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Hydrometer method against Pipette method for Estimating Soil particle size distribution in Some Soil Types Selected from Central Sudan

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Abstract

Assessment of hydrometer against standard pipette methods for particle size measurements has been investigated in twenty-six soil samples collected from different climatological and ecological regions in central Sudan. Soil particle size distribution was determined using the two different methods in an attempt to insure that if the hydrometer method is accurate for particle size measurement for the soils of Sudan or not. The statistical analysis revealed that, there are no significant differences ($P > 0.05$) between the two methods in most studied samples, except in clay and sand contents in the samples from 1st and 2nd Nile River terraces were significantly different ($P < 0.05$). These could be attributed to differences in the soil parent material, as indicated by increases in the clay and sand contents. Regression analysis between the two methods produced coefficient of determination (r^2) values of 0.99 and 0.98 for clay and sand contents, respectively. Depending on the study findings, we conclude that, hydrometer method is somewhat less accurate in the sand measurement as compared to the pipette method; however, it can use it instead of pipette method for determining the soil texture for the soils of Sudan.

Key Words: Central Sudan, Hydrometer method, Ecological regions, Soils of Sudan.

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1. Introduction:

The major soils in Sudan can be divided geographically into three categories; the sandy soils of the northern and west central regions, the clay soils of the central and eastern regions, and the laterite soils of the southern regions. Among all these categories, the clay soils (Vertisols) constitute more than 50% of the soils in Sudan (Elfaki *et al.,* 2016).

Most agricultural and environmental planning requires soil analysis, or at least should require analysis for better implementation for any change. Furthermore, better practical analysis methods can rapidly estimate soil properties needed to improve quantitative assessments of land management problems (Shepherd and Walsh, 2002).

Mechanical analysis known as the determination of the size range of particles present in a soil, expressed as a percentage of the total dry weight. Among the common methods use to determine soil texture, the hand texture method is qualitatively method, but with more experience many people can easily describe the different textural classes sites some useful criteria for field texturing (Soil Survey Staff, 2014b).

Additionally, separation by sieving consider as mostly method used for sand fractionation only (0.05 to 2 mm diameter particles) using American Society for Testing & Materials (ASTM) sieve numbers between 270 or 300 and 10 (openings/inch), respectively. One limitation is that the probability of a particle passing through a sieve in a given time of shaking depends on the nature of the particle, the number of particles of that size, and the properties of the sieve (e.g., particle shape and sieve-opening shape affect probability of passage) (Gee and Bauder, 1986).

The pipette method is often used as the standard to which other methods are compared. It depends upon the fact that sedimentation eliminates from the depth, hour (H), in a time (T), all particles having settling velocities greater than h/t, while retaining at that depth the original concentration of particles having settling velocities less than h/t. The taking of a small volume element by a pipette at a depth h at time t furnishes a sample from which all particles coarser than c (particle diameter as determined by Stokes' equation) have been eliminated, and in which all particles finer than that size are present in the same amount as initially. The volume element at depth h has, an effect, been "screened" by sedimentation, so that the ratio of the weight, w, of particles present in that volume at time t, divided by the weight of particles present in it initially, w0, is equal to P/100, where P is the percentage of particles, by weight, smaller than c. Now, the ratio, w/w0, can also be written as the concentration ratio, c/c0, giving c/c0 = P/100. This equation connects the concentration, c, of the pipette sample, in grams per liter, to the parameter P of the particle-size distribution, c0 being the weight of solids in the entire sample divided by the volume of the suspension. (Sheldrick and Wang, 1993).

The Bouyoucos hydrometer method is somewhat less accurate than the pipette method, but is easier to perform. The theory of the hydrometer method is similar to that of the pipette method except for the manner of determining the concentration of solids in suspension. Letting r represent the suspension density, rl the density of liquid, and rs the particle density, all in grams per liter, the equation with be as, r = rl + (c/1000)(1 - rl/rs). Although the buoyant force on a hydrometer is determined directly by the suspension density r, hydrometer scales can be calibrated in terms of c for particular values of rl and rs. The large size of hydrometer bulb necessary to give adequate sensitivity reduces the depth discrimination of the instrument, but this limitation can be overcome by a simple correction (Day, 1965).

Depending on the degree of accuracy of separation required, and the particle sizes of interest, the hydrometer method is well adapted for fast determinations of general categories of sizes.

Despite the lack of accuracy of hydrometer method for particle size measurement as reported by several researches, but up to the present time it is still the common methods use in Sudan. The objective of this study was to assess and compare the results of the particle size distribution obtained by the standard pipette and hydrometer methods in an attempt to confirm that if the hydrometer method is suitable and could be used to determine the soil texture for soils of Sudan or not.

