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Assessment of the Origin, Formation and Uniformity of Some Soils, South of Rood El Farj - El Dabaa Road

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ABSTRACT

The current study aimed at the assessment of the nature of soil origin, formation and the degree of soil profile uniformity in the area located South of Rood El Farj - El Dabaa Road, north western desert of Egypt. The Sentinel-2A satellite image (2022) and the Digital Elevation Model (DEM) were used to identify the common landforms which are surface of El Diffa plateau, foot slope of plateau, residual hills, local depression, gravelly sand plain, sand sheets and sand dunes. Fifteen soil profiles were morphologically described and sampled and the statistical size parameters and mineralogical constituents of sand fraction were determined. The results obtained indicated that the soil are moderately sorted to poorly sorted, strongly coarse to fine skewed and very platy to very lepto kourtic; indicating the predominance of transportation and deposition of the soil materials within aqueous media. Regarding the mineralogical composition of sand fraction, quertz represents ≥ 90.5% of the light minerals, followed by feldspars (plagioclase, orthoclase and microcline). In addition, muscovite and calcite minerals were detected in minute number. Concerning the heavy minerals, opaques are the major fraction constituent. In connection with the complementary non-opaque minerals, the first abundance are unstable minerals of igneous origin followed by the ultra-stable index minerals (sedimentary origin minerals). Metastable origin minerals are found in palpable portions. The depth-wise distribution of the index minerals as well as the uniformity and weathering ratios change irregularly indicating that the soils are formed of multi-origin parent materials that are still poorly developed.

Keywords: Soil origin, soil formation, soil development, statistical parameter, light and heavy mineral.

1. Introduction

Land reclamation of desert regions is regarded as one of the strategic policies to subdue the problems related to the ever-increasing population in Egypt. The study area represents a part of one of the most encouraging areas for future development projects due to its strategic location, availability of ground water resources, good soil quality and ease of access via the Rood El-Faraj to El-Dabaa road.

The study area is located at the base of a paleo mega delta to the east of the Qattara Paleo Lake, about 50 km south of El Hamam city, and 95 kilometers from Alexandria (Map 1). It extends between latitudes 29°49' and 30°23' N and longitudes 29°16' and 29°52' E, where its altitude ranges from -2 m (below sea level) to 230 m (above sea level), occupying an area of about 688,000 feddan. The area falls under the arid climatic condition, where the total rainfall ranges between 3 and 6 mm/year.

Stratigraphically, many investigations signified that the study area is occupied with three main geological formations (Map 2), namely; Moghra formation (lower Miocene), El-Hagif formation (Pliocene) and sand sheet and sand dunes related to the Quaternary deposits, Shata (1953, 1955 and 1962), Said (1962 and 1990) El-Fayoumy (1964), Sanad (1973), Attia (1975), EGPC - Conoco Coral (1987) and Al-Sayyad (2018).

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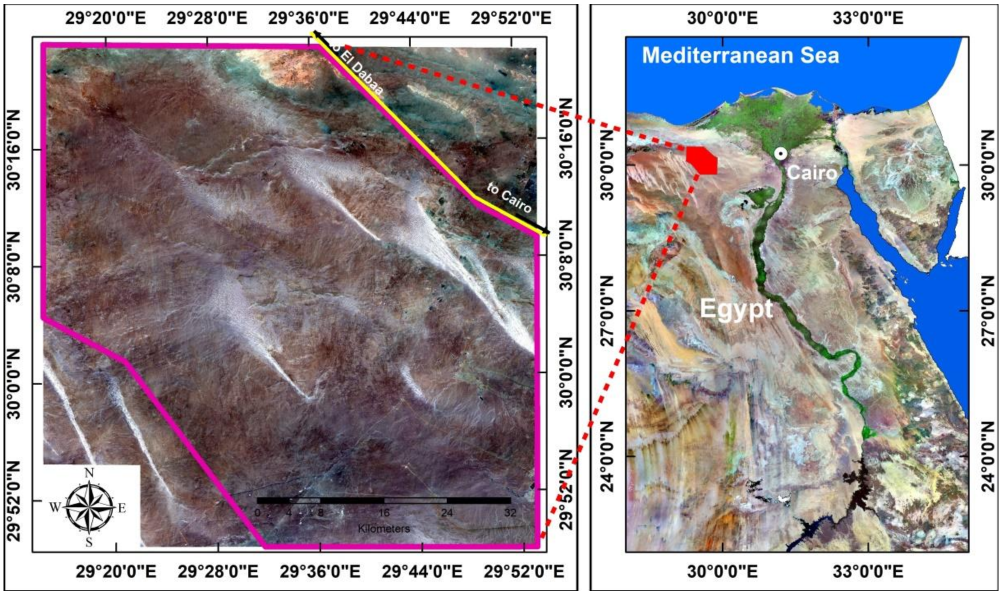
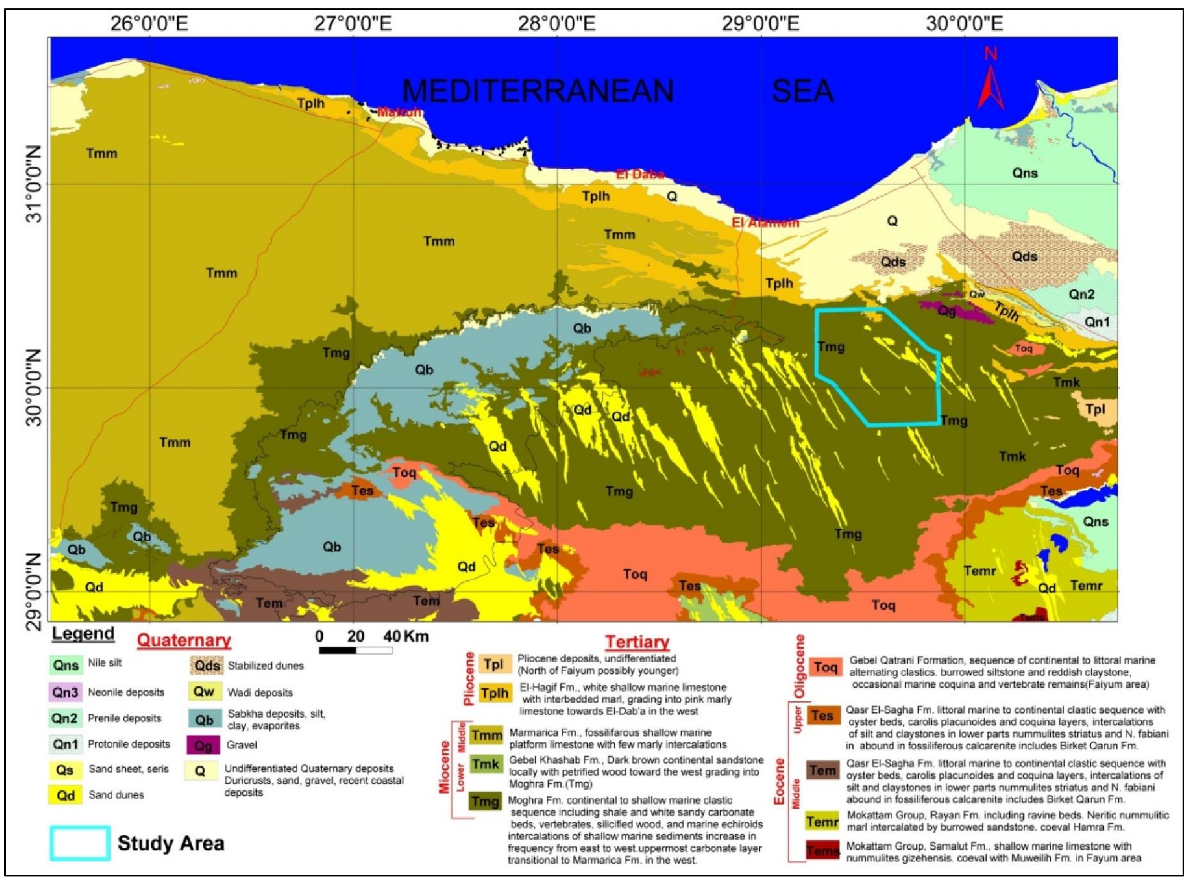
Geomorphologically, the study area could be distinguished into the paleo mega delta covered partially with sand dunes and sand sheets. Exceptional case in the north eastern corner which is occupied with El Diffa plateau, Shata (1955), Al-Sayyad (2018), Yousef *et al*. (2018). The paleo mega delta is thought to be an ancestral Nile delta (Abdel-Rahman and El-Baz, 1979).



