57 kg ha^{-1} observed in Gholar village of Chikhli taluka with an average of 57.39 kg ha^{-1}. The available phosphorus of surface and sub-surface soils were low to high. 0.41 per cent, 30.05 per cent and 69.55 per cent of the surface soils sample were classified into the low, medium and high available phosphorus content categories, respectively and in the case of sub-surface soils sample 2.03 per cent of soils were in the low, 53.19 into the medium and 44.78 per cent into the high categories of availability.

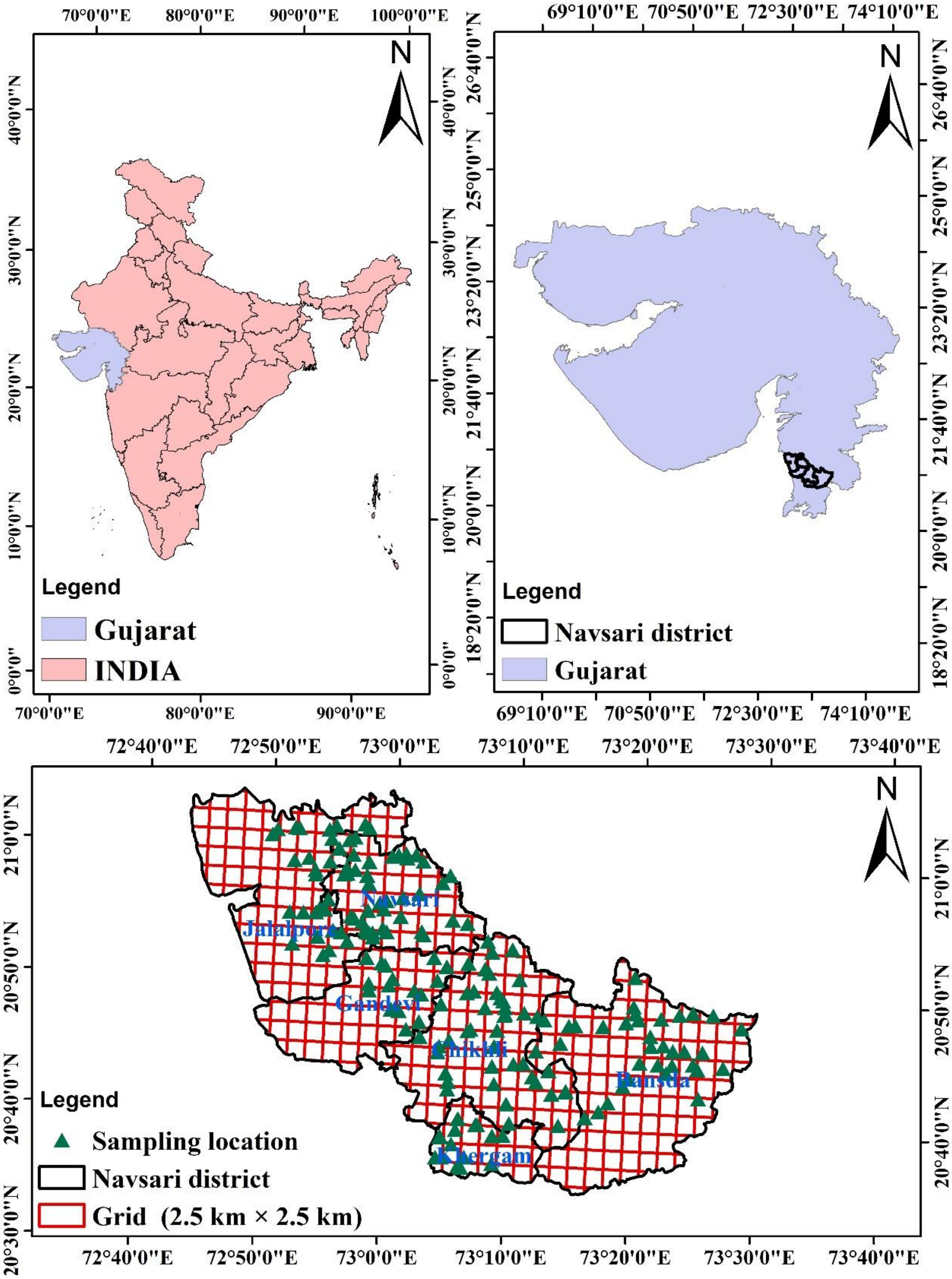
The decrement observed in soil available phosphorus in sub-surface soil probably due to confinement of crop cultivation to the rhizosphere and supplementing the depleted phosphorus by external sources *i.e.,* fertilizers, presence of free iron oxide and exchangeable Al^{3+} in smaller amount as reported by Thangasamy et al. [11] and Sekhar et al. [12]. The higher soil available phosphorus in surface soil might be attributed to fixed phosphorus pool that contains inorganic phosphate compounds which are resistant to mineralization by microorganisms in soil as noted by Bharteey et al. [13]. The decrease in soil available phosphorus with increase in soil depth could be attributed to fixation of released phosphorus by clay mineral and its removal as enumerated by Supriya et al. [14].

