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Studies on forms and distribution of phosphorus in the different soil series of a sub-watershed in northern dry zone of Karnataka

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Abstract
A study was undertaken during 2018-19 in the soils of Babaleshwar East sub-watershed of Vijayapura district which belongs to Northern dry zone of Karnataka to study the forms of phosphorus and their relationship with soil properties. Thirteen soil series were identified in the study area, one representative soil profile was selected from each soil series and horizon-wise soil samples were analyzed for different fractions of phosphorus. Saloid-P, Fe-P, Al-P, Org-P and available-P decreased with profile depth in all the soil series and were positively and significantly correlated with organic carbon. Reductant soluble-P, occluded -P and Ca-P and total-P did not follow definite trend in most of the soil series. Occluded-P was negatively correlated with free $CaCO_3$, whereas Ca-P and total-P were significantly and positively correlated with free $CaCO_3$. Fe-P, Al-P and reductant soluble -P significantly and negatively correlated with pH and free $CaCO_3$. Among the inorganic phosphorus fraction Ca-P was dominant as the soils are under semi-arid region.

Keywords: Forms of phosphorus, soil series, soil profile, sub-watershed

Introduction
Phosphorus (P) is the most studied element but the least understood due to its complex chemistry in the soil. Next to nitrogen, the most critical element influencing plant growth and development is phosphorus. A large proportion of soluble inorganic phosphate added to soil is rapidly fixed as insoluble forms and becomes unavailable to the plants. Chemical fractionation of inorganic forms of phosphorus in soil provides knowledge about proportion phosphorus distributed in different chemical fractions in soils, most commonly saloid-P, Al-P, Fe-P, reductant soluble-P, occluded-P and Ca-P. Since, these forms of phosphorus have different solubility and availability depends on their amount in the soil. The forms of phosphorus are influenced by soil characteristics such as soil reaction, organic matter, free calcium carbonate content and soil texture. The various inorganic P pools were interrelated and contributed to plant available P (Hao *et al*., 2008) [8]. Phosphorus, like any other plant nutrient is present in soil in two major components *i.e*. organic and inorganic. Organic P, which is mainly confined to the surface layer, is mineralized into inorganic forms but, the plants mainly depend on inorganic P forms for their P requirements. Saloid-P, Al-P, Fe-P and Ca-P fractions are the main source of P supply to the plants. The proportion of forms of phosphorus such as Ca-P, Al- P, Fe-P, occluded and organic-P governs the response to applied phosphorus (Singh *et al.*, 2003) [23]. A thorough and proper understanding of distribution of forms of phosphorus in soils gives greater insight into phosphorus dynamics. Therefore, the present study was conducted with objectives; (i) To understand the vertical distribution of forms of phosphorus and (ii) To study the relationship between forms of phosphorus with selected soil properties in the soil different soil series of Babaleshwar East sub-watershed of Vijayapuara district, Karnataka.

Materials and Methods
The selected Babaleshwar East sub-watershed (Vijayapuara district) in Northern dry zone of Karnataka lies between 16°38' and 16°48' North latitudes and 75°34' and 75°41' East longitudes, covering an area of about 4865.77 ha and bounded by Sarawada on the North, Tonashyala on the East, Kakhandaki on the South and Babaleshwara West (Fig. 1).