Map 1: Location of the study area.



Map 2: Geological map of the study area and its vicinities (After EGPC -CONOCO, 1987).

Concerning the soils, DRC staff (2021) carried out regional and reconnaissance survey studies aiming at land evaluation and showed that the soils have a medium to coarse texture varying with depth, that may be attributed to the addition of either coarse deposits from the northern calcareous plateau (Marmarica formation - middle Miocene) and El-Hagif formation (Pliocene), or recent wind-blown sand (sand dunes and sand sheet), or finer detrital material from the erosion and weathering products of Moghra formation (continental to shallow marine clastic sequence, including shale and white sandy carbonate beds, vertebrates, silicified wood, and marine echiroids intercalations of shallow marine sediments).

The pedogenetic study is a trial to contribute and provide knowledge to help in planning for proper agricultural land use program of the desert land. Therefore it is rather essential to conduct it as a step to evaluate their capability.

Passega (1964) and Griffiths (1967) indicated that the grain size measurements were helpful in predicting the conditions of its formation. Pettijohn (1975) ascribed the different types of size frequency distribution to the difference factors, namely; the current velocity, turbulence, density and viscosity of transporting medium and the stability of the flow conditions.

With respect to the mineralogical analysis of the sand fraction, Adams and Matelski (1955) and Pettijohn (1975) referred to it as a useful guide to the source of rocks type of deposits. Brewer, (1960 and 1964) and Bear (1964) added that this analysis can be used as a tool in the assessment of soil profile uniformity and development as well as soil genesis. Birkeland (1974) indicated that several methods depend upon the presence of a specific mineral in measurable amounts. In this regard, this approach was used for a long time by a number of workers in different areas in Egypt (Philip *et al*., 1987; Noaman *et al*., 1988; Noaman, 1989; El-Shazly and Abdel Gaphour, 1990 and Noaman and Saadani, 1990).

Due to the lack of this approach in the study area, the present study aims to assess the genesis, origin, formation, and parent material uniformity of soils through integrated investigation including particle size distribution, statistical size parameters of sand fractions and mineralogical analysis of sand sub fraction. Also, it aims to assess the grade of soil development that may contribute to well think out planning understanding on how to deal with these soils for agricultural use.

2. Materials and Methods

2.1. Satellite images interpretation

To get hold of the objectives of this investigation, the Sentinel-2A satellite image captured in 2022, covering the study area (N0214_R107_T35RQM), (Band 12, 8, 4 with 10m spatial resolution), was obtained from the European Space Agency's (ESA) Copernicus Open Access Hub (https://scihub.copernicus.eu/dhus/#/home). The satellite image was merged and processed with Digital Elevation Model (SRTM-C) of 12.5 m spatial resolution retained from US Geological Survey (USGS) (http://earthexplorer.usgs.gov/), (Fig. 1). The merged image was prepared in ERDAS Imagine 16.5 software to identify the spatial distribution of the dominant landforms units and distribute the representative soil profiles sites of the common landforms (Map 3).

2.2. Soil sampling and laboratory and statistical analyses

Fifteen soil profiles representing the common landforms (Map 3) were morphologically examined and described according to FAO guidelines for soil profile description (FAO, 2006), (Table 1). Forty five soil samples, collected from each layers / genetic horizons were air-dried, ground with a wooden pestle in agate mortar, sieved through a 2 mm sieve and subjected to the following analyses:

- The physical and chemical analyses were performed by using Kellogg Soil Survey Laboratory Methods Manual (Soil Survey Staff, 2014), (Table 2).
- Particle size distribution was mechanically conducted by the dry sieving for the coarse fractions and by the pipette method for fine ones (Retsch 2009). The cumulative percentages of the obtained particle size distribution were plotted against their diameters in Phi units on arithmetic probability graphic by using Golden Software Grapher-15, where Phi= $-\log_2$ (d) (d is the diameter in mm), (Jackson, 1973) (Fig. 2).

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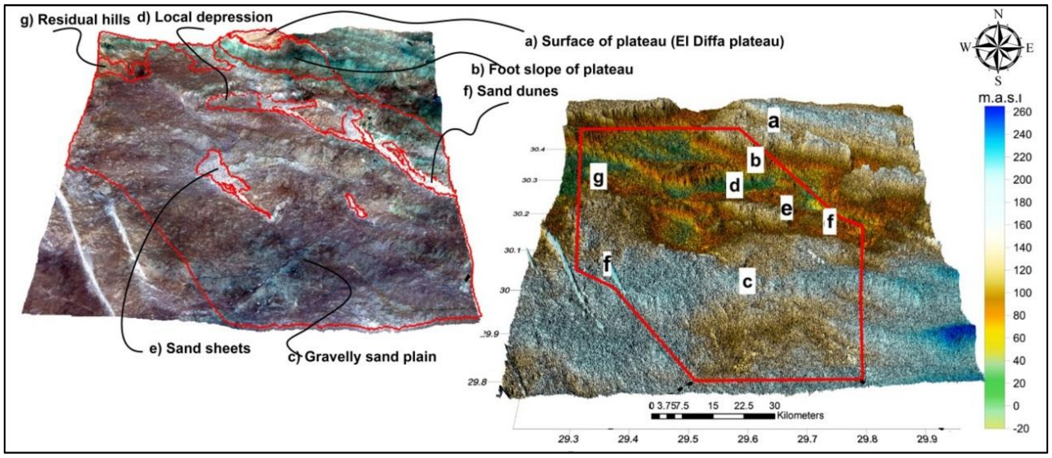


Fig. 1: Digital Elevation Model in 3-D view of the study area showing the main landforms.