The available P_2O_5 content in surface as well as subsurface soils of all talukas except Vansda taluka were in medium to high category. The reason of higher available P_2O_5 content might be the higher application of varying quantum of inorganic P-fertilizers in irrigated soils. Similar trends also observed by Negash and Mohammed [15].

3.3 Available Potassium (K_2O)

The available potassium of the surface soil samples ranged from 202.34 kg ha^{-1} observed in Gadat village of Gandevi taluka to 359.39 kg ha^{-1} observed in Vad village of Khergam taluka with an average of 283.73 kg ha^{-1} while available potassium of the sub-surface soil samples varied from 138.66 kg ha^{-1} observed in Pathari village of Gandevi taluka to 323.35 kg ha^{-1} observed in Chikhli village of Chikhli taluka with an average of 235.94 kg ha^{-1}. The available potassium of surface and sub-surface soil samples were medium to high while sub-surface soil samples were low to high.

Overall, 0.00 percent, 40.66 percent and 59.34 percent of the surface soils sample were classified into the low, medium and high available potassium content categories, respectively and in the case of sub-surface soil samples 0.88 percent of soils were in the low, 84.01 into the medium and 15.11 percent into the high categories of K_2O availability.



Map 1. Location of collection of soil and water samples of sugarcane growing area of Navsari district

In the present study, it was observed that soil available potassium decreased with increase in soil depth may be attributed to more intense weathering, release of labile potassium from organic residue, application of potash fertilizer and upward translocation of potassium fertilizer from lower depth along with capillary raise of ground water as found by Sekhar et al. [16]. The finding is consistent with earlier work as reported by Thangasamy et al. [11], Ashokkumar and

Prasad [17], Bharteey et al. [13] and Kumar et al. [18]. High available K status in major surface and sub-surface soils of study area was probably due the presence of high K- bearing minerals like, feldspar and mica in the parent material. Besides, addition of organic manures might attribute to interaction of organic matter with clay leading to direct addition of potassium in the available form as reported earlier by Paramasivan and Jawahar [19] and Sharma et al. [20]. Thus, the high status of available K in soils indicated that no measures are required for K-management, as available K is quite sufficient to fulfill the crop requirement.

3.4 DTPA-Extractable Iron (Fe)

The DTPA-Fe of surface and sub-surface soil samples were low to high. In case of surface soil samples, 25.01 percent of soil samples were deficient, 35.18 percent were marginal and percent were adequate in DTPA-Fe while in case of sub-surface soil samples, 56.10 percent were deficient, 23.63 percent were marginal and 20.27 percent were adequate in DTPA-Fe. The mean value of DTPA-extractable iron (Fe) in surface soils followed an ascending order: Khergam (13.65 ppm) < Chikhli (12.52 ppm) < Jalalpore (11.37 ppm) < Navsari (10.74 ppm) < Vansda (9.87 ppm) < Gandevi (9.08 ppm). The mean value of DTPA-extractable iron (Fe) in sub-surface soils followed an ascending order: Jalalpore (8.19 ppm) < Khergam (7.07 ppm) < Navsari (6.86 ppm) < Chikhli (6.36 ppm) < Gandevi (5.61 ppm) < Vansda (5.25 ppm). The reason for deficient or marginal DTPA-Fe was low soil organic carbon, higher pH value and $CaCO_3$ content in soils. Rengel [21] stated that organic matter and manure applications affect the immediate and potential availability of micronutrient cations, because micronutrient cations-form organo-metallic complexes as chelates with certain organic molecules and soluble chelates can increase the availability of the micronutrients.

Table 1. Ratings for soil organic carbon and macro nutrients

Sr. No.	Parameters	Rating		
		Low	Medium	High
1	Organic Carbon (%)	<0.50	0.50-0.75	>0.75
2	Available N (kg ha^{-1})	<250	250-500	>500
3	Available P_2O_5 (kg ha^{-1})	<22.9	22.9-57.25	>57.25
4	Available K_2O (kg ha^{-1})	<140	140-280	>280

SHCMS, Govt. of Gujarat [29]

Table 2. Rating for DTPA-extractable micronutrients

Sr. No.	Available Micronutrients (mg kg^{-1})	Rating		
		Deficient	Marginal	Adequate
1	Iron (Fe)	<5	5-10	>10
2	Manganese (Mn)	<5	5-10	>10
3	Zinc (Zn)	<0.5	0.5-1.0	>1.0
4	Copper (Cu)	<0.2	0.2-0.4	>0.4

Anon., [30]