2.Materials and Methods:

2.1 Soil sampling and characterization:

Twenty-six soil samples were collected from five soil profiles in central Sudan, which included; Gedaref zone (profile 1), Soba zone (profile 2), Wad Madani zone (profile 3), 1st and 2nd Nile River terraces (profiles 1 and 2) respectively. Each soil profile was fully described in the field following the format of the FAO (2006), guidelines of soil profile description, sampled according to genetic or pedogenic horizons and classified following the American system for soil classification (Soil survey staff, 2014a).

Each sample was kept in a cloth bag, labeled with; collected data, area, soil profile number, sample depth, then, subjected to the physico-chemical analyses at the soil laboratories in the University of Khartoum. Soil pH was determined in the saturated soil paste using a digital pH meter model (3510, Jenway) and the results were classified according to Marx and Stevens (1999). Electrical conductivity (EC) of the saturation extraction was determined by using a digital EC meter Model (4510, Jenway), and the results were compared according to the classification of Rhoades (1990) as a measure of soil salinity. The soil organic matter (SOM) was determined by using modified Walkley-Black method (Chapman and Pratt, 1961). Total P was determined using wet digesting method and the absorbance of the solutions were read colorimetric by using spectrophotometer model (Lambda EZ 150, PerkinElmer, USA) according to Olsen and Sommers (1982). Calcium carbonate content (% $CaCO_3$) was determined volumetrically using calcimeter according to Balázs *et al.* (2005). The CEC was determined according to Sparks (1996).

2.2 Hydrometer Method:

Samples were quantitatively for determined physical proportions by their settling rates in aqueous solution, where hydrometer was used for this purpose. Soil samples for soluble salts, organic matter were removed using D-sodium hexameta-phosphate (Day, 1965), temperature, and solution viscosity corrections were made, a hydrometer reading of a blank solution was taken for that correction.

2.3 Pipette Method:

The quality of each of the main sand, silt and clay fractions in each soil sample was determined; a 2 mm sieve was used to separate the present sand by wet sieving through a set of nested sieves. The silt and clay in each sample were determined by the pipette that measured the weight percent of sample method. (U.S Soil Salinity Laboratory Staff, 1954).

2.4 Statistical analysis:

Statistical differences between samples were determined using statistical analysis (Snedecor, 1965), using T-test with multiple samples where differences were calculated from various measurements. The means of these differences were obtained ($\bar{D}$), the deviation from each measurement was used to get the standard deviation (s_d). Then the T value was calculated from the equation below:

$$T = \frac{\bar{D}}{s_d}\sqrt{N}$$

Where:

T ≡ Calculated T value

$\bar{D}$ ≡ Means of differences.

s_d≡ Standard deviation.

N ≡ Number of samples

3. Results and Discussion

3.1 Morphological properties

The description of the studied sites and selected morphological properties of the representative soil profiles are presented in (Tables 1and 2), respectively. Profile 1, 2 and 3 were selected from Gedaref zone, Soba zone (Khartoum state), and Wad Madani zone (Gazera State), respectively. While, profiles 4 and 5 were selected from 1st and 2nd Nile River terraces, respectively. The parent materials of profiles 1 and 2 were alluvium/colluvium and old alluvium of the Blue Nile, respectively. Whereas the soil parent material of profiles 3, 4, and 5 were alluvium. Generally, all profiles sites were flat slope and were located inside agricultural zones, except for profile 2 which was located inside forest zone. The field soil texture of all profiles belongs to the five textural classes namely; loam, sandy clay loam, clay loam, silt clay and clay. All profiles showed angular/sub-angular blocky structure at the surface soil horizon and the lower horizons were massive. The quantity of roots in all soil profiles decreased with depth and the boundaries between horizons was generally diffused and smooth (Schoeneberger *et al.,* 2012).

Table 1: Selected site characteristics of the studied representative profiles

Profile No	Location	Coordinates		Parent material	Slope (%)	Land use
		Latitude	Longitude			
P1	Gedaref zone	14° 01"	35° 23"	Alluvium/Colluvium	Flat	Agric.
P2	Soba zone	15° 30"	32 ° 37"	Old alluvium of the Blue Nile	Flat	Forest
P3	Wad Madani zone	14° 23"	33° 29"	Alluvium	Flat	Agric.
P4	1st Nile river terrace	15° 39"	32° 31"	Alluvium	Flat	Agric.
P5	2nd Nile river terrace	15° 39"	32° 31"	Alluvium	Flat	Agric.