From such curves, Phi-percentiles (the values of Φ_5, Φ_{16}, Φ_{25}, Φ_{50}, Φ_{75}, Φ_{84} and Φ_{95}) were extrapolated (Table 3). Based on these Phi-percentiles, the statistical size parameters mentioned by Folk and Ward (1957), namely; graphic mean size diameter (M_z), inclusive graphic standard deviation (sorting coefficient- δ), inclusive graphic skewness (SK) and graphic kurtosis (K_G) were calculated using the following equations (Table 3):

- Mean size (M_Z) = $\Phi_{16} + \Phi_{50} + \Phi_{84} / 3$
- Sorting coefficient (δ) = $(\Phi_{84} - \Phi_{16} / 4) + (\Phi_{95} - \Phi_5 / 6.6)$
- Skewness (SK) = $[\Phi_{84} + \Phi_{16} - 2\ \Phi_{50} / 2(\Phi_{84} - \Phi_{16})] + [\Phi_{95} + \Phi_5 - 2\ \Phi_{50} / 2(\Phi_{95} - \Phi_5)]$
- Kurtosis (K_G) = $(\Phi_{95} - \Phi_5) / 2.44\ (\Phi_{75} - \Phi_{25})$.

Then, the data were statistically evaluated according to Folk and Ward (1957) and Griffiths (1967) to determine the nature of soil depositional environment, soil mode of formation and agent and mechanism of transportation (Table 4).

- The mineralogical analysis of the sand sub fraction was carried out as follow: after removal of carbonates, gypsum, organic matter and sesquioxides (the ordinary treatments) (Soil Survey Staff, 2014), the sand sub fraction 125-250 µm was separated from each sample by dry sieving method (Carver, 1971). Separation of light and heavy minerals was carried out following the procedure described by Biswas and Mukherjee (2006). A separating funnel containing Bromoform (Sp. gr. 2.84 ± 0.02) as a heavy liquid was used. The separated minerals were washed several times with ethanol 95% then oven dried (Mange and Maurer, 1992). The index figure (weight ration of heavy to light minerals) was calculated (El-Demerdash *et al*., 2000). Mounting of the minerals was undertaken according to the method outlined by Karmakar (2014). About 500 grains of the light and heavy minerals were identified by the polarizing microscope (Galehouse, 1971), using a graduated mechanical stage for counting. Identification of the minerals was done using the optical properties as given by Milner (1962), Folk (1980) and Jay (2015). Percentages of the light and heavy minerals were calculated without taking opaques into account, (Cascalho *et al*., 2016).

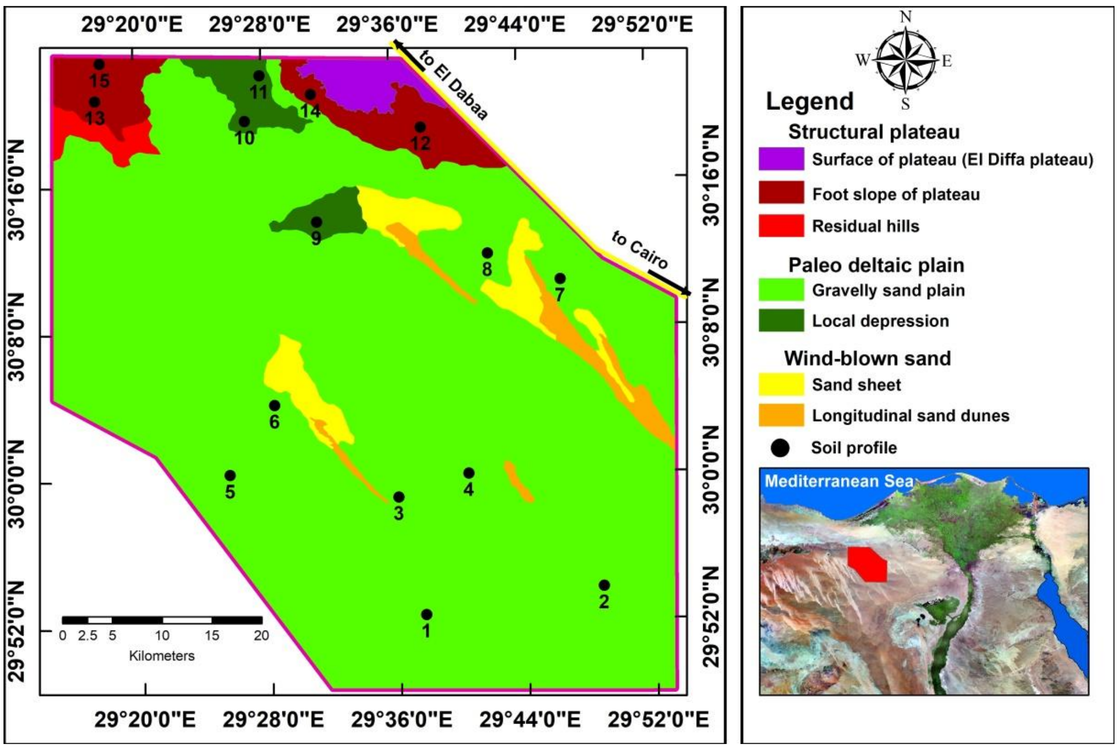
3. Results and Discussion

3.1. Geomorphology

Geomorphologically, the study area could be divided, based on satellite image, topographic and geologic maps, previous literatures, field observations and guided by visual interpretation of Digital Elevation Model (DEM) (Ragab, 2011) into three main geomorphic units in terms of both the surface form and the elevation namely; structural plateau, paleo deltaic plain and wind-blown sand. The structural plateau is classified into surface of El Diffa plateau, foot slope of plateau and residual hills. Paleo deltaic plain is divided into gravelly sand plain and small local depression. Wind-blown sand is appeared as accumulation in different forms of sand sheets and longitudinal sand dunes and could cover one or more of the referred landforms. The recognized landforms mentioned above matched with the previous studies conducted by El Shamy (1968), Said (1960, 1962, 2017), Hafiez (2011) and Al-Sayyad (2018). The spatial distribution of predominant landforms units is shown in map (3). It was considered a geo-base map in choosing the locations of the representative soil profiles.