Table 3. Range, mean and category wise distribution of available nitrogen (N) at surface and sub-surface soil samples in sugarcane growing area

Taluka	No. of Samples	N (kg ha^{-1})		N Distribution (%)		
		Range	Mean	Low	Medium	High
0-22.5 cm depth						
Khergam	16	158.73-359.84	289.86	25.00	75.00	0.00
Vansda	41	132.19-428.65	299.46	24.39	75.61	0.00
Chikhli	39	137.14-391.83	244.10	48.72	51.28	0.00
Navsari	40	141.17-409.14	296.25	27.50	72.50	0.00
Jalalpore	24	141.46-403.45	258.17	54.17	45.83	0.00
Gandevi	19	152.27-354.62	243.09	57.89	42.11	0.00

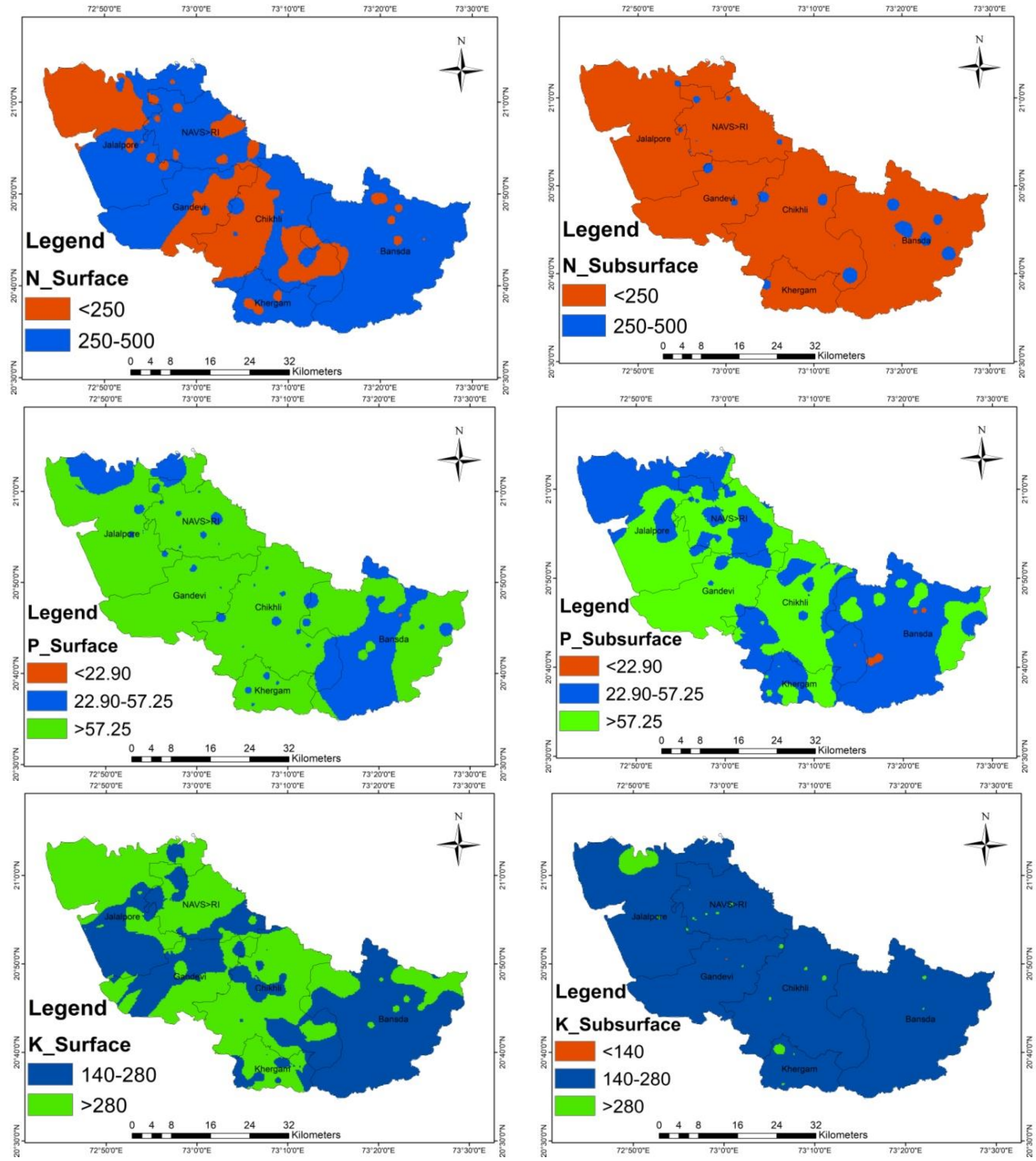
Taluka	No. of Samples	N (kg ha^{-1})		N Distribution (%)		
		Range	Mean	Low	Medium	High
OVERALL	**179**	**132.19-428.65**	**274.38**	**39.61**	**60.39**	**0.00**
22.5-45 cm depth						
Khergam	16	111.46-340.16	182.27	75.00	25.00	0.00
Vansda	41	118.21-388.62	197.14	78.05	21.95	0.00
Chikhli	39	101.91-373.86	164.15	92.31	7.69	0.00
Navsari	40	116.55-334.66	186.92	77.50	22.50	0.00
Jalalpore	24	110.45-321.56	159.78	95.83	4.17	0.00
Gandevi	19	110.93-322.67	176.80	89.47	10.53	0.00
OVERALL	**179**	**101.91-388.62**	**179.17**	**84.69**	**15.31**	**0.00**