Study area represented by semi-arid climate with annual precipitation of 625.10 mm. The entire area of the sub-watershed is underlain by basalt having dark greyish brown to dark brown colour with sandy clay loam to clay in texture. The soil depth is very shallow to very deep and gradient of land was very gently sloping (1-3%). The soils come under moderately eroded and moderately well drained class with < 15 per cent gravel content (non-gravelly). The sub-watershed was subjected to the detail of LRI using IRS P6 LISS IV data at 1:7920 scale in Sujala-III project. Soil resources are mapped at soil phase level and identified thirteen soil series (Anon., 2017). Characteristic features of each soil series are represented in the Fig.2. One representative soil profile was selected from each soil series and horizon-wise soil samples were analyzed for vertical distribution of forms of phosphorus. Processed soil samples (<2 mm) were analyzed for different physico-chemial properties using following standard procedures. The soil samples were analyzed for pH (1:2.5), EC (1:2.5), organic carbon by Walkley and Black's wet oxidation method (Sparks, 1996) [20]. Free $CaCO_3$ and particle size distribution (Piper, 2002) [16]. Forms of phosphorus using P fractionation scheme of Chang and Jackson (1957) [4] as outlined by Peterson and Corey (1966) [15] was employed to determine various inorganic forms of phosphorus. In brief, Saloid-P was extracted from 0.5 g of soil with 25 mL of 1*N* NH_4Cl with half-an-hour shaking and centrifugation at 7000 rpm for 10 minutes. Aluminum-P was extracted from the residual soil with 25 ml of 0.5*N* of NH_4F (pH 8.2) by shaking the suspension for one hour and centrifuged. Iron-P was extracted from the residual soil by shaking with 25ml of 0.1*N* NaOH for seventeen hours and centrifuged at 2000 rpm for 5 minutes. The residual soil was then suspended in 25 ml of 0.3*M* sodium citrate solution and shaken for 15 minutes with 1 g sodium dithionate. Excess of citrate and dithionate was oxidized by adding 1.5 ml of 0.25*M* $KMnO_4$ solution and Reductant soluble-P (RS-P) was estimated. The soil residue left after the estimation of RS-P was added with 50 ml of 0.1*M* NaOH and shaken for one hour and centrifuged to get clear filtrate for estimation of Occluded-P (Occl-P). Finally, Ca-P was extracted by shaking the residual soil with 25 ml of 0.5*N* H_2SO_4 for one hour and centrifuged. The concentration of P in the respective extracts obtained after shaking with each of the extractant was estimated by the ascorbic acid method as outlined by John (1970). The total phosphorus content of soil was determined by digesting samples in microwave digestion system (Anton Paar's Multiwave Go) using conc. HNO_3 and HF followed by vanadomolybdo-phosphoric acid method using spectrophotometer at 470 nm wavelength (Tandon, 1998). The experimental data obtained was subjected to statistical analysis adopting Fisher's method of analysis of variance as outlined by Gomez and Gomez (1984) [7]. Testing of significance was done by SPSS 16.0 version and values are given at 5 per cent and 1 per cent level of significance.