Accordingly, fifteen soil profiles were selected to represent the soils formed on the main landforms units, which are:

Soils of the gravelly sand plain represented by profiles 1 to 8,
Soils of the local depression represented by profiles 9 to 11, and
Soils of foot slope of plateau represented by profiles 12 to 15.



Map 3: Main landforms and the representative soil profile locations in the study area.

3.2. Particle size distribution and soil texture

Data of particle size distribution of the different soil profiles are presented in table (2), which indicates that soil texture varies in the profiles representing the main landforms units and from one location to another within the same unit. The representative soil profiles of gravelly sand plain unit are mainly characterized by medium or coarse sand to slightly gravelly sand textures, while soil profiles of the local depression and foot slope of plateau have medium sand to slightly gravelly sand texture, except the surface layer, sub surface layer and deep layer of the profile Nos. 9, 11 and 14, respectively, where they have gravelly sand texture. The relatively coarse textured soils under study reveal the predominance of physical weathering which acts under arid climatic conditions of torric moisture regime and thermic temperature. Also, the mechanical weathering actions under storm and wind erosion are the main agents responsible for the variation in texture and size fraction from one location to another.

According to Buol *et al*. (2011), detection of lithological discontinuities is based on shifts in sand fraction percentages or abrupt shifts in silt and clay percentages in adjacent horizons. Data in tables (1 and 2) indicate that there are distinct layers in most soil profiles that vary largely in their texture and constituents. Formation of these distinct layers suggests variation in the conditions of deposition and, consequently, stratification is a common feature which characterizes the soils formed in the studied soils.

Table 1: Morphological features of the soil profiles representing the dominating landforms in the study area.

Topography	Profile No.	Depth (cm)	Color			Texture	Structure	Consistency			Lower boundary
			Hue	Dry	Moist			Dry	Stickiness	Plasticity	
Gravelly sand plain											
Gently undulating	1	0-30	10YR	7/4	6/4	Sand	Massive	Slightly hard	Non	Non	Clear
		30-90	10YR	7/4	6/4	Sand	Massive	Slightly hard	Non	Non	Diffuse
		90-150	10YR	7/4	6/4	Sand	Massive	Slightly hard	Non	Non	
Gently undulating	2	0-40	10YR	6/6	5/8	Sandy clay	Sub angular blocky	Slightly hard	Sticky	Plastic	Abrupt
		40-80	10YR	6/6	5/8	Sand	Massive	Hard	Non	Non	Abrupt
		80-150	10YR	8/4	7/4	Sand	Single grain	Loose	Non	Non	
Gently undulating	3	0-40	7.5YR	6/6	5/8	Sand	Massive	Slightly hard	Slightly	Slightly	Abrupt
		40-80	7.5YR	5/6	5/8	Sand	Single grain	Soft	Non	Non	Clear
		80-110	7.5YR	5/6	4/6	Sand	Massive	Hard	Non	Non	
Gently undulating	4	0-20	10YR	8/4	6/6	Sand	Single grain	Loose	Non	Non	Gradual
		20-80	10YR	7/4	6/6	Sand	Single grain	Loose	Non	Non	Gradual
		80-150	10YR	7/4	6/6	Sand	Single grain	Loose	Non	Non	
Gently undulating	5	0-30	7.5YR	7/6	5/6	Sand	Single grain	Soft	Non	Non	Abrupt
		30-70	10YR	6/6	5/6	Sand	Single grain	Soft	Non	Non	Clear
		70-150	10YR	6/8	5/8	Sand	Massive	Slightly hard	Non	Non	
Almost flat	6	0-50	10YR	6/6	5/6	Sand	Single grain	Loose	Non	Non	Abrupt
		50-75	10YR	6/4	5/4	Sandy clay loam	Massive	Soft	Slightly	Slightly	Abrupt
		75-150	10YR	7/3	6/4	Sandy clay loam	Massive	Soft	Slightly	Slightly	
Gently undulating	7	0-30	10YR	7/8	6/8	Sand	Single grain	Soft	Non	Non	Abrupt
		30-90	10YR	6/8	5/8	Sand	Single grain	Soft	Non	Non	Clear
		90-150	10YR	7/8	6/8	Sand	Massive	Slightly hard	Non	Non	
Gently undulating	8	0-50	10YR	7/4	5/6	Sand	Single grain	Loose	Non	Non	Abrupt
		50-100	10YR	7/6	5/6	Sand	Massive	Soft	Non	Non	Clear
		100-150	10YR	7/4	5/4	Sand	Massive	Soft	Non	Non	
Local depression											
Gently undulating	9	0-20	10YR	7/4	5/4	Gravelly sand	Massive	Soft	Non	Non	Abrupt
		20-70	10YR	8/2	7/3	Sand	Massive	Soft	Non	Non	Clear
		70-140	10YR	8/2	7/3	Sand	Single grain	Loose	Non	Non	
Gently undulating	10	0-30	7.5YR	7/6	5/6	Loamy sand	Massive	Soft	Slightly	Non	Clear
		30-100	10YR	8/3	7/3	Sand	Massive	Slightly hard	Non	Non	Clear
		100-150	10YR	8/2	7/3	Sand	Single grain	Loose	Non	Non	
Gently undulating	11	0-30	10YR	7/4	6/6	Sand	Single grain	Loose	Non	Non	Clear
		30-100	10YR	7/8	6/8	Gravelly sand	Massive	Hard	Non	Non	Clear
		100-150	10YR	7/8	6/8	Loamy sand	Massive	Very hard	Slightly	Non	
Foot slope of plateau											
Almost flat	12	0-50	10YR	7/6	6/6	Sand	Massive	Soft	Non	Non	Clear
		50-100	10YR	7/8	6/8	Sand	Massive	Slightly hard	Non	Non	Abrupt
		100-150	10YR	6/8	5/8	Sand	Massive	Hard	Non	Non	
Gently undulating	13	0-30	10YR	7/4	6/6	Sand	Massive	Soft	Non	Non	Abrupt
		30-80	10YR	8/4	7/4	Sand	Massive	Soft	Non	Non	Abrupt
		80-150	10YR	7/4	6/4	Sand	Massive	Slightly hard	Non	Non	
Almost flat	14	0-30	10YR	8/4	6/6	Sand	Massive	Soft	Non	Non	Abrupt
		30-70	10YR	7/4	6/6	Sand	Massive	Slightly hard	Non	Non	Abrupt
		70-120	10YR	7/4	6/6	Gravelly sand	Massive	Hard	Non	Non	
Undulating	15	0-40	10YR	7/6	6/6	Sand	Massive	Soft	Non	Non	Abrupt
		40-90	10YR	8/6	5/8	Sand	Massive	Slightly hard	Non	Non	Abrupt
		90-150	10YR	6/8	5/8	Sand	Massive	Hard	Non	Non	

Table 2: Some physio-chemical characteristics of the soil profiles representing the dominating landforms in the study area.

