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Studies on forms of sulphur in the soils of North Saurashtra agro-climatic zone of Gujarat

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Abstract
The present investigation was for evaluating status of sulphur in the soils of North Saurashtra Agro-climatic Zone of Gujarat state and interrelations among the forms of sulphur, for these four hundred eighty samples (10 soil samples from each taluka) were collected from the cultivated fields. The soil samples were analyzed for different forms of sulphur *viz*., Total S, organic S, non-sulphate S, available-S, sulphate S and water-soluble S. Mean value of 25.72 mg kg^{-1} available sulphur in North Saurashtra Agro-climatic Zone of Gujarat was seen and it was ranged from 2.82 mg kg^{-1} to 84.23 mg kg^{-1}. The overall value of range of Total S in North Saurashtra Agro-climatic Zone of Gujarat was 104.2-3381 mg kg^{-1} with mean value of 867.70 mg kg^{-1}. On the basis of overall data organic S in North Saurashtra Agro-climatic Zone of Gujarat ranged from 77.6 mg kg^{-1} to 3284 mg kg^{-1} with mean value of 824.2 mg kg^{-1}. Non-sulphate S overall ranged from 2.6 to 224.6 mg kg^{-1} in North Saurashtra Agro-climatic Zone of Gujarat was observed with mean value of 26.31 mg kg^{-1}. The overall range of sulphate S in North Saurashtra Agro-climatic Zone of Gujarat was recorded as 0.53-66.39 mg kg^{-1} with mean value of 17.59 mg kg^{-1}. The water- soluble S ranged from 0.95 mg kg^{-1} to 92.27 mg kg^{-1} in North Saurashtra Agro-climatic Zone of Gujarat was observed with mean value of 20.52 mg kg^{-1}. Altogether, the soils of North Saurashtra Agro-climatic Zone of Gujarat had nutrient index values of 2.46 for available sulphur. As per data obtained, it can be concluded based on nutrient index value the soils of North Saurashtra Agro-climatic Zone of Gujarat were medium to high fertility class for available S while the Jamnagar, Amreli and Morbi districts were comparatively deficient in available sulphur on contrary to this Bhavnagar, Rajkot, Dwarka and Surendranagar were surplus in available sulphur content. It can be also concluded that decreasing order for reading of different fractions of sulphur in TS > OS> NSS > AS >WSS > SS. OS contributed maximum to TS.

Keywords: Available sulphur, total sulphur, organic sulphur, non-sulphate sulphur, sulphate sulphur, water soluble sulphur, North Saurashtra

Introduction
Sulphur is an important ingredient for plant growth and development. In addition to nitrogen, phosphorus and potassium, it is currently considered as the fourth key nutrient. Excessive mining of sulphur from soils has resulted in increased sulphur deficiency reports globally, especially in India, due to intensive farming systems and the use of S-free chemical fertilizers (Singh, 2001) [1]. Rice-based cropping systems have showed good responsiveness to S application in the Indo-Gangatic plain. Sulphur mining from soil has substantially increased as a result of the usage of high-analysis chemical fertilizers and the use of high-yielding and hybrid kinds of cereal crops for crop production (Kumar *et al*. 1994) [2].
The importance of secondary nutrients, particularly sulphur (S), and micronutrients is becoming more widely recognized as a result of a rise in their deficiency in numerous crops, resulting in yield and quality losses. In addition to nitrogen, phosphorus, and potassium, sulphur is currently considered the fourth key nutrient. Sulphur deficit in soils and plants has been recorded in numerous parts of the country, including Gujarat.
As a result, research on various features of sulphur, such as its status and interrelationships with other forms of sulphur, is critical to better understanding sulphur as a nutrient in this region's soil, so that it does not become a limiting factor in improving crop yields. As a result, efforts have been made in the current investigation to compile systematic and comprehensive

information on the sulphur status and interrelationships among the forms of sulphur in various soils using a large number of surface samples from each taluka in the North Saurashtra Agro-climatic Zone.

Materials and Methods

The present investigation was undertaken by conducting soil survey of North Saurashtra Agro-climatic Zone of Gujarat state and analysis at the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Junagadh Agricultural University, Junagadh. Different soil fractions of sulphur *viz*, total sulphur, organic sulphur, sulphate sulphur, water soluble sulphur, heat soluble sulphur and non-sulphate sulphur were analyzed.

