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Mineralogy of agricultural soil of selected regions of South Western Karnataka, Peninsular India

P.G. Smitha[1], K. Byrappa[1]* and C. Ranganathaiah[2]
[1]Department of Studies in Earth Science, University of Mysore, Mysore-570 006, India
[2]Department of Studies in Physics, University of Mysore, Mysore-570 006, India
*Corresponding Author's E-mail: kbyrappa@gmail.com

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Abstract

Agricultural soils of selected regions of Southwestern Karnataka, Peninsular India, were subjected to systematic mineralogical characterization along with the study of soil physical properties. Physical properties such as soil texture and micro porosity were studied using particle size analyses and positron annihilation lifetime analysis (PALS) technique, respectively. The latter was used to analyze micro porosity of agricultural soil. Both major and minor minerals were identified and confirmed by some analytical techniques like thin section study, powder X- ray diffraction, X-ray fluorescence spectroscopy and Fourier transform infrared spectroscopy.

Key words

Agricultural soils, Mineralogy, Soil texture

Introduction

Peninsular India is known for its diversity of landforms, landscapes, geological formations as well as natural resources. Western Ghats which form one of the hottest biodiversity hotspots in the world lie within the state of Karnataka, located in this region. About 60% of the entire portion of these Ghats lies in this state. Though this area covers just about 5% of the land area of the entire country, around 27% of all species of higher plants in India (4,000 to 15,000 species) are found here (Nayar *et al*., 2014). Reports on geology, geomorphology etc. are also available from different sources (Iyer, 1994; Manjunatha and Harry, 1994; Murthy and Raghavan, 1994; Radhakrishna and Vidyanandan, 1994). However, for a proper management plan, knowledge based on scientific understanding of the existing natural resources, their quality and quantity etc. are also essential. Biological resources like plants, including cultivated crop varieties derive their nutrients from existing minerals in soil unless provided with some supplementary nutrients in the form of organic and inorganic fertilizers. To plan for a balanced fertilizer management programs it is necessary to understand the basic mineralogy of agricultural soils in the study area.

A review of earlier works and reports have revealed the use of X-ray diffraction, FTIR and XRF techniques to understand mineralogy of soils from different regions. Chauhan (1996) employed modern analytical techniques to study the characteristics of aolian depositions of Arabia and Somalia. Bhattacharya *et al.* (1999) made an attempt to study the role of zeolites in high altitude ferruginous alfisols of humid tropical Western Ghats in India. Deepthy and Balakrishna (2005) studied climatic control on the formation of clay minerals using evidence from weathering profiles from the vicinity of Western Ghats area. Soil characterization has been attempted using modern instruments and analytical techniques such as XRD, XRF and FTIR by various researchers (Ganesh *et al*. 2007, Nayak and Singh, 2007; Palanivel and Velraj, 2007; Pal *et al*. 2009; Ramaswamy and Suresh, 2009). Smitha *et al.* (2007, 2008) established the physico-chemical properties of agricultural soils and their correlation in Bantwal Taluk of south-western Karnataka, India. However, published data on basic mineralogy of agricultural soils around the study area is scarce. Hence, the present study was to understand the mineralogy of agricultural soils from the south-western parts of Karnataka, Peninsular India.

Materials and Methods

Soil samples were collected from agricultural fields of selected villages of Bantwal and Karkala Taluks (Fig.1). Eastern parts of these two taluks are bordered by Western Ghats which show thick forests and high hills; whereas the western part is occupied by long coastal region. The climate in general is of humid tropical type. Lateritic soil is widespread in the districts. The valleys and rivers to the east of coastal region are filled with alluvial soil. There is also a quite large extent of grassland on the upland plateau between coastal plain and inland forests. The hill ranges are under forest cover.

Mineralogy : Powder XRD studies were carried out to determine the minerals present using Bruker AXS D-8 Advance, USA, with a copper target at 40 kV and 40 mA using a graphite monochromator. Powder X-ray diffraction patterns of selected soil samples from Bantwal Taluk (Karpe, Salethur, Eliyanadugodu, and Irvathur) and Karkala Taluk (Nooralabettu, Nadpalu, Kuchur and Bola) were recorded from 3º to 80º 2θ, with a scanning speed of 1^0/ minute, with a step size of 0.01 / sec.