Profile No.	Depth (cm)	Gravel %	Particle size (mm) distribution%						Texture*	$CaCO_3$ %	pH	EC dS/m
			2-1	1-0.5	0.5-0.250	0.25-0.125	0.125-0.063	<0.063				
Gravelly sand plain												
	0-30	9.7	3.02	13.38	47.19	27.77	3.85	4.79	sl. gr. m. S	4.3	9.4	1.7
1	**30-90**	0.0	4.83	16.10	49.76	22.30	5.50	1.50	m. S	3.4	7.6	17.4
	90-150	0.0	1.05	8.07	54.96	31.52	2.27	2.13	m. S	2.8	7.9	4.6
	0-40	0.0	7.00	9.00	15.00	9.00	10.00	50.00	SC	4.9	8.1	7.6
2	**40-80**	0.0	11.12	11.30	14.96	38.51	20.36	3.75	f. S	4.2	7.9	7.0
	80-150	0.0	0.16	3.62	46.92	45.53	0.83	2.94	m. S	3.6	7.8	0.9
	0-40	8.8	7.37	22.74	26.62	26.75	15.99	0.53	sl. gr. c. S	12.5	9.5	0.4
3	**40-80**	10.2	7.33	26.90	36.43	23.80	2.35	3.20	sl. gr. c. S	6.7	8	4.7
	80-110	1.5	7.22	20.81	36.25	27.98	5.83	1.93	c. S	6.5	7.8	9.6
	0-20	5.7	13.30	6.86	17.42	40.84	12.83	8.75	sl. gr. f. S	3.4	9.2	0.1
4	**20-80**	3.4	3.66	19.76	54.79	17.42	3.62	0.74	sl. gr. m. S	3.4	9.9	0.3
	80-150	3.2	4.57	27.21	51.64	13.30	1.74	1.56	sl. gr. m. S	2.1	9.6	0.7
	0-30	5.6	9.82	21.75	22.25	27.65	17.57	0.95	sl. gr. c. S	8.0	9.8	0.5
5	**30-70**	3.3	17.67	47.39	22.28	8.38	1.30	2.98	sl. gr. c. S	6.8	8.4	2.0
	70-150	25.0	22.42	49.25	19.90	6.01	2.13	0.29	v. gr. c. S	5.3	8.8	1.6
	0-50	11.8	13.78	37.44	25.10	19.32	2.09	2.25	sl. gr.c. S	3.4	9.3	0.8
6	**50-75**	5.9	4.00	6.00	7.00	15.00	28.10	39.90	sl. gr. SCL	2.8	7.8	7.4
	75-150	0.0	5.00	7.00	10.00	15.00	18.00	45.00	SCL	1.5	7.4	3.0
	0-30	0.0	4.52	23.81	52.13	15.92	2.92	0.70	m. S	2.6	9.7	0.1
7	**30-90**	10.9	11.53	26.77	45.94	13.50	1.26	1.00	sl. gr. c. S	2.8	9.9	1.4
	90-150	0.0	8.92	48.23	30.78	9.69	2.11	0.26	c. S	2.6	9.6	0.2
	0-50	0.11	2.71	20.42	38.12	29.40	4.64	4.71	m. S	4.3	9.4	0.2
8	**50-100**	0.11	4.44	20.55	35.34	28.10	9.88	1.69	c. S	6.3	9.4	0.3
	100-150	0.11	7.83	17.33	29.37	28.76	11.43	5.28	c. S	6.3	9.5	0.5
Local depression												
	0-20	20.00	1.98	12.83	48.84	27.68	7.72	0.96	gr. m. S	5.6	9.8	0.3
9	**20-70**	0.00	0.68	7.04	49.67	38.50	1.71	2.40	m. S	4.3	9.8	1.0
	70-140	5.26	2.11	15.65	53.25	25.92	2.62	0.45	sl. gr. m. S	4.7	8.5	2.4
	0-30	3.8	5.93	23.91	38.09	19.92	10.29	1.86	sl. gr. c. S	8.4	8.8	0.5
10	**30-100**	0.0	1.08	5.14	21.79	55.41	15.38	1.20	f. S	6.3	9.4	0.8
	100-150	0.0	0.13	3.70	42.27	47.43	2.17	4.30	f. S	6.3	8.3	1.1
	0-30	2.50	8.90	32.30	29.11	18.97	9.94	0.78	sl. gr. c. S	6.8	9.5	0.1
11	**30-100**	25.00	5.44	8.67	20.99	53.85	5.85	5.21	gr. f. S	7.3	7.7	2.0
	100-150	4.29	2.10	2.66	3.76	75.21	12.67	3.60	sl. gr. f. S	7.2	9.2	1.5
Foot slope of plateau												
	0-50	0.0	0.61	9.98	77.38	8.28	0.56	3.19	m. S	5.3	8.9	0.1
12	**50-100**	0.0	0.20	5.35	86.71	5.82	1.66	0.26	m. S	5.3	8.1	0.6
	100-150	0.0	0.87	6.10	40.40	43.96	0.25	8.41	m. S	5.1	7.9	3.7
	0-30	1.3	3.87	20.48	55.16	17.28	2.64	0.57	m. S	6.3	9.1	0.1
13	**30-80**	3.3	10.36	33.46	37.52	16.97	0.49	1.20	sl. gr. c. S	5.7	8.9	0.5
	80-150	0.9	4.34	24.70	47.81	19.44	3.31	0.40	c. S	5.9	8.3	0.8
	0-30	3.13	8.43	11.92	26.06	34.55	10.49	8.55	sl. gr. m. S	6.0	8.9	0.1
14	**30-70**	5.56	21.41	11.27	20.70	28.10	16.84	1.69	sl. gr. c. S	6.4	9.1	0.4
	70-120	20.00	8.92	20.67	29.72	27.98	4.13	8.58	gr. c. S	5.3	8.9	0.8
	0-40	8.33	29.63	42.24	19.42	5.83	2.31	0.56	sl. gr. c. S	5.3	7.9	2.1
15	**40-90**	12.50	24.05	46.73	22.23	5.16	0.32	1.52	sl. gr. c. S	5.3	7.5	2.1
	90-150	7.69	19.82	54.31	19.75	4.71	1.05	0.36	sl. gr. c. S	5.3	7.6	2.4

* Texture: (f. S) fine Sand, (m. S) medium Sand, (c. S) coarse Sand, (sl. gr. f. S) slightly gravelly fine Sand, (sl. gr. m. S) slightly gravelly medium Sand, (sl. gr. c. S) slightly gravelly coarse Sand, (SCL) Sandy Clay Loam, (SC) Sandy Clay.