Ten surface soil samples were collected from Rajkot, Paddhari, Lodhika, Jam Kandorna, Kotda Sangani, Jasdan, Vinchiya, Gondal talukas of Rajkot district, Jamnagar, Jam Jodhpur, Jodiya, Dhrol, Lalpur, Kalavad of Jamnagar district, Dwarka, Bhanvad, Kalyanpur, Jam khambhaliya of Devbhumi- Dwarka, Morbi, Tankara, Halvad (zone 5), Wankaner, Maliya-Miana of Morbi district, Surendranagar, Chuda, Chotila, Dhrangadhra, Lakhatar, Limbdi, Muli, Patli, Sayla and Thangadh of Surendranagar district, Amreli, Babra, Dhari, Khambha, Kunkavav-Vadia, Lathi, Lilia, Savarkundla of Amreli district and Bhavnagar, Gariadhar, Jesar, Palitana, Sihor, Umrala, Vallabhipur of Bhavnagar district.

All the soil samples collected were analyzed for different forms of sulphur by using standard methods. Total sulphur was determined by using method given by Chaudhary and Cornfield (1966) [3] while organic sulphur was determined by using method given by Bardsley and Lancaster (1965) [4] Sulphate sulphur, water soluble sulphur and heat soluble sulphur was determined by using method given by Williams and Steinbergs (1959) [5]. The non-sulphate sulphur is estimated by difference between the total sulphur and sum of organic and sulphate sulphur.

Results and Discussion

Status of heat-soluble or available sulphur in North Saurashtra Agro-climatic Zone of Gujarat

The overall range of available S in North Saurashtra Agro-climatic Zone of Gujarat was 2.82-84.23 mg kg^{-1} with mean value of 25.72 mg kg^{-1}. The data revealed that lowest mean value of available S (21.01 mg kg^{-1}) was obtained from the samples of Amreli district and highest mean value of available S (31 mg kg^{-1}) was found in samples of Bhavnagar district (Fig. 1).