Table 2: Selected morphological properties of the representative profiles

Profile No.	Depth (cm)	Color (moist)	Texture[a] (field)	Structure[b]	Roots[c]	Boundary[d]	Diagnostic characteristics
P1	0-18	2.5Y 3/2	C	2fabk	1f	cw	Cracks up to 4 cm
	18-48	2.5Y 3/2	C	1fabk	1f	cw	Cracks at the base of the horizon
	48-80	2.5Y 3/2	C	1fsbk	1f	cw	Cracks up to 3 cm
	80-105	10YR 6/3	C	ma	1f	cw	Slickensides not clearly visible
	105-150	10YR 6/3	C	2csbk	1f	cw	-
P2	0-30	7.5YR 4/4	L	ma	2f	cs	-
	30-45	10YR 4/4	Cl	1msbk	2f	is	-
	45-107	10YR 4/3	C	2abk	2f	ds	-
	107-150	10YR 5/6	C	2sbk	-	ds	Slightly cemented
	0-27	2.5YR 3/2	Cl	2fabk	1f	cw	Cracks up to 4 cm
P3	27-56	2.5YR 3/2	C	1fabk	2f	cw	Cracks at the base of horizon
	56-84	2.5YR 3/2	C	1cabk	1f	iw	Cracks up to 2cm
	84-130	10YR 6/3	C	ma	1f	cw	-
	130-150	10YR 6/3	C	2csbk	2f	cw	-
P4	0-12	10YR 3/3	C	3fg	4f	cs	-
	12-48	10YR 3/3	Scl	1csbk	4vf	cw	-
	48-68	10YR 3/2	Scl	2abk	3vf	cw	Common krotovina
	68-86	10YR 3/3	Scl	ma	3vf	aw	-
	86-111	10YR 3/2	Scl	ma	3vf	cw	-
	111-150	10YR 3/3	Scl	ma	3vf	cw	-

P5	0-12	10YR 3/3	C	2sbk	3f	cs	Few cracks
	12-36	10YR 4/3	Sic	1msbk	1vf	cs	Few soft $CaCO_3$ aggregates
	36-57	10YR 3/3	C	1mabk	1vf	cs	Soft lime aggregates, common termites
	57-83	10YR 3/2	C	1abk	1f	cs	Soft $CaCO_3$, common krotovina
	83-111	10YR 3/2	C	ma	-	ws	Hard $CaCO_3$ concretion and $CaSO_4$
	111-150	10YR 3/2	C	ma	-	ws	Hard $CaCO_3$s concretion and $CaSO_4$

Texture[a]; C: clay; Scl: Sandy clay loam; Sic: silty clay; Cl: clay loamy; L: loam. Structure[b]; 1: weak; 2: moderate; 3: strong; f: fine; m: medium; c: coarse; sbk: subangular blocky; abk, angular blocky; ma: massive. Roots[c]; 1: very few; 2: few; 3; moderate; 4: common; f: fine; m: medium; c: coarse. Boundary[d]; a: abrupt; c: clear; d: diffuse; i: irregular; s: smooth; w: wavy.

3.2 Physico-chemical soil properties

The data in Table 3 shows maximum, minimum, and average values of selected physico-chemical soil properties of the studied representative profiles. The texture of the studied samples from profile 1 (Gadaref zone), profile 3 (Wad Madani zone) and profile 5 (2nd Nile river terrace) is dominantly by clay fraction and ranged from 49.8 to 65.9 %. In contrast, the texture of the studied samples at the Soba zone and 1st Nile river terrace was dominated by mixture of clay and sand fractions. Soil pH varied from alkaline to strongly alkaline (Marx and Stevens, 1999) with pH values ranged from 7.51 to 8.5. The EC values ranged from 0.3 to 22 dS m^{-1}, suggesting non-saline to extremely saline conditions at the different sites (Rhoades, 1990). The content of the calcium carbonate ($CaCO_3$) varied among the soil profiles and ranged from 3.99 to 34.58 %, suggesting slightly calcareous to strongly calcareous (FAO, 2006). Organic matter content and P content were low among all samples and their values ranged from (300 to 1000 mg kg^{-1}) and (3.8 to 6.8 mg kg^{-1}) respectively. The ESP values of samples from profiles 1 (Soba zone), profile 2 (Wad Madani zone) and profile 3 (2nd Nile river terrace) suggestion sodic/alkali conditions with average of 35.06, 24.08, and 45.42, respectively. Contrary to that, samples from Gedaref zone and 1st Nile river terrace showed slightly and non-sodic conditions with average ESP of 5.76 and 3.16, respectively. This could be due to higher leaching of the basic cations from these profiles as is expected especially during high precipitation at Gedaref zone and annual flooding at 1st Nile river terrace. These findings were in agreement with Sulieman *et al.* (2016). The highest CEC values were obtained in the soil samples at Gedaref zone, Wad madani zone, and Soba zone with average of 56.9 C mol+ kg^{-1}, 50.0 C mol+ kg^{-1}, and 44.3 C mol+ kg^{-1}, respectively. This may indicates domination of 2:1 clay minerals in these soils. Similar findings were reported by Sulieman *et al.* (2016). The CEC values in soil samples from 1st Nile River terrace showed higher values with an average of 31.32 C mol+ kg^{-1} as compared to 2nd Nile River values with an average of 6.31 C mol+ kg^{-1}, which is contrary to what is expected (increase in CEC content with distance from the River Nile). This could be due to the fact that soil profile from 1st Nile River terrace was in farm which receives organic matter as the result for the application of organic fertilizers (especially farm yard manure). Also, possible reason may due to falls of this profile within the concave site which receives water from runoff and flood. Recently, it has been reported that the clay content and CEC were significantly decrease from 1st River Nile terrace to the 3rd Nile terrace (Sulieman *et al.*, 2016).