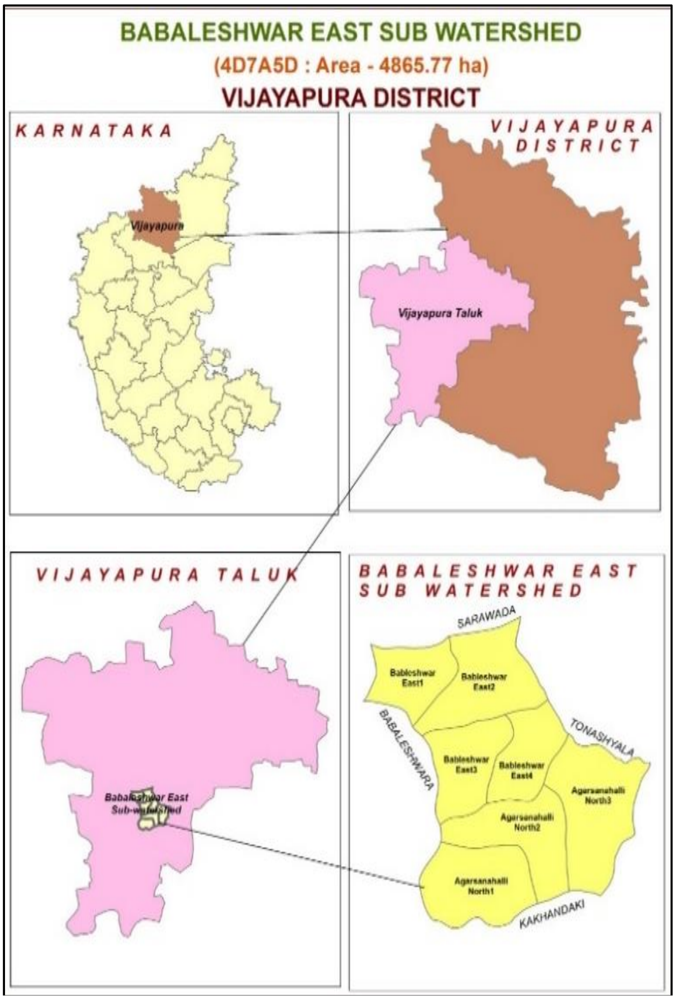

Fig 1: Location map of Babaleshwar East sub-watershed

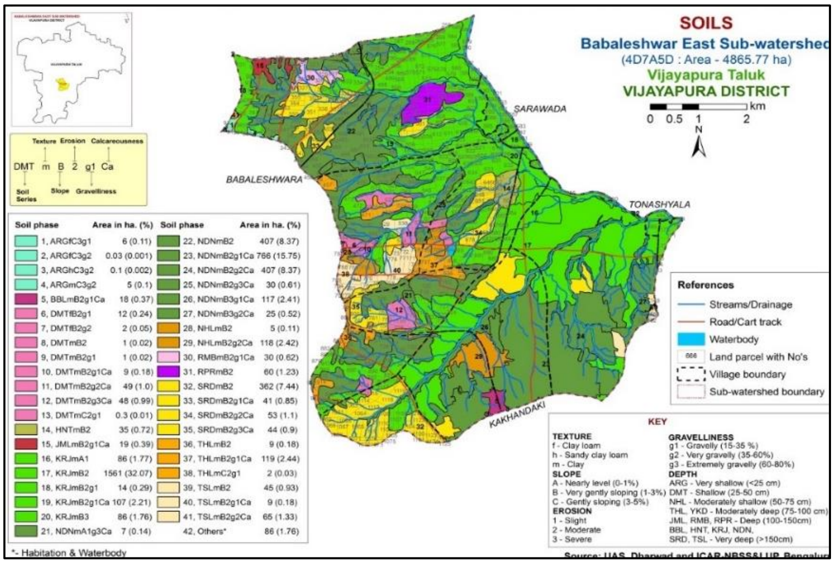

Fig 2: Different soil series of Babaleshwar East sub-watershed

Results and Discussion

Physico-chemical properties of soil (cf Table 1)

The texture of the soils varied from sandy clay loam to clay. The sand, silt and clay contents of soils ranged from 10 to 60, 12 to 31 and 27 to 71 per cent, respectively. The sand content in soils was higher in surface layers, whereas clay content higher in lower layers. There was no definite trend of the particle size distribution with respect to depth in all the soil series. The soil pH varied from slightly alkaline to strongly alkaline (7.94 to 9.53) and electrical conductivity (EC) (0.11 to 0.86 dS m^{-1}) in soils was well within the permissible limits (< 1.0 dS m^{-1}) there was no salinity hazard in the soils. Both pH and EC values did not follow any definite trend with depth in all the soil series it might be due to differential losses of bases over time. The organic carbon (OC) content (0.7 to 6.2 g kg^{-1}) in general ranged from low to medium and decreased with depth in all the soil series. Higher OC at the surface is mainly due to accumulation of organic materials through crop residue and external applications in the surface soils. The free calcium carbonate ($CaCO_3$) content (23.3 to 565.8 g kg^{-1}) in soils did not follow any definite pattern in its distribution with soil depth in all the series increased free lime with soil depth and attributed it to illuviation of $CaCO_3$ along with clay (Patil *et al*., 2014, Pulakeshi *et al*., 2014 and Denis *et al.*, 2015) [14, 17, 5].

Vertical distribution of phosphorus forms in the soils (cf. Table 2)

Forms of phosphorus

Saloid bound phosphorus (Saloid-P)

The content of saloid-P decreased with soil depth in all the soil series and among Ap horizons, its content ranged from 2.15 mg kg^{-1} (DMT series) to 4.69 mg kg^{-1} (ARG series). The surface layers of black soils contain higher amount of saloid-P compared to lower layers might be due to the influence of added of inorganic fertilizers, manures and readily mineralizable organic-P present in soils. The content of saloid-P was very low compared to other forms of P might be due to the high P-fixing capacity of soils, as well as due to conversion of readily soluble forms of P into less soluble forms with progress of time. Similar observations were also described in the soils of Northern dry zone of Karnataka (Sabyasachi Majumdar, 2014) and in the soils of Gadag district of Karnataka (Patil and Patil, 2019) [18, 13].

Aluminum bound phosphorus (Al-P)

The content of Al-P decreased with soil depth in all the soil series and among Ap horizons, the highest (27.13 mg kg^{-1}) Al-P was found in ARG series and lowest (18.15 mg kg^{-1}) in THL series. Similar outcomes were also reported by Bhavsar *et al.* (2018) [2] in soils of Nagpur and Patil and Patil (2019) [13] in soils of Kanaginhal sub-watershed of Gadag district. Higher values of Al-P in the surface horizons compared to lower horizons of some Vertisols due to a higher content of aluminum oxides in surface soils and increased content of free $CaCO_3$ in the soil with increasing depth lead to reduced content of Al -P content.