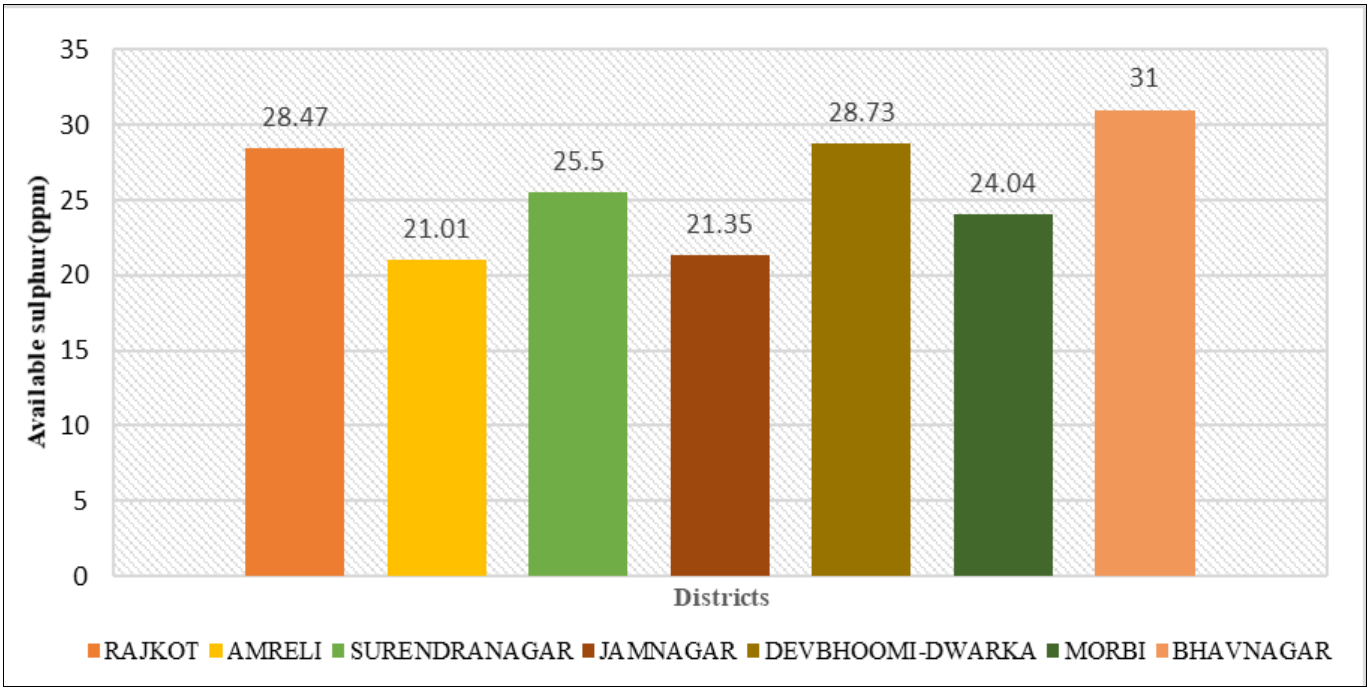

Fig 1: District wise distribution of available sulphur (ppm) on mean value basis

Whatever the outcomes of available sulphur came it was comparable to that obtained by Gupta and Submaria (1997) [6] findings in accessible sulphur concentration in the soils of Jammu area of Jammu and Kashmir, Khamparia *et al.* (2000) [7] findings as available sulphur status ranged from 0.7 -110.8 mg kg^{-1} soil with a mean value of 27.7 mg kg^{-1}, Jetpara *et al.* (2009) [18] studied as available sulphur over a cycle of ten years in the soils of Saurashtra agro-climatic zone of Gujarat during the year 1990 and 2000, Singh *et al.* (2009) [9] findings as available S varied from 4.6 to 118.4 mg kg^{-1}, Patel *et al.* (2011) [10] in soil of Banaskantha district of Gujarat were also giving the result comparable to research findings and Sutaria *et al.* (2016) [11] observation as available S ranged from 3.6 to 141.8 mg kg^{-1}.

Status of total sulphur in North Saurashtra Agro-climatic Zone of Gujarat

The overall value of range of Total S in Northern Saurashtra Agro-climatic Zone was 104.2-3381 mg kg^{-1} with mean value of 867.7 mg kg^{-1}. The data revealed that lowest mean value of total S (484.5 mg kg^{-1}) was obtained from the samples of Rajkot district and highest mean value of total S (1089 mg kg^{-1}) was found in samples of Bhavnagar district (Fig. 2).