Table 3: Maximum, minimum, and average values of some physico-chemical soil properties of the representative profiles

Profiles sites		Characteristics									
		Clay %	Silt %t	Sand %	pH	EC dSm^{-1}	$CaCO_3$ %	O. M $mg\ kg^{-1}$	P $mg\ kg^{-1}$	ESP	CEC C mol+ Kg^{-1}
Gedaref zone	Max	65.90	12.0	26.5	7.97	2.9	13.46	700	5.8	10.17	58.5
(Profile 1)	Min	62.50	10.8	22.1	7.80	0.7	7.47	300	3.8	2.66	55.9
	Average	63.94	11.3	24.8	7.88	1.65	9.55	500	4.92	5.76	56.9
Soba zone	Max	57.2	13.6	47.0	8.40	22.0	8.31	600	5.7	38.42	49.3
(Profile 2)	Min	39.5	12.1	30.2	8.17	3.2	6.42	300	4.3	32.23	35.1
	Average	50.75	12.8	36.5	8.25	12.68	7.52	400	5.15	35.06	44.33
Wad Madani zone	Max	63.3	13.7	36.5	8.35	8.7	9.32	600	6.3	34.52	55.2
(Profile 3)	Min	49.8	12.5	24.2	8.11	1.0	5.19	400	4.7	15.19	44.1
	Average	57.22	13.1	29.6	8.21	4.09	7.21	400	5.24	24.08	50.00
1st Nile river terrace	Max	54.4	14.6	59.7	8.14	0.7	5.2	1000	7.6	3.49	47.8
(Profile 4)	Min	26.3	14.0	31.0	7.51	0.3	3.99	700	4.7	3.03	22.9
	Average	35.67	14.1	50.2	7.96	0.65	4.42	800	5.68	3.16	31.32
2nd Nile river terrace (Profile 5)	Max	54.5	11.9	37.3	8.17	6.1	34.58	700	5.1	45.8	7.05
	Min	50.4	11.2	34.5	7.94	1.4	16.69	500	4.1	45.1	5.89
											6.31
	Average	51.78	11.5	36.8	8.07	3.44	25.08	600	4.87	45.42	

3.3 Differences in the soil particle size determined by the Pipette and hydrometer Methods

Statistical comparisons of the soil particle size results obtained by the different two methods are shown in Table 4, and the % of clay, silt and sand contents are presented in Table 5. Despite, the theory of hydrometer method results are similar to that of the Pipette method; however, we found that among all studied samples there is a significant difference in the clay and sand fractions, clay fraction determined by the Pipette and hydrometer methods in the soil samples from 1st and 2nd Nile River terraces respectively (Table 4). Reason for this deviation from trend when compared to the other studied samples is unknown, but may be related to differences in the soil parent material which are sediment annually. Similar results were mentioned by Sulieman and Sallam (2016). Consequently, the textural classes as determined by hydrometer method were disagreed from standard pipette method for 11 of 26 soil samples, which constitute about 42% of the total samples (Table 6). Therefore, the textural class of these samples must be avoided when used for soil classification. Previously, it has been reported that, the determination of soil texture as well the textural class must be performed only when the soil texture obtained using standard pipette or Bouyoucos-Days methods in order to be used for classification purpose (Miller *et al.,* 1988). The significant difference in the particle size fractions between the Pipette and hydrometer meter has been reported by many researches such as (Kettler *et al.,* 2001; Coates and Hulse 2012; and Beretta *et al.,* 2014) On the other hand, the differences in the soil texture obtained by the two methods has also been reported in the gypseous soils (Pearson *et al.,* 2014) and gypsiferrous soils (Sulieman and Sallam, 2016). Furthermore, Arriaga et al, (2006), reported that the pipette method is the standard method for determine soil particle size distribution because it is precise and reproducible. Contrast to that, Beverwijk (1967) suggested that the hydrometer can be used instead of the Pipette method only in cases where the pre-treatment of the sample completely destroys the SOM and a total dispersion of the sample is achieved. However, this method requires considerable time, but it is better to use it instead of hydrometer method. Moreover, pipette method is considered as standard method for calcareous and gypsiferous soil (Janitz, 1986).