3.3. Nature of soil depositional environment and soil mode of formation

It is well known that soils are either inherited from the parent material (residual) or are originally transported or transported and mixed with residual material. Also, Statistical size measures serve as a guide in the explanation of the environment of deposition, soil mode of formation and agent of transportation. Inclusive graphic standard deviation (sorting coefficient, δ) as well as inclusive graphic skewness (SK) are not only helpful in assessing and describing soil sediments, but also indicating the differentiation and / or stratification of the soil materials. It is also known that the sediments transported by wind are usually well sorted, and those transported by water or weathered in situ are usually poorly sorted while the moderately sorted sediments suggest two means of transportation and deposition, i.e. water and wind (Inman, 1952). Moreover, Folk and Ward (1957) stated that sorting is a sinusoidal function of mean size, so the values increase with transport owing to the decrease in the mean size of sediments.

According to the above consideration and based on the obtained data of the statistical parameters presented in tables (3 and 4) and Fig. (2), it is evident that most of the soil samples of the studied profiles display a domination of medium size fraction, as the graphic mean values (M_z) range from 0.65 to 3.61, 1.40 to 2.58 and 0.65 to 2.05 for gravelly sand plain, local depression and foot slope of plateau, respectively.

Regarding the values of inclusive graphic standard deviation (δ) of the different soil samples, the data achieve a moderately to poorly sorted nature, as its values range from 0.58 to 1.98, 0.63 to 1.31 and 0.56 to 1.41 for gravelly sand plain, local depression and foot slope of plateau, respectively. These patterns suggest that there are two means of transportation and deposition, either mainly by water (aqueous environment) in the majority of the studied soils or by wind agent as a subsequent aeolian mean of processes of deposition of some areas at different landforms.

Concerning the values of inclusive graphic skewness (SK), the data indicate the wide variations in all the main landforms units of the current study, i.e. the range is strongly coarse skewed to fine skewed for soils of gravelly sand plain, and coarse skewed to fine skewed for both soils of local depression and foot slope of plateau. The abrupt changes in that statistical parameter within the studied soils suggest different cycles of deposition sharing in the soil formation of those landforms.

Regarding the graphic kurtosis (K_G) parameters, the data display the wide range of values; from 0.63 (very platy kurtic) to 1.98 (very leptokourtic). Taking into consideration the platy kurtic and very platy kurtic, values indicate that water is the main factor responsible for soil formation, while mesokourtic and leptokurtic values indicate the involvement of wind and water action in the formation of soils. Consequently, the aforementioned data led to the fact that the soils under consideration are mainly deposited by water action in the paleo time and recently, some small areas were covered by aeolian sand deposits.

3.4. Mechanism of transportation

In order to determine the mechanism of transportation of the soils parent materials, the median grain size values (The median grain size is the size such that 50 percent of the sample is coarser than this size) are obtained by intersecting the cumulative curve at the 50 percent and reading the diameters equivalent to these percentile values in Φ units and/or in microns (μm). The obtained data was presented in tables (3 and 4). They generally show moderate variations for the mechanism of transportation and are in a quite agreement with soil mode of formation. As for the transporting medium of the soil materials, the fine-grained sizes more than 4 Φ represent detritus transported in suspension, whereas the coarse-grained sizes less than 2 Φ represent detritus transported in traction. Overlap of the two trends occurs in the region 2 to 4 Φ representing saltation (Griffiths, 1967). Concerning the values of Φ_{50}, data display that the soil samples represent detritus transported by traction in aqueous medium as found in the majority of the studied soils of different landforms. On the other hand, some local areas constitute sediments are transported by saltation in aqueous medium as found in the deep layers of some soil profiles (6, 10 and 11).