Iron bound phosphorus (Fe-P)

The Fe-P content was highest (17.29 mg kg^{-1}) in ARG series and lowest (10.32 mg kg^{-1}) in DMT series, among Ap horizons and decreased with depth in all the soil series. Bhavsar *et al.* (2018) and Patil and Patil (2019) [13, 2] were reported similar results. The higher content of Fe-P in surface soils horizons might be attributed to the occurrence of higher organic matter which releases organic acids and leads to the ferrous iron solubilization along with phosphates resulting in precipitation of ferrous phosphate and also due to higher amount of calcium carbonate at higher pH, where activity of iron was a smaller amount to precipitate phosphorus into Fe-P (Sacheti and Saxena, 1973 and Jaggi, 1991) [19, 9].

Reductant soluble phosphorus (RS-P)

The distribution of RS-P with soil depth did not follow any definite pattern. However, its content was highest in surface horizons of the most the soil series. Among Ap horizons, the RS-P content was highest (88.86 mg kg^{-1}) in HNT series and lowest (41.29 mg kg^{-1}) in RMB series. The similar results reported by Viswanath and Doddamani (1991) [22]. The low value of RS-P was observed in the soils having relatively higher pH and sand content. This might be due to iron and aluminum bound P content and rise in the content of calcium bound P and also Red-P as also reported by Bhavsar *et al.* (2018) and Patil and Patil (2019) [13, 2].

Occluded phosphorus (Occl-P)

The distribution of the Occl-P in soils of the different soil series did not show definite trend, except in few soil series where it slightly decreased with depth of soil. Among Ap horizons, it was highest (45.51 mg kg^{-1}) in ARG series and lowest (32.28 mg kg^{-1}) in KRJ series. The similar results reported by Viswanath and Doddamani (1991) and Gajbhiye (2001) [22, 6]. The highest Occl-P content was accumulated in the surface horizons indicating non-mobility of P in soils down to lower layers (Bhavsar *et al.*, 2018) and Patil and Patil (2019) [13, 2].

Calcium bound phosphorus (Ca-P)

In all the soil series, no definite trend in distribution of Ca-P with soil depth was observed. Among Ap horizons, it was highest (247.29 mg kg^{-1}) in KRJ series and lowest (165.24 mg kg^{-1}) in ARG series. Its content of Ca-P depends on presence or absence of $CaCO_3$ in soil profile horizons. In general, the content of Ca-P was low in surface soil horizons and increase with depth might be due to lower pH and free $CaCO_3$ content in surface soils and its content increase with soil depth (Puranik *et al.*, 1979 and Patil and Patil, 2019) [13].

Total mineral phosphorus (Tot. Min. P)

The Tot. Min. P was computed by adding above all inorganic fractions of phosphorus and its distribution did not follow any definite pattern in respect to soil depth in most of the soil series and Among the Ap horizons, its values ranged from 305.91 mg kg^{-1} (RMB series) to 398.25 mg kg^{-1} (KRJ series). The contribution of Tot. Min.-P to the total-P was more compare to organic-P in studied soils as the soils are under semi-arid region. These results were in accordance with opinions of Gajbhiye (2001) and Patil and Patil (2019) [13, 6].

Organic phosphorus (Org. P)

The content of Org. P decreased with soil depth in all the series and its content was highest (233.77 mg kg^{-1}) in Ap horizon of HNT series and lowest (120.52 mg kg^{-1}) in Ap horizon of NHL series. Similar results were also reported by Bhavsar *et al.* (2018) and Patil and Patil (2019) [13, 2]. The decrease of organic phosphorus with down the soil depth might be due to the decrease the amount organic matter in the soils as depth increase. Similar opinions were reported by the Viswanath and Doddamani (1991) [22]. Since all soils were calcareous in nature, organic phosphorus was relatively low.

Total phosphorus (Total-P)

Total-P content did not follow any definite pattern in its distribution with depth of soil. However, in some soil series decreased with depth. Among the Ap horizons, the total-P content was highest (599.96 mg kg^{-1}) in KRJ series and lowest (457.25 mg kg^{-1}) in THL series. The content of total-P in soils decrease with depth in some soil series might be due to the content of organic phosphorus decrease down the depth and in most of the soil series exhibited an did not show any definite pattern in its distribution with soil depth it might be due variation in Tot. Min. P content of soil. These results were in line with findings of Viswanath and Doddamani (1991), Gajbhiye (2001) and Patil and Patil (2019) [22, 6, 13].