Table 4: Statistical Comparison between the Pipette and hydrometer methods

Profiles zones	Texture	Tabulated T -value	Calculated T - value
Gedaref zone	Clay	5.598	3.387 N.S
(Profile 1)	Silt	5.598	1.000 N.S
	Sand	5.598	5.015 N.S
Soba zone	Clay	7.453	2.413 N.S
(Profile 2)	Silt	7.453	3.643 N.S
	Sand	7.453	5.731 N.S
Wad Madani zone (Profile 3)	Clay	5.598	4.488 N.S
	Silt	5.598	3.510 N.S
	Sand	5.598	4.341 N.S
1st Nile river terrace (Profile 4)	Clay	4.773	8.177 *
	Silt	4.773	2.850 N.S
	Sand	4.773	4.976 *
2nd Nile river terrace (Profile 5)	Clay	4.773	7.369 *
	Silt	4.773	2.591 N.S
	Sand	4.773	4.087 N.S

$^{N.S}$ ≡ Non –Significant

* ≡ Significant at $P < 0.05$

Table 5: Comparison between hydrometer method and Pipette method for PSD of the studied samples

Profiles zones	Depth (cm)	Hydrometer method			Pipette method		
		Clay	Silt	Sand	Clay	Silt	Sand
Gedaref zone	0 -18	63.7	11.2	25.1	65.9	12.0	22.1
	18 -48	59.9	11.2	28.9	63.1	11.5	25.4
	48 -80	60.8	10.9	28.3	63.1	11.2	25.7
	80 -105	62.4	10.5	27.1	62.5	11.0	26.5
	105 -150	62.5	10.7	26.8	65.1	10.8	24.1
Soba zone	0 -30	39.2	11.8	49.0	39.5	13.6	47.0
	30 -45	47.5	10.8	41.7	49.1	12.8	38.1
	45 -107	53.8	11.5	34.7	57.2	12.6	30.2
	107 -150	51.8	12.5	35.7	57.2	12.1	30.7
Wad Madani zone	0 -27	47.2	14.1	38.7	49.8	13.7	36.5
	27 -56	49.9	12.7	37.4	51.5	13.5	35.0
	56 -84	53.8	12.4	33.8	58.2	13.1	28.7
	84 -130	61.4	11.4	27.2	63.3	12.9	23.8
	130 -150	61.8	12.8	25.4	63.3	12.5	24.2
1st Nile river terrace	0 -12	53.4	14.6	32.0	54.4	14.6	31.0
	12 - 48	52.5	13.7	33.8	54.4	14.1	31.5
	48 - 68	24.3	13.5	62.2	26.3	14.1	59.6
	68 - 86	24.7	12.8	62.5	26.3	14.0	59.7
	86 -111	23.9	14.5	61.6	26.3	14.0	59.7
	111 -150	56.8	12.5	30.7	59.7	14.0	26.3
2nd Nile river terrace	0 -12	49.4	10.9	39.7	51.4	11.9	36.7
	12 -36	47.5	11.2	41.3	51.4	11.7	36.9

36 -57	49.2	10.7	40.1	51.4	11.5	37.1
57 -83	47.8	10.8	41.4	51.4	11.3	37.3
83 -111	48.9	14.5	36.6	51.4	11.3	37.3
111 -150	49.2	14.7	36.1	51.4	11.3	37.3

Table 6: Classification of soil textural class according to hydrometer and Pipette methods

Profiles zones	Depth (cm)	Textural class	
		Hydrometer method	Pipette method
Gedaref zone	0 -18	Clay	Clay
	18 -48	Clay	Clay
	48 -80	Clay	Clay
	80 -105	Clay	Clay
	105 -150	Clay	Clay
Soba zone	0 -30	Loam	Loam
	30 -45	Clay loam	Clay loam
	45 -107	Clay	Clay
	107 -150	Clay	Clay
Wad Madani zone	0 -27	Clay loam	Loam clay
	27 -56	Clay loam	Clay
	56 -84	Clay	Clay
	84 -130	Clay	Clay
	130 -150	Clay	Clay
1st Nile river terrace	0 -12	Clay	Clay
	12 - 48	Clay	Clay
	48 - 68	Sandy clay loam	Loam
	68 - 86	Sandy clay loam	Loam
	86 -111	Sandy clay loam	Loam
	111 -150	Clay	Clay

2nd Nile river terrace	0 -12	Clay loam	Clay
	12 -36	Clay loam	Clay
	36 -57	Clay loam	Clay
	57 -83	Clay loam	Clay
	83 -111	Clay loam	Clay
	111 -150	Clay loam	Clay

Plots of the depth means for the % clay, silt and sand contents in the all profiles sites of the hydrometer method against pipette method are shown in (Fig. 1 to 5). As shown in these figures the clay and silt fractions determined by the pipette method showed higher values in all studied samples as compared to hydrometer method. Contrary to that, the sand fraction values determined by hydrometer method were observed in all samples to be higher than those determined by the pipette method. This could be due to overestimation in sand fraction when determined by using hydrometer method. Overestimation in sand fraction has been reported by several researches such as (Norambuena *et al*., 2002; Beretta *et al.*, 2014).