Major and minor elements : X-ray fluorescence spectroscopy (XRF) study reveals the elemental composition and their percentage concentration. Sample powders were pelletized using minipress supplied by M/S Philips, The Netherlands and were taken in an aluminum cup of 4.4 cm diameter at the bottom and 5.0 cm diameter at the top with cup height around 1 cm. The cup was completely filled with sample. The size of the powder was around 20-50 microns. The data were recorded using XRF, Philips, model PW2400, The Netherlands.

Thin section study : Soil samples collected were prepared for thin section study by sieving a portion in 45 mesh size sieve. The mesh size was used so as to enable the samples to be studied for microscopic analysis. The samples were then spread on glass slides and fixed with Canada balsam. These micro slides were observed under plain polarized light (2.5X) using Leitz Petrological microscope, Germany.

Textural analysis : About 2 kg of raw soil sample was subjected to sieving using standard sieves of different mesh size. Sand, silt and clay portions were separated and measured. Silt and clay composition was analyzed using hydrometer method (Baruah and Barthakur, 1997) based on which textural analyses were conducted.

Major functional groups : The major functional groups in these agricultural soils were identified by using Fourier transform infra-red (FTIR) spectroscopy. The FTIR spectra of selected representative soil samples were recorded on JASCO Model FTIR 460 Plus in the range of 400-4000 cm^{-1}. Samples for IR spectroscopic studies were prepared by taking fine powder of each sample and mixed with potassium bromide in 1:150 ratio and the mixture was ground in an agate mortar for homogeneity and then pressed into a pellet, which was mounted on FTIR instrument. IR spectra were interpreted using literature data (Nakamoto, 1963; Rao, 1963; Van der merel and Beutelspacher, 1976).

Positron annihilation lifetime spectroscopy studies : Positron annihilation studies were carried out to evaluate free volume of pores and interconnecting channels in soil samples. Soil sample under study was pressed into two identical pellets of 1 cm diameter with 1.2 mm thickness and used in positron lifetime measurements. Positron lifetime spectra were recorded using Positron Lifetime Spectrometer, consisting of fast-fast coincidence unit with BaF_2 detectors coupled to XP2020/Q photo multiplier tubes. The spectrometer has time resolution of 220 ps. Of the four lifetime components, τ_3 and τ_4 are the lifetimes of *o*-Ps which annihilates in micro pores of soils. The respective intensities of τ_3 and $_4$ are I_3 and I_4, which represents, the number of density of the respective size micro pores. Relation between *o*-Ps lifetime and size of the pores (free volume cavities) were given by Nakanishi *et al.* (1988).

Results and Discussion

X- ray diffraction studies showed existence of major minerals as gibbsite, quartz, kaolinite and hematite, along with minor minerals as halloysite and montmorillonite (Table 1). The results confirmed the presence of clay minerals such as montmorillonite, halloysite and kaolinite along with other major minerals like quartz and gibbsite (Fig. 2a, b). However, quartz was the dominant mineral and match well with sand content of the area.

The major and minor elements were identified by XRF studies, which revealed elemental composition and their

Table 1 : Minerals identified in soil samples by XRD analysis

Minerals present	*Å d-spacing*	Powder diffraction data (reference) file
Gibbsite	4.85 (002), 4.38, 4.32, 3.18, 2.45, 2.42, 2.38, 2.24, 2.16, 2.04, 1.99, 1.80, 1.78, 1.68, 1.45, 1.42 and 1.40	74-1775
Quartz	4.26, 3.34, 2.45 and 1.81.	05-490
Hematite	3.67(102), 2.69, 2.51, 2.20, 1.84, 1.69, 1.48 and 1.45	87-1166
Kaolinite	7.15 (001), 4.36, 3.57 (002), 2.34 (003) and 1.48	80-0886
Halloysite	10.04 (001), 4.35, 3.34, 2.54, 1.47 and 1.28	29-1489
Montmorillonite	14.47, 12.26, 4.45, 2.56 and 1.49	03-0016