Table 4. Range, mean and category wise distribution of available P_2O_5 of soil samples at surface and sub-surface soil samples in sugarcane growing area

Taluka	No. of Samples	P_2O_5 (kg ha^{-1})		P_2O_5 Distribution (%)		
		Range	Mean	Low	Medium	High
0-22.5 cm depth						
Khergam	16	40.26-97.32	71.95	0.00	25.00	75.00
Vansda	41	18.48-96.44	60.71	2.44	43.90	53.66
Chikhli	39	31.36-98.23	76.12	0.00	23.08	76.92
Navsari	40	32.39-99.33	75.09	0.00	22.50	77.50
Jalalpore	24	34.11-107.32	64.64	0.00	50.00	50.00
Gandevi	19	44.19-96.31	77.16	0.00	15.79	84.21
OVERALL	**179**	**18.48-107.32**	**70.56**	**0.41**	**30.05**	**69.55**
22.5-45 cm depth						
Khergam	16	30.38-88.58	54.16	0.00	62.50	37.50
Vansda	41	10.16-98.11	48.10	12.19	60.98	26.83
Chikhli	39	31.15-99.57	64.42	0.00	41.03	58.97
Navsari	40	30.11-91.36	59.61	0.00	50.00	50.00
Jalalpore	24	31.32-81.13	53.45	0.00	62.50	37.50
Gandevi	19	39.32-98.55	66.08	0.00	42.11	57.89
OVERALL	**179**	**10.16-99.57**	**57.39**	**2.03**	**53.19**	**44.78**

Table 5. Range, mean and category wise distribution of available potassium (K_2O) at surface and sub-surface soil samples in sugarcane growing area

Taluka	No. of Samples	K_2O (kg ha^{-1})		K_2O Distribution (%)		
		Range	Mean	Low	Medium	High
0-22.5 cm depth						
Khergam	16	233.09-359.39	289.20	0.00	62.50	37.50
Vansda	41	204.19-325.25	272.95	0.00	53.66	46.34
Chikhli	39	208.12-351.53	286.53	0.00	38.46	61.54
Navsari	40	221.18-348.63	287.89	0.00	27.50	72.50
Jalalpore	24	205.65-338.42	286.23	0.00	25.00	75.00
Gandevi	19	202.34-328.94	284.70	0.00	36.84	63.16
OVERALL	**179**	**202.34-359.39**	**283.73**	**0.00**	**40.66**	**59.34**
22.5-45 cm depth						
Khergam	16	173.45-323.35	246.94	0.00	75.00	25.00
Vansda	41	148.10-284.64	226.70	0.00	95.12	4.88
Chikhli	39	153.64-304.24	237.18	0.00	89.74	10.26
Navsari	40	171.36-287.12	236.77	0.00	85.00	15.00
Jalalpore	24	166.39-302.71	246.94	0.00	75.00	25.00
Gandevi	19	138.66-285.58	228.48	5.26	84.21	10.53
OVERALL	**179**	**138.66-323.35**	**235.94**	**0.88**	**84.01**	**15.11**



0-22.5 cm depth **22.5-45.0 cm depth**

Map 2. N, P_2O_5 and K_2O of sugarcane growing soil

Here, the DTPA-extractable iron observed higher in surface soil over sub-surface soil which might be due to accumulation of soil organic carbon in surface soil as soil organic carbon due to its affinity, influence the solubility and availability of iron.

Here, the DTPA-extractable iron observed higher in surface soil over sub-surface soil which might be due to accumulation of soil organic carbon in surface soil as soil organic carbon due to its affinity, influence the solubility and availability of iron by chelation effect, might protected iron from oxidation and precipitation which consequently increase the availability of iron as reported by Thangasamy et al. [11], Kumar and Naidu [22], Sekhar et al. [16] and Supriya et al. [14]. Another reason might be due to precipitation of iron by calcium carbonate concretion and high pH of sub-surface soil which decrease its availability in sub-surface soil as noted by Sekhar et al. [16] and Supriya et al. [14]. High fineness of soil texture results in higher DTPA-extractable iron as finer fraction helpful in improving structure and aeration of soil as enumerated by Thangasamy et al. [11].