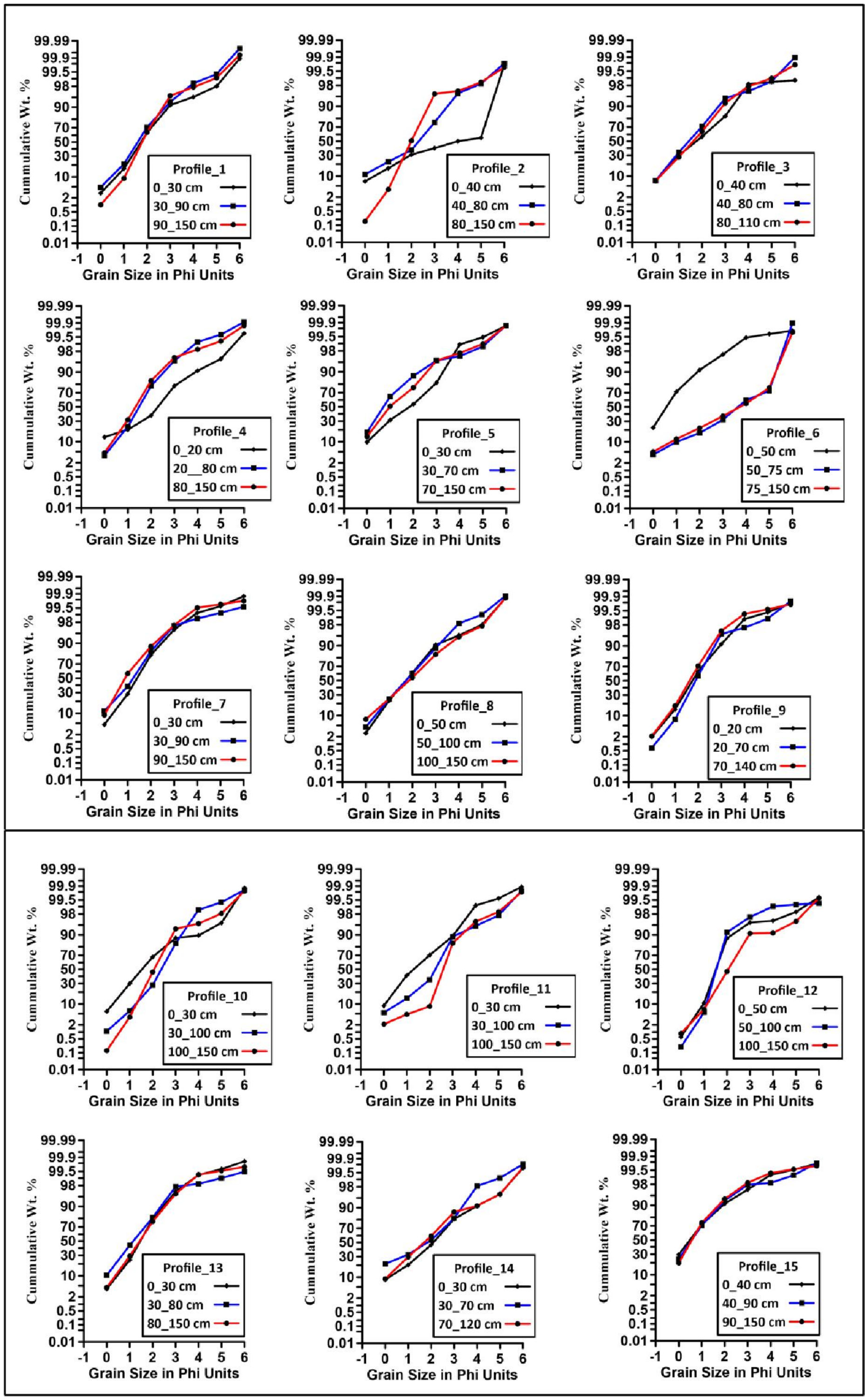


Fig. 2: Cumulative curves of the representative soil profiles.

Table 3: Statistical size parameters and percentile media size values of the soil profiles representing the dominating landforms in the study area.

Profile No.	Depth (cm)	Phi values							Statistical size parameters				Median (M) (µm)
		Φ_5	Φ_{16}	Φ_{25}	Φ_{50}	Φ_{75}	Φ_{84}	Φ_{95}	M_Z	δ	SK	K_G	
						Gravelly sand plain							
1	**0-30**	0.21	1.04	1.19	1.75	2.26	2.68	4.00	1.82	0.98	0.16	1.45	308.02
	30-90	0.06	0.83	1.11	1.61	2.15	2.51	3.29	1.65	0.91	0.05	1.27	362.19
	90-150	0.67	1.23	1.39	1.81	2.24	2.47	3.03	1.83	0.67	0.05	1.15	291.35
2	**0-40**	-0.26	0.94	1.60	3.99	5.23	5.34	5.58	3.42	1.98	-0.42	0.66	75.40
	40-80	-0.63	0.49	1.18	2.29	2.95	3.22	3.85	2.00	1.36	-0.31	1.03	214.81
	80-150	1.04	1.44	1.60	2.02	2.37	2.61	2.95	2.02	0.58	-0.01	1.02	248.72
3	**0-40**	-0.26	0.49	0.80	1.76	2.61	3.09	3.59	1.78	1.23	-0.01	0.87	312.77
	40-80	-0.10	0.43	0.78	1.44	2.08	2.42	3.14	1.43	0.99	0.02	1.02	395.66
	80-110	-0.10	0.54	0.96	1.65	2.29	2.61	3.43	1.60	1.05	-0.03	1.09	346.68
4	**0-20**	-1.82	0.41	1.41	2.29	2.93	3.40	4.86	2.03	1.76	-0.24	1.81	204.45
	20-80	0.25	0.75	1.02	1.47	2.00	2.29	3.01	1.50	0.80	0.09	1.15	374.00
	80-150	0.01	0.51	0.86	1.31	1.84	2.05	2.77	1.29	0.80	0.01	1.15	421.10
5	**0-30**	-0.70	0.40	0.78	1.84	2.70	3.10	3.52	1.78	1.31	-0.13	0.90	279.80
	30-70	-0.72	0.03	0.18	0.73	1.37	1.82	3.01	0.86	1.01	0.21	1.28	656.59
	70-150	-0.55	0.12	0.42	1.00	1.99	2.28	2.99	1.13	1.08	0.15	0.92	524.71
6	**0-50**	-0.32	-0.21	0.04	0.65	1.20	1.53	2.55	0.65	0.87	0.17	1.01	717.81
	50-75	0.18	1.94	2.52	3.68	5.04	5.20	5.45	3.61	1.61	-0.20	0.86	77.28
	75-150	0.09	1.50	2.19	3.74	4.93	5.15	5.42	3.46	1.72	-0.30	0.80	86.70
7	**0-30**	0.01	0.59	0.96	1.36	1.86	2.14	2.83	1.36	0.81	0.02	1.28	402.26
	30-90	-0.32	0.23	0.62	1.23	1.72	2.03	2.74	1.16	0.91	-0.06	1.14	444.65
	90-150	-0.35	0.23	0.42	0.84	1.50	1.78	2.55	0.95	0.83	0.20	1.10	552.97
8	**0-50**	0.20	0.78	1.06	1.70	2.36	2.69	4.04	1.72	1.06	0.13	1.21	293.93
	50-100	0.07	0.70	1.02	1.70	2.42	2.75	3.52	1.71	1.04	0.04	1.01	317.48
	100-150	-0.28	0.57	1.02	1.82	2.70	3.02	4.04	1.81	1.27	0.00	1.06	275.88
						Local depression							
9	**0-20**	0.37	1.05	1.32	1.77	2.37	2.70	3.32	1.84	0.86	0.09	1.15	311.20
	20-70	0.82	1.25	1.47	1.87	2.32	2.55	2.95	1.89	0.65	0.03	1.02	268.03
	70-140	0.37	0.92	1.15	1.60	2.10	2.30	2.82	1.61	0.71	0.01	1.06	346.53
10	**0-30**	-0.05	0.52	0.87	1.55	2.35	2.80	4.82	1.62	1.31	0.22	1.35	362.23
	30-100	0.87	1.52	1.92	2.37	2.80	3.07	3.57	2.32	0.80	-0.10	1.26	189.53
	100-150	1.10	1.45	1.65	2.07	2.50	2.67	4.02	2.06	0.75	0.16	1.41	244.48
11	**0-30**	-0.23	0.30	0.60	1.25	2.22	2.65	3.37	1.40	1.13	0.19	0.91	436.80
	30-100	-0.08	1.12	1.60	2.20	2.67	2.85	4.02	2.05	1.05	-0.18	1.56	220.93
	100-150	1.10	2.17	2.30	2.57	2.87	3.00	3.87	2.58	0.63	-0.02	1.98	169.91
						Foot slope of plateau							
12	**0-50**	0.70	1.07	1.22	1.50	1.80	1.97	2.92	1.51	0.56	0.17	1.59	370.08
	50-100	0.97	1.17	1.30	1.55	1.75	1.87	2.50	1.53	0.56	0.09	1.39	362.23
	100-150	0.82	1.35	1.57	2.05	2.52	2.75	4.69	2.05	0.94	0.18	1.67	236.63
13	**0-30**	0.12	0.75	1.02	1.47	1.95	2.20	2.85	1.47	0.77	0.00	1.21	397.55
	30-80	-0.10	0.25	0.57	1.15	1.82	2.10	2.70	1.16	0.89	0.07	0.92	460.35
	80-150	0.00	0.60	0.92	1.40	1.95	2.30	2.95	1.43	0.87	0.05	1.18	397.55
14	**0-30**	-0.08	0.75	1.20	2.07	2.82	3.22	4.82	2.01	1.36	0.03	1.24	232.71
	30-70	-0.10	-0.28	0.30	1.87	2.72	3.07	3.64	1.56	1.40	-0.17	0.63	271.96
	70-120	-0.43	0.42	0.85	1.65	2.50	2.90	4.77	1.66	1.41	0.11	1.29	322.98
15	**0-40**	-0.78	-0.43	-0.10	0.50	1.15	1.60	2.55	0.56	1.01	0.16	1.09	783.49
	40-90	-0.60	-0.18	0.05	0.57	1.17	1.55	2.40	0.65	0.88	0.17	1.09	718.07
	90-150	-0.78	-0.08	0.17	0.60	1.05	1.42	2.27	0.65	0.84	0.10	1.43	711.53