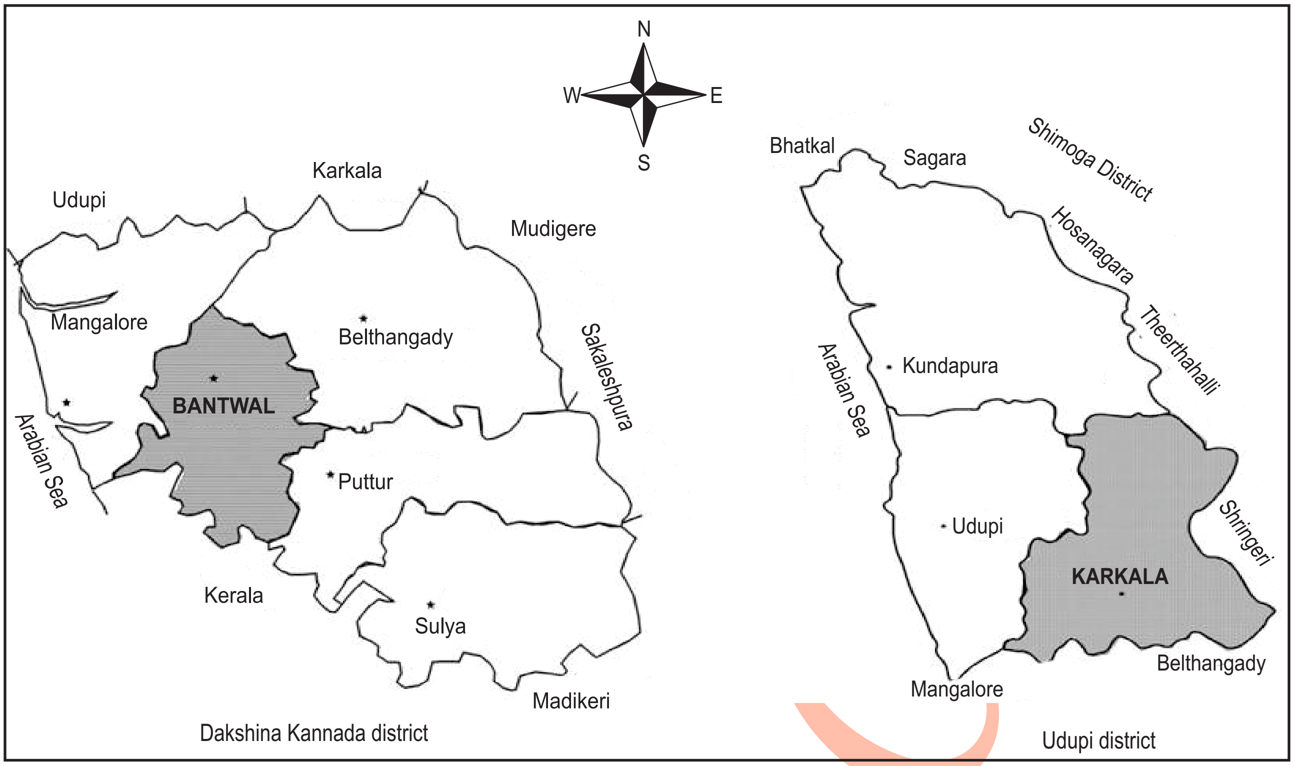

Fig. 1 : Study area of Bantwal and Karkala Taluk in Karnataka

percentage concentration (Table 2). Thin section study of the representative soil samples from agricultural lands of Bantwal taluk revealed the presence of quartz, pyroxene, biotite, magnetite, feldspar, ilmenite and rarely rutile. In the representative samples of Karkala Taluk, along with quartz, the soil was rich in magnetite. Apart from these, the sections revealed the presence of feldspars, smectite, altered biotite, rutile and ilmenite. Diverse texture has been noticed in the agricultural soil of Bantwal Taluk. It ranges from sandy loam, silty clay loam, silty-loam and loam texture; while most of the agricultural soil of Karkala showed comparatively more uniform silty-loam texture, a very small percentage showed loam soil (Table 3).