Table 1: Physico-chemical properties of different soil series of Babaleshwar East sub-watershed

Soil series	Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture	pH (1:2.5)	EC (1:2.5) (dS m^{-1})	OC (g kg^{-1})	Free $CaCO_3$ (g kg^{-1})
ARG	Ap	0-13	60	13	27	Sandy clay loam	7.94	0.17	2.1	23.3
BBL	Ap	0-10	23	25	52	Clay	9.05	0.29	4.7	143.3
	Bw	10-40	22	25	53	Clay	9.22	0.36	3.5	144.5
	Bss	40-90	28	21	51	Clay	8.93	0.48	2.5	142.5
	$Bssk_1$	90-150	31	26	43	Clay	8.78	0.46	1.4	113.3
	$Bssk_2$	150-180	40	31	29	Clay loam	8.48	0.49	0.8	140.0
DMT	Ap	0-24	46	26	28	Clay loam	8.43	0.23	6.2	157.5
	Bw	24-42	36	22	42	Clay	8.75	0.22	4.9	173.3
HNT	Ap	0-15	39	28	33	Clay	8.43	0.11	5.7	118.3
	Bw_1	15-49	34	27	39	Clay	8.61	0.14	5.5	123.3
	Bw_2	49-80	25	18	57	Clay	8.25	0.15	3.9	200.8
	Bw_3	80-130	21	18	61	Clay	8.98	0.23	3.4	125.8
	BCk_1	130-160	58	13	29	Sandy clay loam	8.93	0.26	2.0	137.5
	Bss	160-200	27	22	51	Clay	8.96	0.45	1.2	151.7
JML	Ap	0-31	40	19	41	Clay	8.74	0.13	4.5	412.5
	Bss_1	31-60	45	21	34	Clay loam	9.19	0.20	2.7	355.0
	Bss_2	60-97	37	20	43	Clay	9.33	0.30	2.1	502.5
	BCk	97-112	32	23	45	Clay	8.67	0.40	0.8	555.8
KRJ	Ap	0-16	24	25	51	Clay	8.65	0.16	6.2	103.3
	Bw	16-30	23	25	52	Clay	8.72	0.23	5.7	97.5
	Bss_1	30-60	17	30	53	Clay	9.18	0.34	4.7	105.0
	Bss_2	60-90	15	30	55	Clay	9.31	0.45	3.4	117.5
	Bss_3	90-120	15	28	57	Clay	9.24	0.39	2.3	132.5
	Bss_4	120-160	17	24	59	Clay	9.22	0.66	1.8	141.7
NDN	Ap	0-18	36	17	47	Clay	8.51	0.13	5.9	108.3
	Bw	18-40	39	16	45	Clay	8.67	0.19	5.1	101.7
	Bwk_1	40-70	32	21	47	Clay	9.05	0.21	4.5	134.2
	Bwk_2	70-90	41	14	45	Clay	9.26	0.41	3.7	75.0
	Bwk_3	90-120	31	13	56	Clay	9.27	0.45	1.8	44.2
	Bwk_4	120-150	30	15	55	Clay	9.37	0.49	1.2	98.3
	Bwk_5	150-190	33	14	53	Clay	9.36	0.51	0.8	55.8
NHL	Ap	0-20	18	19	63	Clay	8.45	0.16	5.1	209.2
	Bwk	20-60	17	24	59	Clay	8.62	0.14	4.9	175.8
RMB	Ap	0-20	36	21	43	Clay	8.47	0.16	3.1	280.8
	BCk_1	20-50	34	24	42	Clay	8.76	0.15	2.7	334.2
	BCk_2	50-78	40	22	38	Clay loam	8.56	0.17	2.3	490.0
	BCk_3	78-110	39	23	38	Clay loam	8.75	0.11	1.1	565.8
	BCk_4	110-143	35	28	37	Clay loam	8.92	0.19	0.7	332.5
RPR	Ap	0-15	16	23	61	Clay	8.96	0.23	5.9	95.0
	Bw	15-35	14	21	65	Clay	8.92	0.29	5.1	100.0
	Bss_1	35-70	13	16	71	Clay	9.26	0.36	4.3	116.7
	Bss_2	70-110	10	20	70	Clay	9.35	0.49	3.3	120.0
	$Bssk_1$	110-160	15	19	66	Clay	8.96	0.86	1.8	154.2
SRD	Ap	0-10	38	16	46	Clay	8.45	0.21	4.9	108.3
	Bw	10-30	29	21	50	Clay	8.84	0.22	4.3	106.7
	Bss_1	30-60	34	12	54	Clay	9.22	0.36	3.9	116.7
	Bss_2	60-100	36	12	52	Clay	9.25	0.43	3.5	132.5
	Bwk_1	100-140	28	18	54	Clay	9.53	0.46	2.3	144.2
	Bwk_2	140-180	25	18	57	Clay	9.36	0.41	1.4	135.8
THL	Ap	0-20	30	23	47	Clay	8.57	0.22	5.4	110.8
	BCk_1	20-40	28	20	52	Clay	8.64	0.23	3.5	102.5
	BCk_2	40-78	32	26	42	Clay	8.66	0.15	2.1	208.3
	CBk	78-109	31	21	48	Clay	8.82	0.16	1.1	241.7
	CB	109-140	30	24	46	Clay	9.06	0.16	0.8	204.2
TSL	Ap	0-20	35	31	34	Clay loam	8.63	0.16	4.5	109.2
	Bw_1	20-50	27	29	44	Clay	9.12	0.25	3.9	96.7
	Bw_2	50-90	30	27	43	Clay	9.24	0.22	3.3	189.2