3.5 DTPA-extractable Mn

The DTPA-Mn of the surface soil samples ranged from 1.10 ppm observed in Khundh village of Chikhli taluka to 29.36 ppm observed in Sagra village of Jalalpore taluka with an average of 17.76 ppm while DTPA-Mn of the sub-surface soil samples varied from 0.20 ppm observed in Khundh village of Chikhli taluka to 29.08 ppm observed in Acchavani village of Khergam taluka with an average of 11.06 ppm. The DTPA-Mn of surface and sub-surface soils were low to high.

The overall results revealed that the major surface soils of Navsari district fall majorly into adequate (>10 ppm) and marginal (5-10 ppm) category available manganese status. However, the sub-surface soil samples of Navsari district majorly fall into the marginal category (5-10 ppm) and adequate category. An increase in clay content enhances the exchangeable sites of soil colloids, thereby improving their holding capacity. This, in turn, protects against precipitation and oxidation while increasing the availability and solubility of nutrients, as also reported by Abdel Rahman et al. [23] in the soils of Chamranagar district, Karnataka, India.

The DTPA- manganese decreased with increase in calcium carbonate content and soil depth as reported by Supriya et al. [14]. Thangasamy et al. [11] found that with increase in soil organic carbon and clay content of soil, there is increase in DTPA- extractable manganese as it improves structure and aeration condition of soil and its availability decrease with increase in activity of soil microorganisms which oxidizes soluble manganese.

3.6 DTPA-Extractable Zinc

The DTPA-Zn of the surface soil samples ranged from 0.20 ppm observed in Sarona village of Navsari taluka to 6.89 ppm observed in Dhaman and Adada village of Navsari taluka with an average of 1.65 ppm while DTPA-Zn of the sub-surface soil samples varied from 0.05 ppm observed in Bamanvel and Ambach village of Chikhli taluka to 3.64 ppm observed in Ashtgam village of Navsari taluka with an average of 0.85 ppm. The available zinc of surface and sub-surface soils were low to high.

The behaviour of DTPA-Zn paralleled the availability of DTPA-Fe in the soils of the Navsari district. The proportionately higher availability of DTPA- Zn in the soils might be attributed to the reduced pH, which enhances the supply of available Zn. The results were in good agreement with the findings of Arunachalam et al. [24].

Table 6. Range, mean and category wise distribution of DTPA-Fe at surface and sub-surface soil samples in sugarcane growing area

Taluka	No. of Samples	DTPA-Fe (ppm)		DTPA-Fe Distribution (%)		
		Range	Mean	Deficient	Marginal	Adequate
0-22.5 cm depth						
Khergam	16	3.67-26.49	13.65	25.00	31.25	43.75
Vansda	41	1.43-24.46	9.87	26.83	39.02	34.15
Chikhli	39	0.97-29.30	12.52	10.26	38.46	51.28
Navsari	40	3.24-29.90	10.74	32.50	30.00	37.50
Jalalpore	24	3.71-26.85	11.37	29.17	25.00	45.83
Gandevi	19	3.17-28.08	9.08	26.32	47.37	26.32
OVERALL	**179**	**0.97-29.90**	**11.10**	**25.01**	**35.18**	**39.81**
22.5-45 cm depth						
Khergam	16	2.10-17.33	7.07	50.00	25.00	25.00
Vansda	41	0.35-16.15	5.25	63.41	24.39	12.20
Chikhli	39	0.56-16.36	6.36	56.41	20.51	23.08
Navsari	40	2.11-24.97	6.86	52.50	30.00	17.50
Jalalpore	24	1.92-20.09	8.19	45.83	20.83	33.33
Gandevi	19	1.92-21.40	5.61	68.42	21.05	10.53
OVERALL	**179**	**0.35-24.97**	**6.45**	**56.10**	**23.63**	**20.27**

Table 7. Range, mean and category wise distribution of DTPA-Mn at surface and sub-surface soil samples in sugarcane growing area

Taluka	No. of Samples	DTPA-Mn (ppm)		DTPA-Mn Distribution (%)		
		Range	Mean	Deficient	Marginal	Adequate
0-22.5 cm depth						
Khergam	16	4.16-28.85	17.32	6.25	18.75	75.00
Vansda	41	6.24-29.52	17.66	0.00	17.07	82.93
Chikhli	39	1.10-28.85	18.49	15.38	7.69	76.92
Navsari	40	4.41-29.02	16.91	2.50	22.50	75.00
Jalalpore	24	3.32-29.63	16.15	4.17	20.83	75.00
Gandevi	19	7.53-28.59	20.69	0.00	10.53	89.47
OVERALL	**179**	**1.10-29.63**	**17.76**	**4.72**	**16.23**	**79.05**
22.5-45 cm depth						
Khergam	16	1.07-29.08	9.71	25.00	37.50	37.50
Vansda	41	1.00-25.22	11.61	9.76	41.46	48.78
Chikhli	39	0.20-28.66	12.69	23.08	15.38	61.54
Navsari	40	1.20-24.14	11.17	15.00	37.50	47.50
Jalalpore	24	1.20-20.55	7.48	25.00	54.17	20.83
Gandevi	19	1.70-26.23	12.00	10.53	36.84	52.63
OVERALL	**179**	**0.20-29.08**	**11.06**	**18.06**	**37.14**	**44.80**