IR spectral data of important minerals identified were recorded. In the O-H stretch region, absorbance bands at 3,695, 3,623, 1,033, 1,021 cm^{-1} indicated kaolinite (Madejova´, 2003, Nayak and Singh, 2007). Bands between 900 and 1100 cm^{-1} represented Si-O-Al bonding. The characteristic band around 1640 cm^{-1} indicated the presence of water molecule. In some samples, gibbsite was found along with kaolinite (Fig. 3a, b). However, the pattern did not show the presence of other minerals like quartz and hematite, which were observed in XRD studies.

PALS method is unique and gives fast and reliable results (Table 4). A correlation between soil physico-chemical parameters of the region and microporosity was reported by Smitha (2007). XRF study of representative soil sample from Eliyanadugodu indicates 52 % of SiO_2 and 34.3 percent of AlO_3 by

Table 2 : XRF results of soil sample from Bantwal and Karkala Taluk

Sample location	Elements analyzed and concentration in %			
	As element	%	As Oxide	%
	Na	0.14	Na_2O	0.2
	Mg	0.62	MgO	1.0
	Al	18.1	Al_2O_3	34.3
Eliyanadugodu, Bantwal taluk	Si	24.3	SiO_2	52.0
	P	0.07	P_2O_5	0.18
	K	0.8	K_2O	1.0
	Ca	0.1	CaO	0.14
	Ti	0.8	TiO_2	1.3
	Fe	6.9	Fe_2O_3	9.9
	Zr	0.03	ZrO_2	0.04
	S	0.05		
	As element	%	As oxide	%
	Na	0.12	Na_2O	0.16
	Mg	0.5	MgO	0.83
	Al	14.3	Al_2O_3	26.9
	Si	28.4	SiO_2	60.7
Kuchuru, Karkala taluk	P	0.1	P_2O_5	0.25
	K	1.7	K_2O	2.05
	Ca	0.3	CaO	0.36
	Ti	0.5	TiO_2	0.77
	Fe	5.4	Fe_2O_3	7.8
	Zr	0.02	ZrO_2	0.03
	S	0.08		