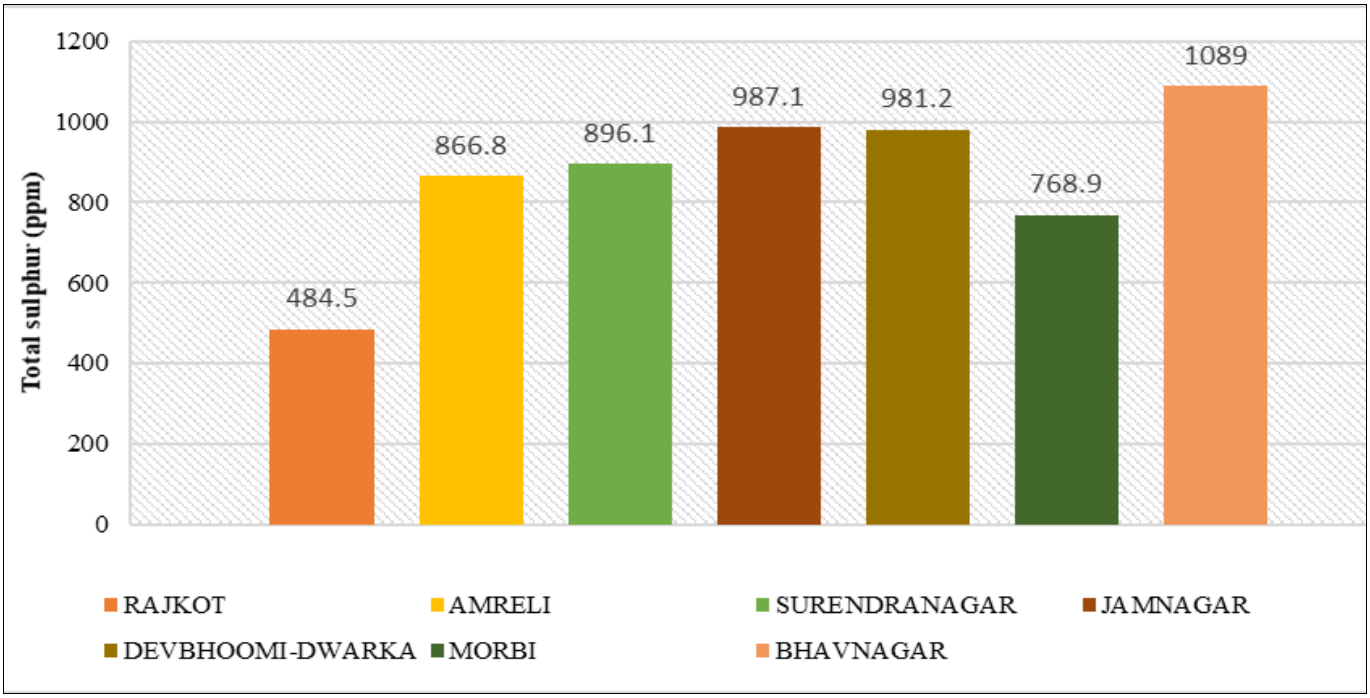

Fig 2: District wise distribution of total sulphur (ppm) on mean value basis

The data obtained for total sulphur during analysis was in line to that obtained by Lande *et al.* (1977) [12] as total sulphur in saline soils ranged from 425.7 to 1057 ppm, with an average of 840.4 ppm, demonstrating that total sulphur in saline soils was much higher than in normal soils, Douli and Bandyopadhyay (1983) [13] found that total sulphur content ranged from 368 to 2206 ppm, with a mean of 1011 ppm, Bhatnagar *et al.* (2003) [14] reported that the total sulphur in surface soil of Vertisols ranged from 798 to 987 mg kg $^{-1}$ with mean value of 892 mg kg^{-1} and total S content in soils of the Osmanabad district of Maharashtra varied between 300-2500 mg kg^{-1} with a mean value of 1654 mg kg^{-1} in vertisols, according to Narale *et al.* (2017) [15].

Status of organic sulphur in North Saurashtra Agro-climatic Zone of Gujarat

The overall range of organic S in North Saurashtra Agro-climatic Zone of Gujarat recorded as 77.6-3284 mg kg^{-1} with mean value of 824.2 mg kg^{-1}. The data revealed that lowest mean value of organic S (443.9 mg kg^{-1}) was recorded from the soil samples of Rajkot district and highest mean value of organic S (1040 mg kg^{-1}) was recorded in soil samples of Bhavnagar district (Fig. 3).