	CBk$_1$	90-120	26	29	45	Clay	9.22	0.25	2.0	229.2
	CBk$_2$	120-170	25	29	46	Clay	9.27	0.26	1.4	233.3

Table 2: Vertical distribution of forms of phosphorus in different soil series of Babaleshwar East sub-watershed

Soil series	Horizon	Depth (cm)	Saloid-P	Al-P	Fe-P	RS-P	Occl-P	Ca-P	Total mineral-P	Organic-P	Total-P
			(mg kg^{-1})								
ARG	Ap	0-13	4.69	27.13	17.29	66.23	45.51	165.24	326.09	167.42	493.51
BBL	Ap	0-10	3.96	25.64	16.12	62.12	35.67	246.18	389.69	202.94	592.63
	Bw	10-40	3.81	25.07	14.12	69.38	40.59	236.20	389.17	199.44	588.61
	Bss	40-90	3.62	20.51	14.30	53.13	38.13	230.99	360.68	182.60	543.28
	Bssk$_1$	90-150	2.97	17.29	13.20	49.20	36.28	220.84	339.78	172.57	512.35
	Bssk$_2$	150-180	1.45	13.06	12.13	39.12	42.43	228.53	336.72	170.95	507.67
DMT	Ap	0-24	2.15	23.98	10.32	72.63	32.74	236.98	378.80	169.68	548.48
	Bw	24-42	1.53	22.14	9.12	61.12	48.13	269.21	411.25	142.61	553.86
HNT	Ap	0-15	3.37	21.63	13.83	88.86	38.74	184.94	351.37	233.77	585.14
	Bw$_1$	15-49	2.51	21.52	12.41	83.23	39.36	229.15	388.18	185.15	573.33
	Bw$_2$	49-80	1.53	19.21	12.18	89.09	32.28	251.29	405.58	172.34	577.92
	Bw$_3$	80-130	1.23	17.60	11.3	63.08	43.05	237.14	373.40	121.82	495.22
	BCk	130-160	0.61	15.91	10.14	68.12	38.13	239.28	372.19	115.41	487.60
	Bss	160-200	0.30	15.53	8.13	49.28	39.36	242.37	354.97	45.24	400.21
JML	Ap	0-31	3.78	22.48	15.35	42.61	39.89	197.25	321.36	156.28	477.64
	Bss$_1$	31-60	2.26	21.83	14.86	46.92	35.84	186.17	307.88	113.27	421.15
	Bss$_2$	60-97	1.96	21.51	11.81	50.19	44.58	237.78	367.83	92.71	460.54
	BCk	97-112	0.89	19.45	9.36	39.46	34.98	272.61	376.75	76.50	453.25
KRJ	Ap	0-16	2.76	21.52	13.12	81.28	32.28	247.29	398.25	201.71	599.96
	Bw	16-30	2.15	20.91	12.41	63.89	42.74	245.75	387.85	173.35	561.20
	Bss$_1$	30-60	1.53	19.60	9.31	65.93	39.36	252.52	388.25	142.30	530.55
	Bss$_2$	60-90	1.51	18.29	8.98	56.22	41.92	254.05	380.97	136.27	517.24
	Bss$_3$	90-120	0.65	15.19	8.17	58.82	36.28	255.28	374.39	128.85	503.24
	Bss$_4$	120-160	0.41	12.63	5.01	41.24	35.97	257.44	352.70	125.61	478.31
NDN	Ap	0-18	3.69	21.52	14.31	62.59	35.36	226.69	364.16	144.90	509.06
	Bw	18-40	3.07	19.59	14.01	54.39	35.06	210.39	336.51	154.41	490.92
	Bwk$_1$	40-70	1.84	17.6	13.29	59.21	34.44	240.22	366.60	116.52	483.12
	Bwk$_2$	70-90	1.23	17.29	11.32	41.01	36.59	191.08	298.52	113.53	412.05
	Bwk$_3$	90-120	0.92	15.98	10.33	45.92	35.36	181.18	289.69	98.21	387.90
	Bwk$_4$	120-150	0.61	13.68	9.20	40.71	35.44	202.94	302.58	87.49	390.07
	Bwk$_5$	150-190	0.45	13.15	8.39	39.02	41.82	182.41	285.24	44.26	329.50