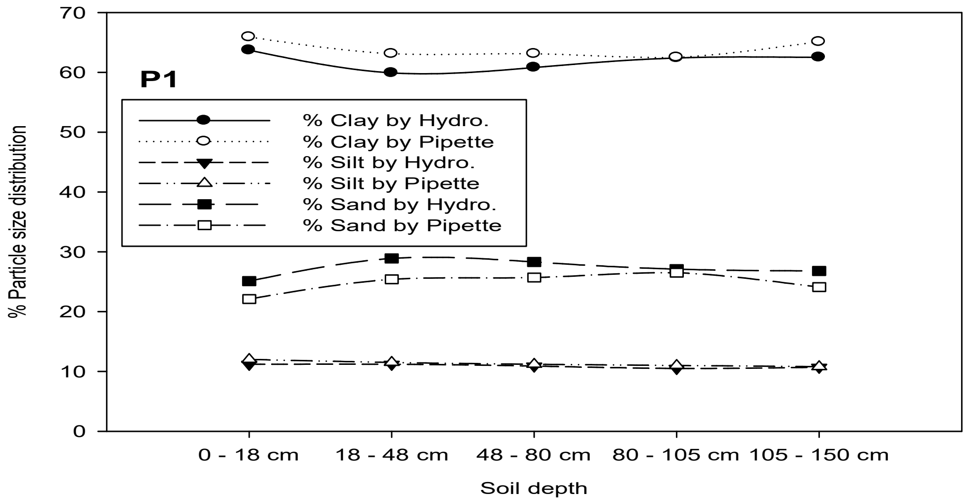

Fig. 1. Differences between clay, silt and sand fractions contents of the soil samples from profile No. 1 (Gedaref zone) measured by using hydrometer method and Pipette method.

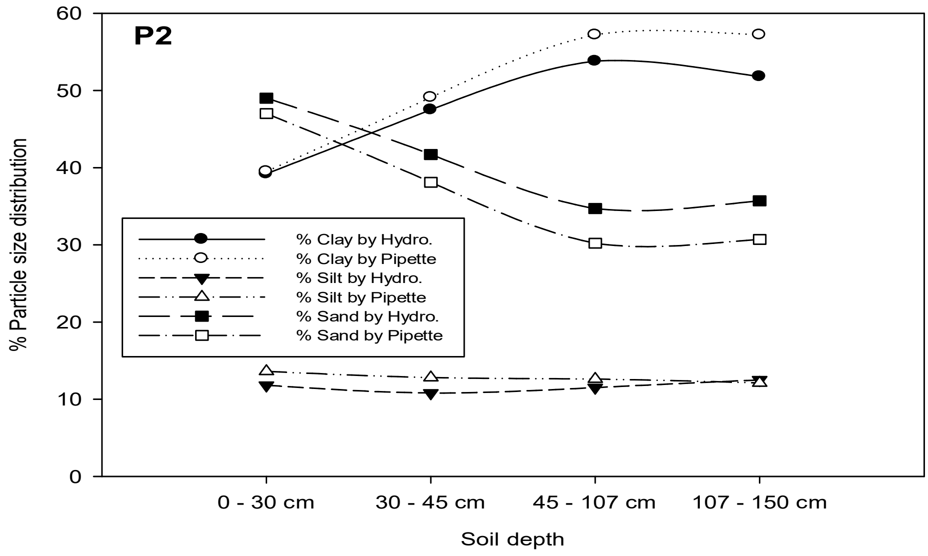

Fig. 2. Differences between clay, silt and sand fractions contents of the soil samples from profile No. 2 (Soba zone) measured by using hydrometer method and Pipette method.

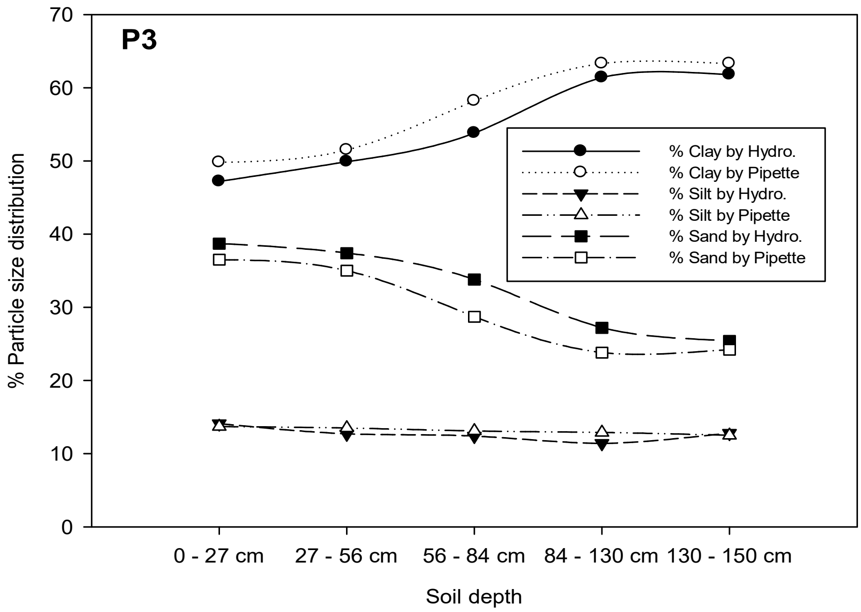

Fig. 3. Particle Differences between clay, silt and sand fractions contents of the soil samples from profile No. 3 (Wad Madani zone) measured by using hydrometer method and Pipette method.