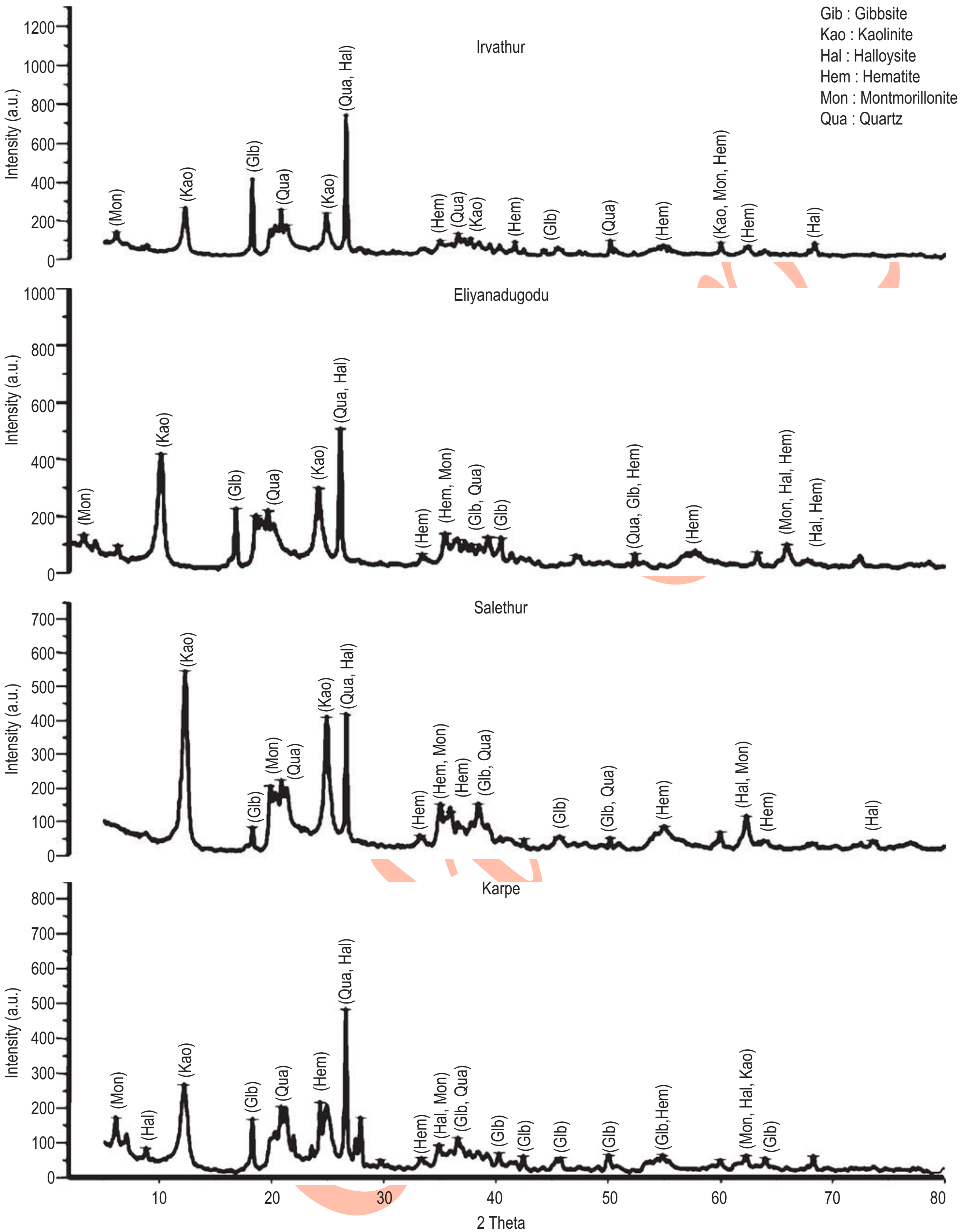

Fig. 2 (a) : XRD of soil samples from Bantwal Taluk confirming the presence of Gibbsite, Kaolinite, Halloysite, Hematite, Montmorillonite and Quartz