NHL	Ap	0-20	3.38	22.18	14.36	53.28	35.05	243.91	372.16	120.52	492.68
	Bwk	20-60	2.76	21.52	14.01	58.12	38.74	229.45	364.60	103.81	468.41
RMB	Ap	0-20	3.61	22.44	14.34	41.29	39.06	185.17	305.91	158.71	464.62
	BCk$_1$	20-50	2.75	20.83	13.18	45.81	34.74	196.86	314.17	137.87	452.04
	BCk$_2$	50-78	2.19	18.52	11.29	39.12	33.82	236.53	341.47	116.81	458.28
	BCk$_3$	78-110	0.84	17.59	10.30	38.12	34.74	256.83	358.42	74.61	433.03
	BCk$_4$	110-143	0.23	15.58	9.98	35.12	34.44	205.78	301.13	48.54	349.67
RPR	Ap	0-15	4.45	23.37	16.10	81.29	39.05	179.02	343.28	155.11	498.39
	Bw	15-35	4.61	20.37	14.03	88.13	36.59	233.76	397.49	105.76	503.25
	Bss$_1$	35-70	3.07	19.68	13.29	62.79	43.97	239.53	382.33	93.95	476.28
	Bss$_2$	70-110	2.76	17.06	13.19	54.18	39.66	254.05	380.90	76.33	457.23
	Bssk$_2$	110-160	2.15	15.75	12.03	40.21	37.20	255.59	362.93	30.83	393.76
SRD	Ap	0-10	4.22	21.52	16.30	65.21	35.97	222.07	366.29	159.08	525.37
	Bw	10-30	3.99	20.91	14.33	68.72	36.59	200.24	344.78	151.87	496.65
	Bss$_1$	30-60	3.69	19.6	13.71	61.63	43.35	206.27	348.25	136.99	485.24
	Bss$_2$	60-100	2.76	18.98	13.41	59.43	40.28	213.25	348.11	128.73	476.84
	Bwk$_1$	100-140	1.23	15.68	11.20	45.63	36.90	227.61	338.25	114.42	452.67
	Bwk$_2$	140-180	0.61	13.08	10.18	41.05	35.05	215.01	314.98	96.22	411.20
THL	Ap	0-20	3.95	18.15	14.85	55.16	36.22	201.25	329.58	127.67	457.25
	BCk$_1$	20-40	3.12	17.95	12.11	57.26	56.94	225.69	373.07	119.61	492.68
	BCk$_2$	40-78	2.41	16.64	11.51	54.25	34.58	226.69	346.08	75.17	421.25
	CBk	78-109	2.02	13.01	9.30	44.21	34.15	274.41	377.10	61.85	438.95
	CB	109-140	0.92	11.45	10.95	39.14	32.86	214.01	309.33	46.98	356.31
TSL	Ap	0-20	3.92	19.98	15.81	60.38	37.20	207.01	345.30	167.85	513.15
	Bw$_1$	20-50	3.38	19.37	13.12	63.25	37.82	206.08	343.02	133.76	476.78
	Bw$_2$	50-90	2.76	17.06	11.18	54.18	35.05	215.92	336.15	116.19	452.34
	CBK$_1$	90-120	2.15	15.75	10.33	45.73	34.74	228.84	337.54	74.82	412.36
	CBK$_2$	120-170	0.92	12.45	8.13	40.68	33.51	274.67	370.36	49.92	420.28

Correlation between the forms of phosphorus and selected soil properties (cf. Table 3)

The Saloid-P exhibited a significant and positive correlation with organic (r = 0.621**) and negative correlation with soil pH. Significant and negative relationship of Saloid-P with soil pH (r = 0.413**) and free $CaCO_3$ (r = -0.211) might be due to conversion of loosely held surface adsorbed-P into less soluble form of P. Similar results were reported in Gajbhiye (2001) [6].