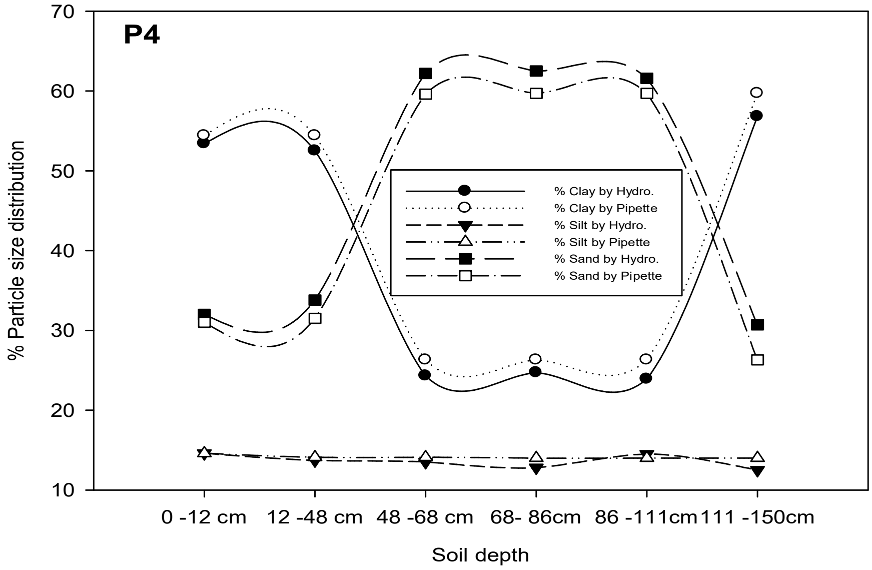

Fig. 4. Differences between clay, silt and sand fractions contents of the soil samples from profile No. 4 (1st Nile River terrace) measured by using hydrometer method and Pipette method.

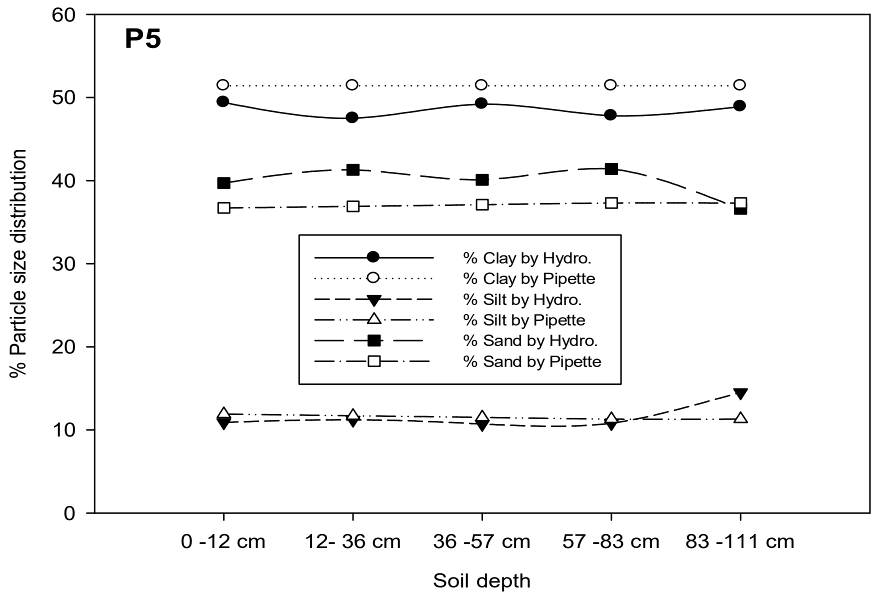

Fig. 5. Differences between clay, silt and sand fractions contents of the soil samples from profile No. 5 (2nd Nile River terrace) measured by using hydrometer method and Pipette method.

Figures 6 and 7 shows the regression of the results of hydrometer method against the pipette method for clay and sand fractions contents, respectively. Regression of clay content form the hydrometer against pipette methods revealed a high correlation between the two methods ($y = 1.008x + 1.969$, $r^2 = 0.99$). Meanwhile, the regression between the two methods for sand measurement also showed a high correlation ($y = 0.999x – 2.64$, $r^2 = 0.98$). Our findings were similar to that obtained by Kettler et al. (2001).