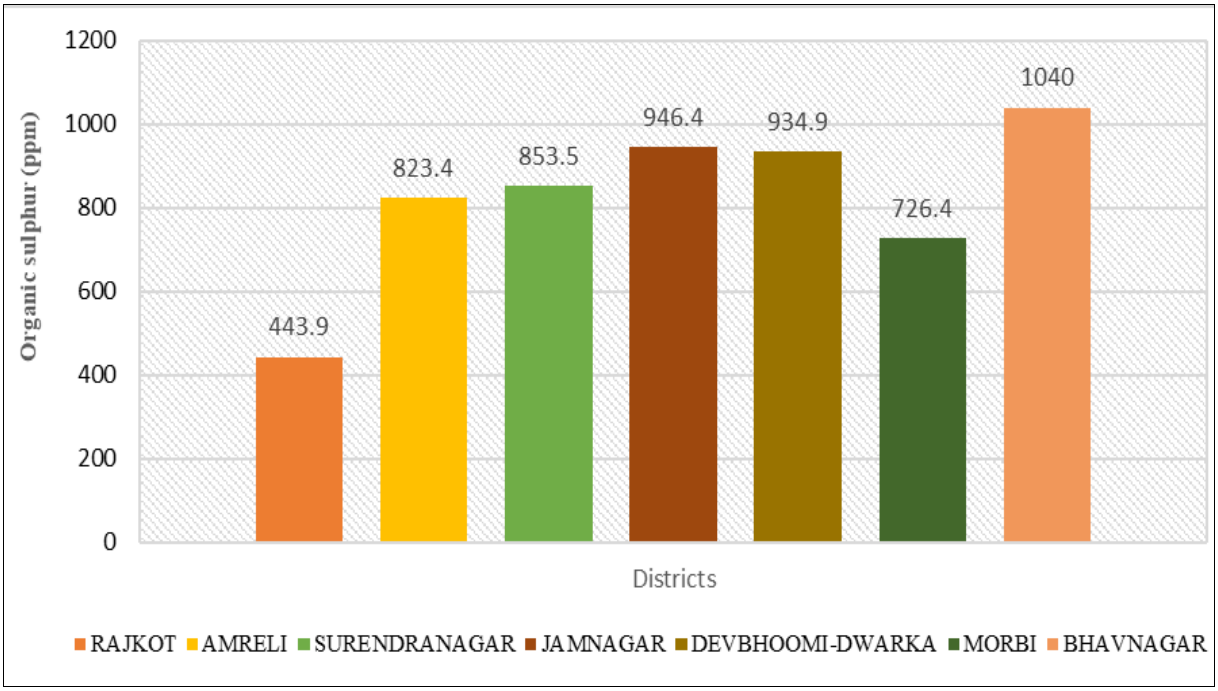

Fig 3: District wise distribution of organic sulphur (ppm) on mean value basis

The result obtained for organic sulphur is agree with to that obtained by Trivedi *et al.* (2000) [16] studied organic sulphur in soil profiles of Madhya Pradesh, Jat and Yadav (2006) [17] findings and the result of Pareek (2007) [18] findings in soil

samples of Pantnagar, Uttarakhand.

Status of non-sulphate sulphur in North Saurashtra Agro-climatic Zone of Gujarat

The overall range of non-sulphate S in North Saurashtra Agro-climatic Zone of Gujarat was 2.6-224.6 mg kg^{-1} with mean value of 26.31 mg kg^{-1}. The data revealed that lowest mean value of non-sulphate S (24.09 mg kg^{-1}) was obtained from the samples of Morbi district and highest mean value of non-sulphate S (29.66 mg kg^{-1}) was found in samples of Jamnagar (Fig. 4).

The result obtained was in line with to that obtained by Douli and Nayek (1981) [19] as they reported that non-sulphate sulphur ranged from 13 to 70 ppm (mean 29.14 ppm), Singh (2015) [20] observed as non-SO_4 sulphur concentration ranging from 25 to 105 mg kg^{-1} in soils from Agra, Uttar Pradesh, with mean of 60 mg kg^{-1}, In the soils of Rajkot agro-climatic zone of Gujarat, Sutaria *et al.* (2016) [11] detected as 3.6 to 157.1 mg kg^{-1} non-sulphate sulphur (mean 31.2 mg kg^{-1}) in the soils of Rajkot of Gujarat.