The Al-P and Fe-P had significant and negative correlation with pH (r = -0.466** and r = -0.433**, respectively) and free $CaCO_3$ (r = -0.466** and r= -0.433**, respectively) this might be due to lower activity of Al and Fe with increasing pH, thus P is not precipitated as Fe-P and Al-P in larger amount. Similar results were noticed by Gajbhiye (2001) [6] in soils of Nagpur and Trivedi *et al.* (2010) [21] in Inceptisols and Alfisols of Madya Prdesh. Both Al and Fe bound P exhibited a significant and positive correlation with organic carbon (r = 0.679** and r = 0.540**, respectively) this might be due to the mineralization of organic P and conversion into Fe-P and Al-P. When soluble-P is added, it reacts with Fe and Al of soil clay mineral to form insoluble Fe-P and Al-P (Kanwar and Grewal, 1990) [10].

Reductant soluble-P had significant and negative correlation with soil (r = -0.323**) and free $CaCO_3$ (r = -0.433**). Occluded-P had negative correlation with soil pH (r = -0.043) and free $CaCO_3$ (r = -205) which indicated higher pH and higher amount of free $CaCO_3$ found less iron oxides to precipitate phosphorus in these forms. RS-P and Occl-P showed a significant and positive correlation with organic carbon. Similar finding were observed by Trivedi *et al.* (2010) [21] and Sabyasachi Majumdar *et al.* (2016).

Correlation between free $CaCO_3$ and Ca-P was highly significant and positive (r = -0.235*), high free $CaCO_3$ content of soils might have reacted with soluble P resulting in higher Ca-P in studied soils significant correlation between Ca-P and free $CaCO_3$ indicates the higher availability of Ca-P in calcareous soil. These results were in accordance with findings of Gajbhiye (2001) and Patil and Patil (2019) [13, 6].

It was observed that, organic-P had significant and positive correlation with organic carbon (r = -0.635**) and significant negatively correlated with pH (r = -0.431*) and free $CaCO_3$ (r = -0.284*). Since studied soils were calcareous in nature, organic phosphorus was relatively low compared to total inorganic phosphorus (Bhavsar *et al.*, 2018) [2].

The high amount of free $CaCO_3$ and organic carbon content in soil increased the amount of total-P. The increased amount of free $CaCO_3$ in soil decreased significantly saloid-P, Fe-P and Al-P forms, while Ca-P is increased due to solubilisation of free $CaCO_3$. The total-P showed significant and positive correlation with organic carbon and free $CaCO_3$. Trivedi *et al.* (2010) [21] also recorded similar results.

Table 3: Correlation between the forms of phosphorus and available phosphorus with selected soil properties in different soil series of Babaleshwar East sub-watershed

	pH	OC	Free $CaCO_3$	Clay
Saloid-P	-0.413**	0.621**	-0.211	0.005
Al-P	-0.466**	0.679*	0.017	-0.153
Fe-P	-0.433**	0.540**	-0.143	-0.084
RS-P	-0.323**	0.738**	-0.433**	0.077
Occl-P	-0.043	0.087	-0.205	0.080
Ca-P	-0.091	-0.071	0.235*	0.272*
Total mineral-P	-0.178	0.439**	-0.045	0.256
Organic-P	-0.431*	0.635**	-0.284**	-0.250
Total-P	-0.407**	0.688**	0.232**	-0.057

**. Correlation is significant at the 1% level; *. Correlation is significant at the 5% level

Conclusion

The present study on vertical distribution of forms of phosphorus and their relationship with soil properties in the soils of indicates that Ca-P was dominant among the inorganic phosphorus fractions as the soils are under semi-arid region. Saloid-P, Fe-P, Al-P and organic-P decreased with soil profile depth in all the series and were positively and significantly correlated with organic carbon. Reductant soluble-P, occluded-P, Ca-P and total-P did not follow definite trend with depth in most of the soil series. Occluded-P was negatively correlated with free $CaCO_3$, whereas Ca-P and total-P were significantly and positively correlated with free $CaCO_3$. Fe-P, Al-P and reductant soluble-P were significantly and negatively correlated with pH and free $CaCO_3$ content of soils.

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