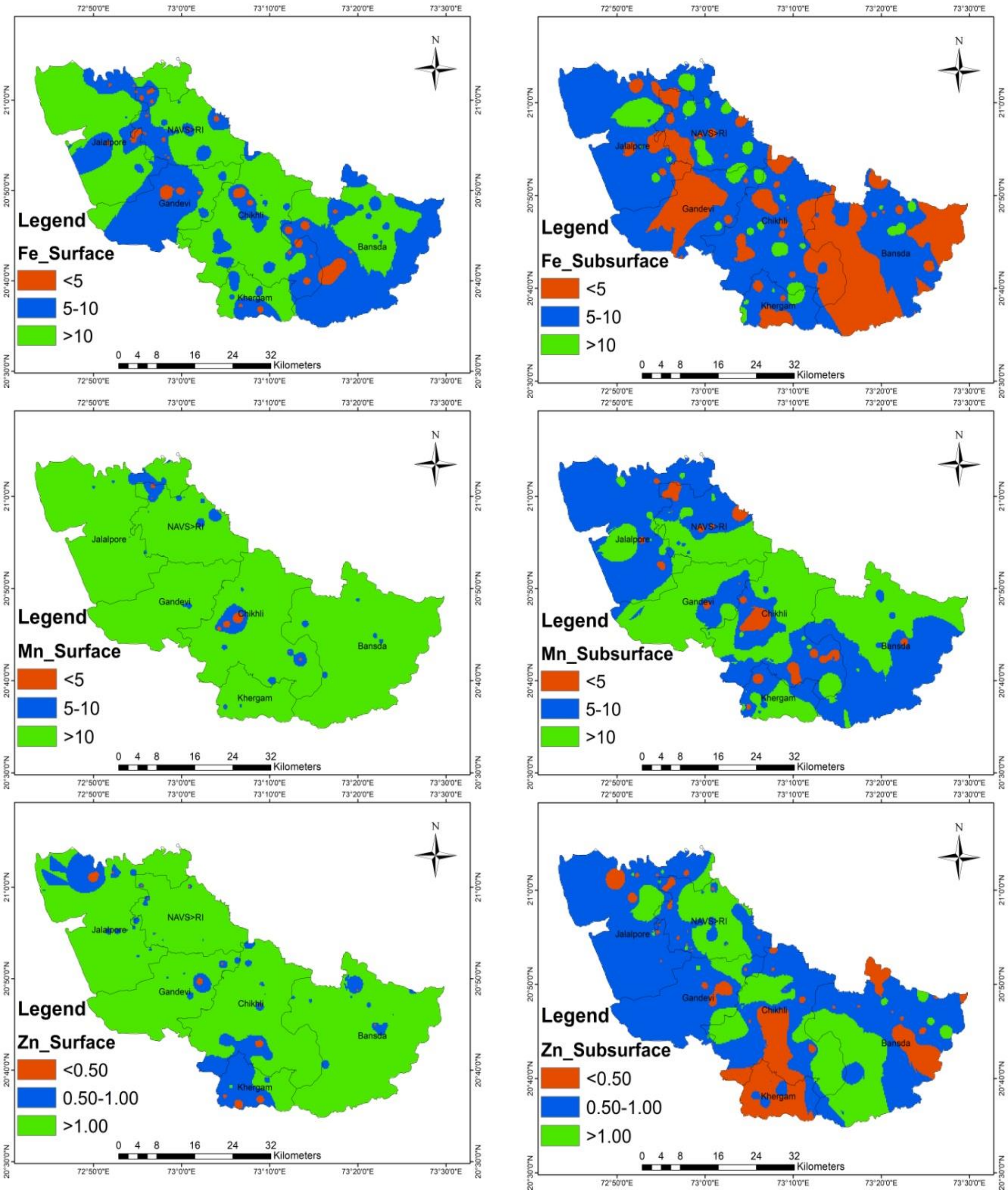
Table 8. Range, mean and category wise distribution of DTPA-Zn at surface and sub-surface soil samples in sugarcane growing area