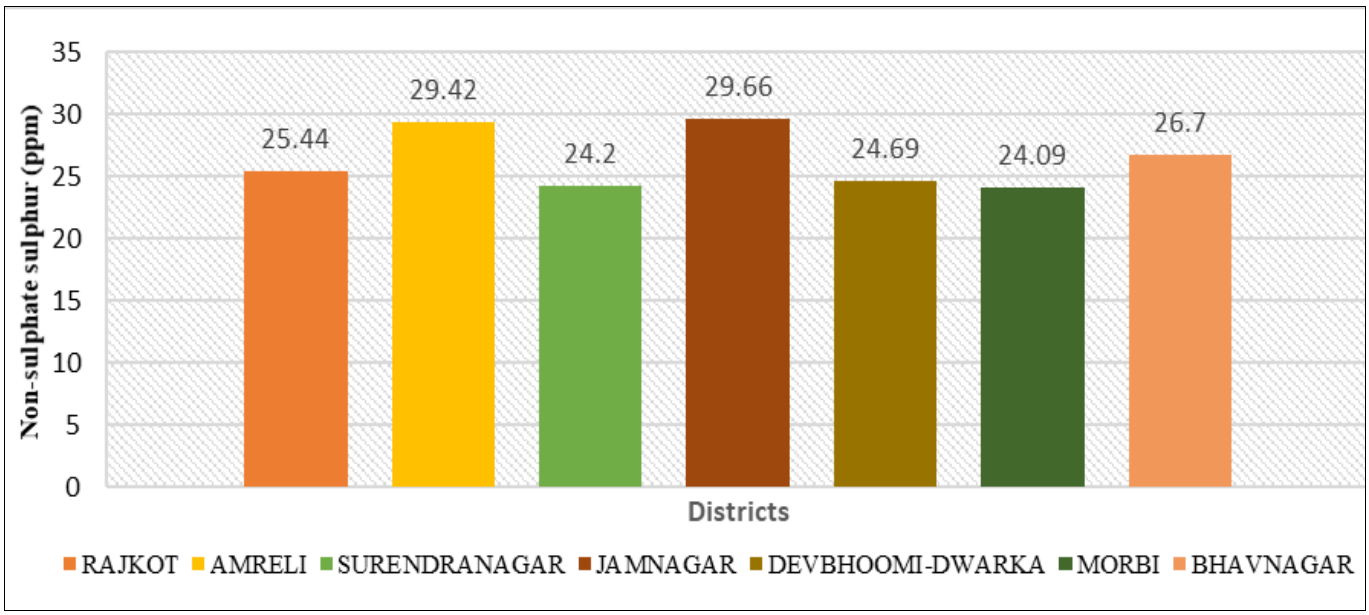

Fig 4: Overall non-sulphate status in North- Saurashtra Agro-climatic Zone of Gujarat

Status of sulphate sulphur in North Saurashtra Agro-climatic Zone of Gujarat

The overall range of sulphate S in North Saurashtra Agro-climatic Zone of Gujarat was recorded as 0.53-66.39 mg kg^{-1} with mean value of 17.59 mg kg^{-1}. The data revealed that lowest mean value of sulphate S (13.89 mg kg^{-1}) was obtained from the samples of Amreli district and highest mean value of sulphate S (21.66 mg kg^{-1}) was recorded in samples of Devbhoomi Dwarka (Fig. 5).