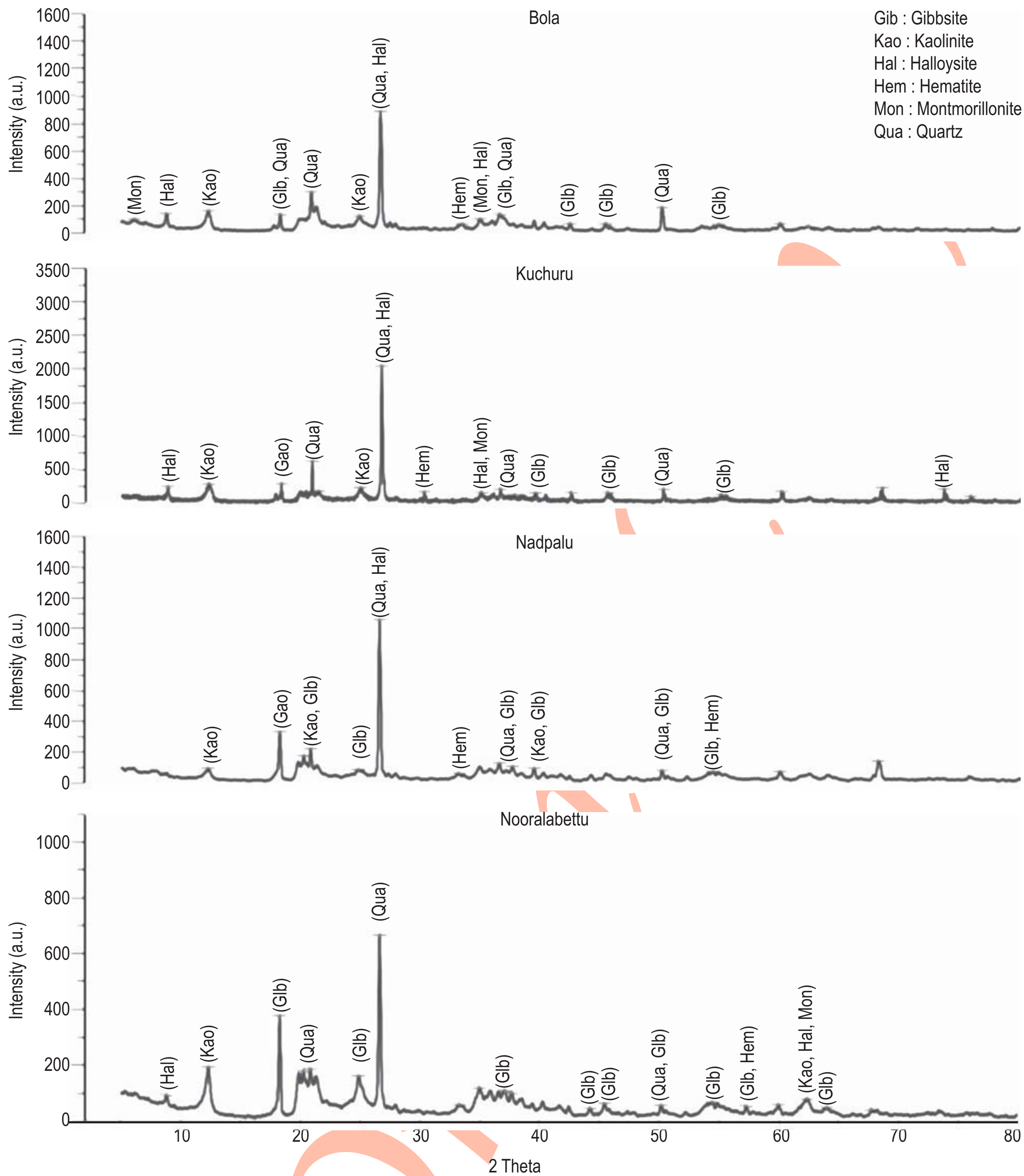

Fig. 2 (b) : XRD pattern of soil samples from Karkala Taluk confirming the presence of Gibbsite, Kaolinite, Hematite, Halloysite, Montmorillonite, and Quartz

weight (Table2), which confirms the abundance of quartz and gibbsite. But Salethur area showed that kaolinite and quartz were dominant as compared to other minerals in the soil sample and this result compares well with the sand- clay ratio for that area.

As SiO_2 concentration increased, the fractional free volume showed negative correlation suggesting that the paramagnetic species, oxygen, quenches the ortho-positronium (O- Ps) lifetimes and its intensity. For silt, a positive correlation,

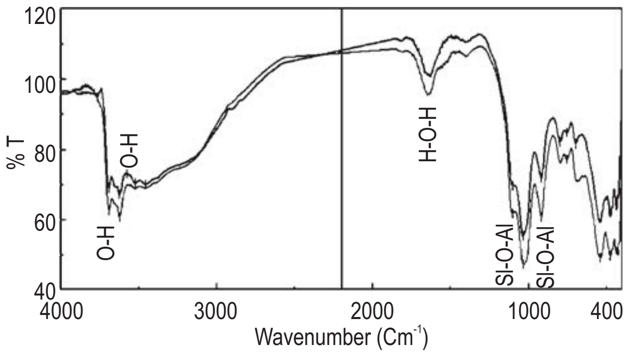

Fig. 3 (a) : Superimposed FTIR spectra of soil samples from Karpe and Eliyanadugodu village confirming the presence of kaolinite and gibbsite

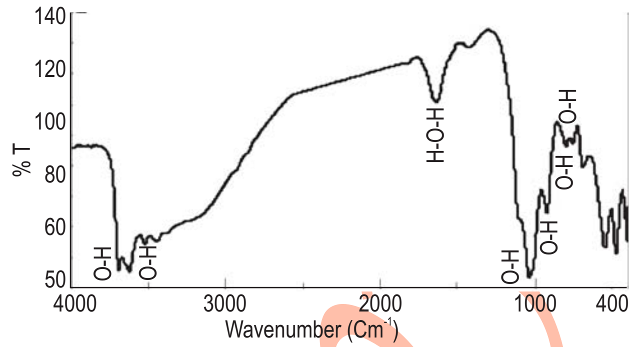

Fig. 3 (b) : FTIR spectrum of soil sample from Nooralabettu village (Karkala Taluk) showing strong, mild and weak absorption bands and confirming the presence of kaolinite

Table 3 : Percent sand, silt, clay and textural classifications of representative soil samples from Bantwal and Karkala Taluks