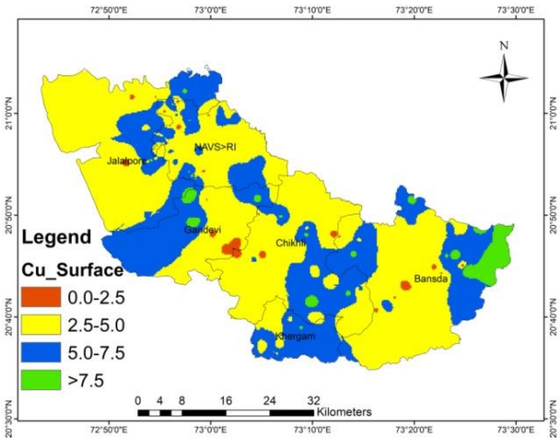
Taluka	No. of Samples	DTPA-Zn (ppm)		DTPA-Zn Distribution (%)		
		Range	Mean	Deficient	Marginal	Adequate
0-22.5 cm depth						
Khergam	16	0.33-1.20	0.73	25.00	62.50	12.50
Vansda	41	0.42-6.39	1.98	9.76	19.51	70.73
Chikhli	39	0.22-6.08	1.54	7.69	20.51	71.79
Navsari	40	0.20-6.89	1.97	5.00	20.00	75.00
Jalalpore	24	0.28-3.94	1.39	25.00	16.67	58.33
Gandevi	19	0.21-5.41	1.61	15.79	21.05	63.16
OVERALL	**179**	**0.20-6.89**	**1.65**	**14.71**	**26.71**	**58.59**
22.5-45 cm depth						
Khergam	16	0.14-0.77	0.39	68.75	31.25	0.00
Vansda	41	0.06-3.09	0.95	34.15	31.71	34.15
Chikhli	39	0.05-2.66	0.81	38.46	30.77	30.77
Navsari	40	0.06-3.64	1.00	32.50	27.50	40.00
Jalalpore	24	0.08-2.01	0.81	41.67	25.00	33.33
Gandevi	19	0.19-3.08	0.81	31.58	42.11	26.32
OVERALL	**179**	**0.05-3.64**	**0.85**	**41.19**	**31.39**	**27.43**

Table 9. Range, mean and category wise distribution of DTPA-Cu at surface and sub-surface soil samples in sugarcane growing area

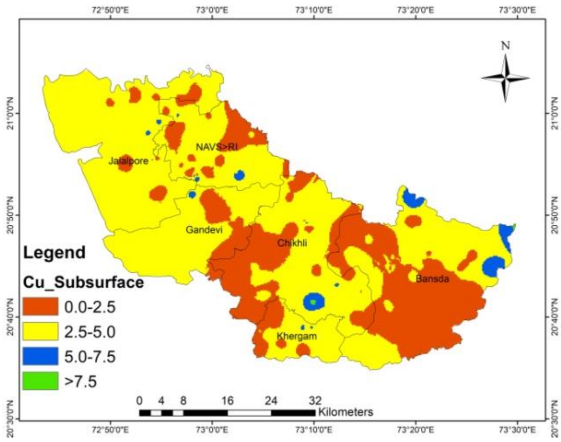
Taluka	No. of Samples	DTPA-Cu (ppm)		DTPA-Cu Distribution (%)		
		Range	Mean	Deficient	Marginal	Adequate
0-22.5 cm depth						
Khergam	16	1.32-7.78	5.22	0.00	0.00	100.00
Vansda	41	1.69-11.63	5.11	0.00	0.00	100.00
Chikhli	39	1.75-9.49	4.57	0.00	0.00	100.00
Navsari	40	1.02-11.68	4.94	0.00	0.00	100.00
Jalalpore	24	1.79-7.89	4.21	0.00	0.00	100.00
Gandevi	19	1.86-11.69	4.91	0.00	0.00	100.00
OVERALL	**179**	**1.02-11.69**	**4.83**	**0.00**	**0.00**	**100.00**

Taluka	No. of Samples	DTPA-Cu (ppm)		DTPA-Cu Distribution (%)		
		Range	Mean	Deficient	Marginal	Adequate
22.5-45 cm depth						
Khergam	16	0.84-4.93	2.65	0.00	0.00	100.00
Vansda	41	0.57-8.07	2.85	0.00	0.00	100.00
Chikhli	39	0.57-8.07	2.85	0.00	0.00	100.00
Navsari	40	0.21-6.89	3.02	0.00	2.50	97.50
Jalalpore	24	0.57-5.25	2.71	0.00	0.00	100.00
Gandevi	19	0.87-5.53	2.88	0.00	0.00	100.00
OVERALL	**179**	**0.21-8.07**	**2.86**	**0.00**	**0.42**	**99.58**





0 - 22.5 cm depth



22.5 -45.0 cm depth

Map 3. Fe, Mn, Zn and Cu of sugarcane growing soil

The lower DTPA-extractable zinc content was found with increase in soil pH and decrease in organic matter which resulted in formation of insoluble compound of zinc like insoluble calcium zincate as reported by Kumar and Naidu [22], Sekhar et al*.* [16] and Supriya et al*.* [14]. The surface soil showed higher DTPA-extractable zinc content than sub-surface soil which may be attributed to variable intensity of pedogenic process and more complexing with organic matter which results in chelating of zinc as noted by Kumar et al. [18].