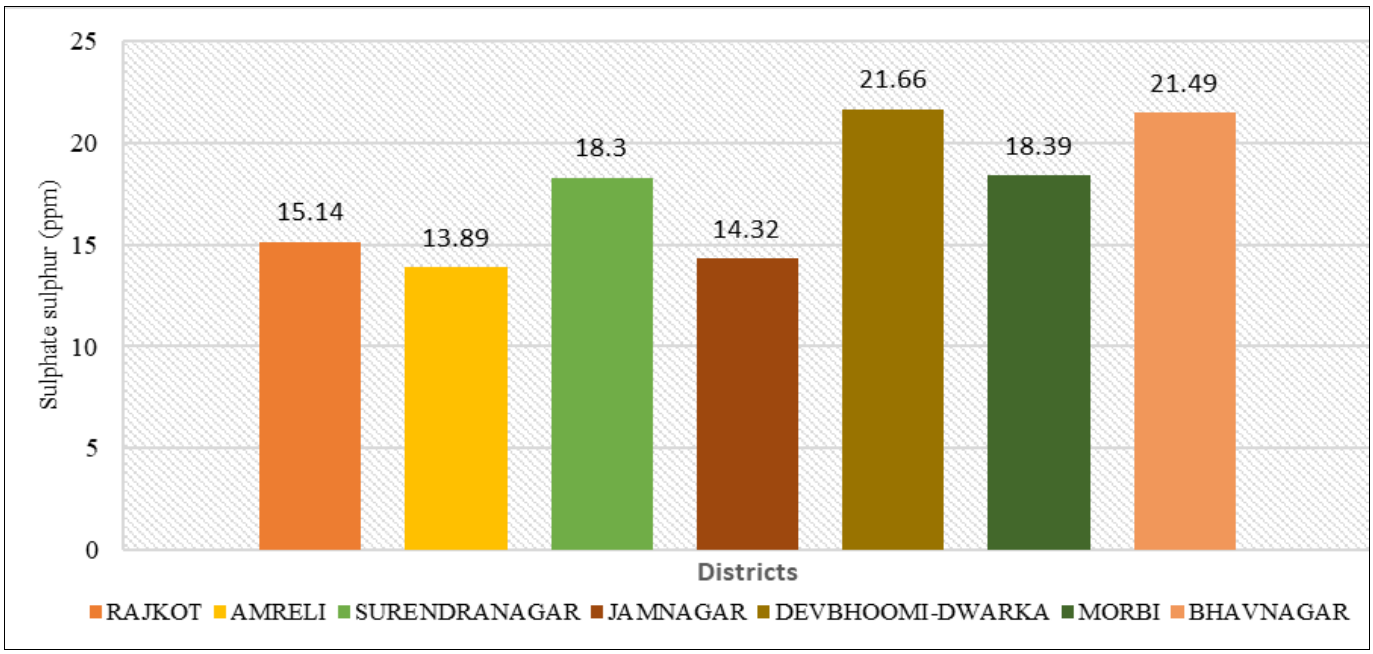

Fig 5: District wise distribution of sulphate sulphur (ppm) on mean value basis

The result obtained is similar to Arora *et al*. (1988) [21] stated that the $CaCl_2$ extractable sulphate sulphur ranged from 5.1 to 46.0 ppm in major soil series in Punjab, Sharma *et al.* (2000) [22] studied that respective ranges of calcium chloride extractable (sulphate) sulphur were 10.1 to 47.5, 3.7 to 56.2 and 3.7 to 47.5 mg kg^{-1} in Alfisols, Inceptisols and Mollisols in some parts of Western Uttar Pradesh, Jat and Yadav (2006) [17] studied eighty surface soil samples and observed that sulphate sulphur ranged from 4.1 to 39.95 mg kg^{-1} and Kour *et al*. (2010) [23] found sulphate S concentrations ranged from 5.5 to 43.7 mg kg^{-1}, with an average of 20.6 mg kg^{-1}.

Status of water soluble sulphur in North Saurashtra Agro-climatic Zone of Gujarat

The overall range of water- soluble S in North Saurashtra Agro-climatic Zone of Gujarat was observed as 0.95-92.27 mg kg^{-1} with mean value of 20.52 mg kg^{-1}. The data revealed that lowest mean value of water soluble S (19.16 mg kg^{-1}) was obtained from the samples of Jamnagar district and highest mean value of water soluble S (23.88 mg kg^{-1}) was found in samples of Bhavnagar district (Fig. 6).