Village	Sand (%)	Silt (%)	Clay (%)	Textural class
Taluk Bantwal				
Karpe	51	45	4	Sandy loam
Thumbe	29	51	20	Silty clay loam
Narikombu	71	25	4	Sandy loam
Salethur	38	49	13	Loam
Vittal mudnur	54	38	8	Sandy loam
Vittal padnur	50	44	6	Sandy loam
Kadeshwalya	61	38	1	Sandy loam
Eliyanadugodu	45	51	4	Silty loam
Pilathabettu	48	42	10	Loam
Taluk Karkala				
Nooralabettu	40	42.5	17.5	Loam
Irvatturu	66	30.6	3.4	Sandy loam
Nadpalu	62	33	5	Sandy loam
Kuchur	54	34	12	Sandy loam
Bola	53	43	4	Sandy loam
Kadthala	53	43	4	Sandy loam
Shirlalu	63	34	3	Sandy loam

Table 4 : Positron annihilation lifetime analysis results for representative soil samples from Bantwal and Karkala Taluks

Village	V_f Å^3	F_{vr}	t_3 (ns)	I_3 (%)
Taluk Bantwal				
Karpe	48.4	1.54	1.43	3.2
Thumbe	64.5	1.48	1.63	2.3
Narikombu	33.5	0.83	1.17	2.5
Salethur	42.4	1.73	1.35	4.1
Vittal mudnur	85.4	1.79	1.87	2.1
Vittal padnur	68.8	1.57	1.68	2.2
Kadeshwalya	45.4	1.41	1.39	3.1
Eliyanadugodu	101.3	2.12	2.04	2.1
Pilathabettu	67.1	1.81	1.66	2.7
Taluk Karkala				
Nooralabettu	49.9	1.59	1.45	3.2
Irvatturu	57.1	1.48	1.54	2.6
Nadpalu	74.9	1.57	1.75	2.1
Kuchuru	61.2	1.34	1.59	2.2
Bola	79.2	1.56	1.8	1.98
Kadthala	67.1	1.4	1.66	1.92
Shirlalu	72.2	1.38	1.72	2.09

was found significant at 0.01 level, suggesting that the particle size varies creating bigger size micro-voids. A positive correlation was, therefore, observed. Only Bantwal region showed a positive correlation with regard to cation exchange capacity (CEC) suggesting that as this component increased, the micro-void porosity also increased. A similar correlation was observed for organic matter as well as for total nitrogen. As organic matter concentration increase, the size of micro-voids increased, thereby showing a positive correlation in micro-void porosity size. No such correlation was observed in the samples collected from Karkala region.

Iron was present in the sample as Fe_2O_3, It appeared that the positron got annihilated in the inter-granular region (Chakrabarti *et al*., 2005); thereby an increased free volume was associated with the atoms and the grain surfaces and this showed a positive correlation with positron data. This observation is specific to Bantwal soil samples. The other elemental specie, manganese, which was present only in the Karkala region, showed a positive correlation. So, the interpretation was similar to Fe_2O_3 of Bantwal region. The last element that showed negative correlation was calcium. This was specific to Karkala soil samples. Calcium usually annihilates in ionic form possessing positive charge, which repels the positron. It, therefore, reduced the probability of o-Ps formation; hence, the observed correlation for the positron-parameters.

Better understanding is possible, if the present study is carried out on a larger scale with many data points within the two districts to get a comprehensive baseline information. Though bed rock contributes a lot to the overlying soil, it is not always the only factor that influences the type of soil lying over. For example, greater part of North Karnataka is covered by black soil and it covers all types of rocks (GoK, 2005). Hence, while studying soil mineralogy, a study of bedrock composition and ion mobility from bed rock to topsoil at each sampling site would help in establising the contribution of bedrock as against the contribution of transported material to soil fertility. Climate is also a controlling factor in soil mineralogy (Michalopoulos and Aller, 1995, Kump *et al.* 2000, Deepthy and Balakrishna, 2005). Hence, there is a need to establish the effect of climatic factors on soil mineralogy and in turn fertility of soil in this region, since it receives heavy rainfall during southwest monsoon season. Floods also bring a lot of nutrients in the form of suspended sediment load, which gets deposited over the low-lying agricultural lands along the rivers and influences the crop productivity, too.

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