3.7 DTPA-Extractable Cu

The DTPA-Cu of the surface soil samples varied from 1.02 ppm observed in Amri village of Navsari taluka to 11.69 ppm observed in Ganghor village of Gandevi taluka with an average of 4.83 ppm while DTPA-Cu of the sub-surface soil samples varied from 0.21 ppm observed in Amri village of Navsari taluka to 8.07 ppm observed in Borigavtha and Rumla village of Vansda and Chikhli taluka with an average of 2.86 ppm. The DTPA-Cu of surface soil samples were high while sub-surface soil samples were medium to high.

The overall results revealed that majorly all surface and sub-surface soils of Navsari District came under "adequate" DTPA-Cu category (> 0.40 ppm). The mean value of Cu in both surface and sub-surface soil, were arranged in following ascending order *viz*., Khergam (5.22 ppm) < Vansda (5.11 ppm) < Navsari (4.94 ppm) < Gandevi (4.91 ppm) < Chikhli (4.57 ppm) < Jalalpore (4.21 ppm) in surface soils and Navsari (3.02 ppm) < Gandevi (2.88 ppm) < Vansda and Chikhli (2.85) < Jalalpore (2.71 ppm) < Khergam (2.65 ppm) in sub-surface soils sample. Irrespective of surface and sub-surface soil samples, all were classified within the adequate category according to percentage distribution. Similar result reported by Shirgire et al*.* [25] in soils of coastal Jamnagar district in Saurashtra region of Gujarat and Choudhary et al*.* [26] in soils of paddy and sugarcane growing areas of Navsari district in Gujarat.

The chelating agent of organic compounds that are released during the decomposition of organic matter left after crop harvesting and higher biological activity might be the reason of high soil DTPA-extractable copper and manganese content as reported by Thangasamy et al. [11], Kumar and Naidu [22], Sekhar et al*.* [16] and Kumar et al. [18]. The organic acid released during the decomposition of organic matter solubilizes copper by chelation and complexation and as a result of organic binding, there is more dissolved copper in solution than normally occurs in absence of organic matter as noted by Thangasamy et al. [11]. Organic matter act as chelating agent for complexation of these micronutrients which reduces their adsorption, oxidation and precipitation into unavailable form, so it increases availability of DTPA-extractable micronutrients as found by Narsaiah et al*.* [27]. Similar line of work for DTPA-extractable micronutrients was also reported by Sekhar et al*.* [16], Kumar et al. [18], Meena and Mathur [28] and Sekhar et al*.* [12].

4. CONCLUSION

The available nitrogen, phosphorus and potassium of surface soil ranged from 132.19 to 428.65 kg ha^{-1}, 18.48 to 107.32 kg ha^{-1} and 202.34 to 359.39 kg ha^{-1} while sub-surface soil varied from 101.91 to 388.62 kg ha^{-1}, 10.16 to 99.57 kg ha^{-1} and 138.66 to 323.35 kg ha^{-1} respectively. Based on this available nitrogen and phosphorus of surface and sub-surface soil were classified as low to medium and low to high respectively, while available potassium of surface and sub-surface soil was categorized as medium to high and low to high respectively. The DTPA-extractable micronutrients of surface and sub-surface soil were classified as deficient to adequate except DTPA-Cu which was found to be adequate in surface soil and marginal to adequate in sub-surface soil. The surface soil DTPA-Fe, DTPA-Mn, DTPA-Zn and DTPA-Cu ranged from 0.97 to 29.90 ppm, 1.10 to 29.63 ppm, 0.20 to 6.89 ppm and 1.02 to 11.69 ppm respectively. The sub-surface soil DTPA-Fe, DTPA-Mn, DTPA-Zn and DTPA-Cu varied from 0.35 to 24.97 ppm, 0.20 to 29.08 ppm, 0.05 to 3.64 ppm and 0.21 to 8.07 ppm respectively.

Study of available nutrients in soils to ascertain their present fertility conditions is important to maintain soil fertility and sugarcane crop productivity. The soils of sugarcane growing area of Navsari district showed low OC, available N and S while other nutrients were normal in range for sugarcane cultivation. There is a need for correcting deficiencies of specific nutrients for sustained crop production. Thus, evaluating and assessing nutrient status is a must under various soil survey systems in order to recommend soil and crop specific nutrients.

The study further suggest that this kind of area and crop specific model should be developed and put into the practice for sustainable agriculture and prosperity.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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The peer review history for this paper can be accessed here:
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