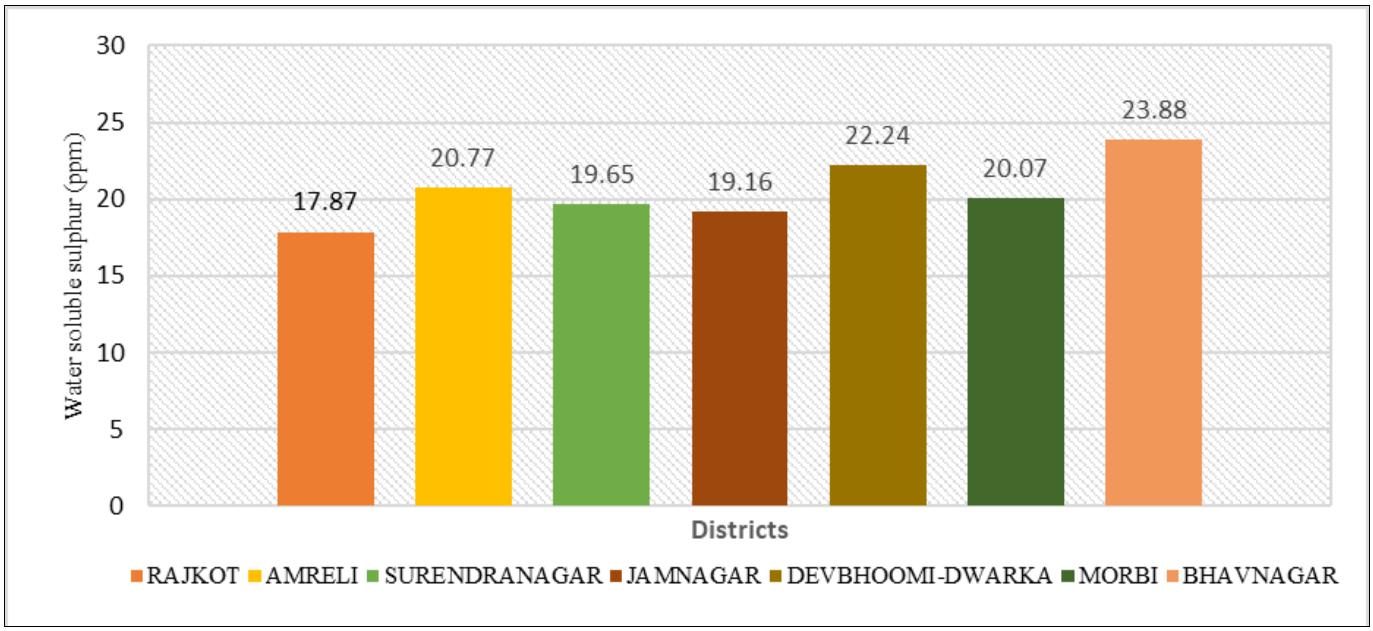

Fig 6: District wise distribution of water-soluble sulphur (ppm) on mean value basis

The result obtained is similar to Karwasara *et al.* (1986) [24] observed that water soluble sulphur content varied from 14.0 to 85.6 ppm with an average of 31.1 ppm in Hisar soils. According to Balanagoudar and Satyanarayana (1990) [25], the amount of water-soluble sulphur ranges from 1.4 to 230.6 ppm, with a mean value of 28.7 ppm and Kour *et al.* (2010) [23] found a wide range of water-soluble sulphur (12 to 66.5 mg kg^{-1}), with a mean of 32.1 mg kg^{-1}.

Table 1: Range and mean of different forms of sulphur (ppm) in different districts of North Saurashtra Agro-climatic Zone of Gujarat

Name of districts	AS	SS	WSS	OS	TS	NSS
Rajkot	4.17-84.23 (28.47)	2.2-65.67 (15.14)	2.14-58.80 (17.87)	82.85-3138 (443.9)	119.4-3187 (484.5)	10.78-61.97 (25.44)
Amreli	3.44-59.60 (21.01)	1.36-37.13 (13.89)	0.95-92.27 (20.77)	77.6-3284 (823.4)	104.2-3331 (866.8)	9.82-224.6 (29.42)
Surendranagar	5.63-69.47 (25.5)	0.53-55.66 (18.3)	1.10-51.73 (19.65)	160.2-3012 (853.5)	223.1-3055 (896.1)	2.60-132.9 (24.20)
Jamnagar	2.82-60.48 (21.35)	0.59-46.67 (14.32)	2.95-46.98 (19.16)	154.6-3127 (946.4)	205.8-3175 (987.1)	14.3-127 (29.66)
Devbhoomi-Dwarka	4.19-70.58 (28.73)	3.60-63.45 (21.66)	6.91-45.50 (22.24)	278.2-2381 (934.9)	334.6-2445 (981.2)	8-52.89 (24.69)
Morbi	4.52-75.92 (24.04)	1.23-66.39 (18.39)	2.18-53.95 (20.07)	171.1-2187 (726.4)	212.8-2234 (768.9)	3.48-45.20 (24.09)
Bhavnagar	7.50-83.12 (31)	1.59-62.87 (21.49)	2.64-70.95 (23.88)	171.8-2861 (1040)	215.1-2983 (1089)	4.29-44.67 (26.70)
Overall	2.82-84.23 (25.72)	0.53-66.39 (17.59)	0.95-92.27 (20.52)	77.6-3284 (824.2)	104.2-3381 (867.7)	2.60-224.6 (26.31)

Note: Values in parenthesis are mean value

Conclusion

The soils of North Saurashtra Agro-climatic Zone of Gujarat are calcareous in nature and alkaline in reaction. Based on nutrient index values of soils and the criteria suggested by Parker *et al.* (1951) [26] the soils of Northern Saurashtra were medium to high fertility class for available S while the Jamnagar, Amreli and Morbi districts were comparatively deficient in available sulphur. As per data obtained, it can be concluded that decreasing order for reading of different fractions of sulphur in TS > OS> NSS > AS >WSS > SS. Among the fractions OS contributed maximum to TS.

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