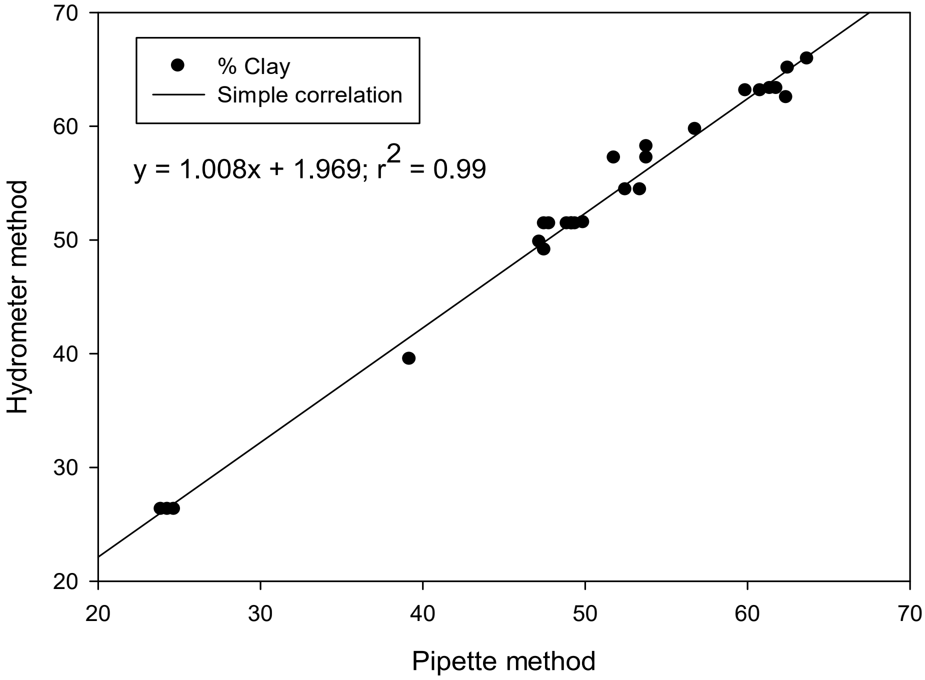

Fig. 6. Correlation between hydrometer method vs pipette method for determination of clay fraction. Each point pollted represents the % clay of all studied samples taken at each soil horizon.

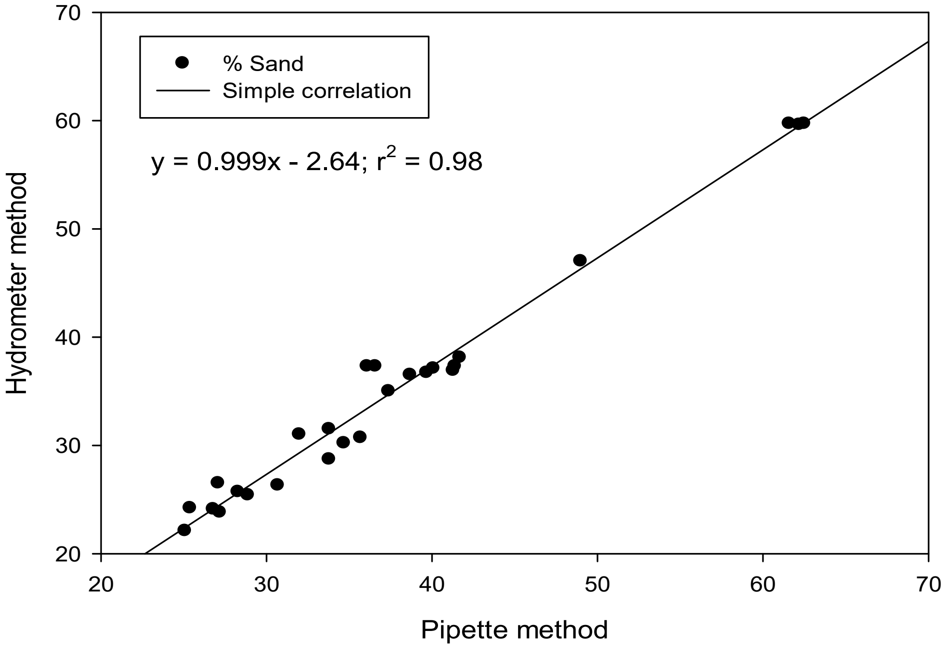

Fig. 7. Correlation between hydrometer method vs pipette method for determination of sand fraction. Each point pollted represents the % sand of all studied samples taken at each soil horizon.

4. CONCLUSIONS

After comparing the particle size distribution as well as soil texture obtained by the standard pipette method against hydrometer method, we concluded that; pipette method is consider accurate method for particle size destitution; however, there are many advantages when using hydrometer method for particle size distribution such as; it's easy to complete a lot of samples analysis without so much effort, no other chemicals are needed, no long waiting periods. In addition to that there is no significant difference between it and the standard pipette method in the most studied samples. Depending on our study results, we recommend that the particle size distribution determined by hydrometer method is suitable for the soils of Sudan.

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