Table 4: Summary of the indication of statistical size parameters and mechanism of transportation.

Profile No.	Depth (cm)	Mean size (M_{Z})	Sorting (δ)	Skewness (SK)	Kurtosis (K_G)	Mechanism of transportation
				Gravelly sand plain		
1	**0-30**	m.S	Moderately sorted	Fine skewed	Leptokurtic	Traction
	30-90	m.S	Moderately sorted	Near symmetrical skewed	Leptokurtic	Traction
	90-150	m.S	Moderately sorted	Near symmetrical skewed	Leptokurtic	Traction
2	**0-40**	v.f.S	Poorly sorted	Strongly coarse skewed	Very platykurtic	Saltation
	40-80	m.S	Poorly sorted	Strongly coarse skewed	Mesokurtic	Saltation
	80-150	f.S	Moderately sorted	Near symmetrical skewed	Mesokurtic	Saltation
3	**0-40**	m.S	Poorly sorted	Near symmetrical skewed	Platykurtic	Traction
	40-80	m.S	Moderately sorted	Near symmetrical skewed	Mesokurtic	Traction
	80-110	m.S	Poorly sorted	Near symmetrical skewed	Mesokurtic	Traction
4	**0-20**	f.S	Poorly sorted	Coarse skewed	Very leptokurtic	Saltation
	20-80	m.S	Moderately sorted	Near symmetrical skewed	Leptokurtic	Traction
	80-150	m.S	Moderately sorted	Near symmetrical skewed	Leptokurtic	Traction
5	**0-30**	m.S	Poorly sorted	Coarse skewed	Platykurtic	Traction
	30-70	c.S	Poorly sorted	Fine skewed	Leptokurtic	Traction
	70-150	m.S	Poorly sorted	Fine skewed	Mesokurtic	Traction
6	**0-50**	c.S	Moderately sorted	Fine skewed	Mesokurtic	Traction
	50-75	v.f.S	Poorly sorted	Coarse skewed	Platykurtic	Saltation
	75-150	v.f.S	Poorly sorted	Strongly coarse skewed	Platykurtic	Saltation
7	**0-30**	m.S	Moderately sorted	Near symmetrical skewed	Leptokurtic	Traction
	30-90	m.S	Moderately sorted	Near symmetrical skewed	Leptokurtic	Traction
	90-150	c.S	Moderately sorted	Near symmetrical skewed	Mesokurtic	Traction
8	**0-50**	m.S	Poorly sorted	Near symmetrical skewed	Leptokurtic	Traction
	50-100	m.S	Poorly sorted	Near symmetrical skewed	Mesokurtic	Traction
	100-150	m.S	Poorly sorted	Near symmetrical skewed	Mesokurtic	Traction
				Local depression		
9	**0-20**	m.S	Moderately sorted	Near symmetrical skewed	Leptokurtic	Traction
	20-70	m.S	Moderately sorted	Near symmetrical skewed	Mesokurtic	Traction
	70-140	m.S	Moderately sorted	Near symmetrical skewed	Mesokurtic	Traction
10	**0-30**	m.S	Poorly sorted	Fine skewed	Leptokurtic	Traction
	30-100	f.S	Moderately sorted	Coarse skewed	Leptokurtic	Saltation
	100-150	f.S	Moderately sorted	Fine skewed	Leptokurtic	Saltation
11	**0-30**	m.S	Poorly sorted	Fine skewed	Mesokurtic	Traction
	30-100	f.S	Poorly sorted	Coarse skewed	Very leptokurtic	Saltation
	100-150	f.S	Moderately sorted	Near symmetrical skewed	Very leptokurtic	Saltation
				Foot slope of plateau		
12	**0-50**	m.S	Moderately sorted	Fine skewed	Very leptokurtic	Traction
	50-100	m.S	Moderately sorted	Near symmetrical skewed	Leptokurtic	Traction
	100-150	f.S	Moderately sorted	Fine skewed	Very leptokurtic	Saltation
13	**0-30**	m.S	Moderately sorted	Near symmetrical skewed	Leptokurtic	Traction
	30-80	m.S	Moderately sorted	Near symmetrical skewed	Mesokurtic	Traction
	80-150	m.S	Moderately sorted	Near symmetrical skewed	Leptokurtic	Traction
14	**0-30**	f.S	Poorly sorted	Near symmetrical skewed	Leptokurtic	Saltation
	30-70	m.S	Poorly sorted	Coarse skewed	Very platykurtic	Traction
	70-120	m.S	Poorly sorted	Fine skewed	Leptokurtic	Traction
15	**0-40**	c.S	Poorly sorted	Fine skewed	Mesokurtic	Traction
	40-90	c.S	Moderately sorted	Fine skewed	Mesokurtic	Traction
	90-150	c.S	Moderately sorted	Near symmetrical skewed	Leptokurtic	Traction

3.5. Soil genesis and origin

The study of the soil genesis and parent material origin is of a prime step to distinguish and release the soil forming processes and their intensities. One of the concepts that may be recommended as a criterion for this respect is the mineralogical composition of sand fraction as assemblage of mineral frequencies and ultra-stable ratios for soil origin (Haseman and Marshall, 1945 and Barshad, 1964). Several investigators emphasized the importance of the heavy minerals (sp.gr.> 2.84) in identifying the soil origin, among them, Mitchell (1975), Folk (1980), Mange and Maurer (1992).

3.5.1. Light minerals

In the light of data illustrated in table (5), it is worthy to mention that the assemblage frequency of light minerals (sp.gr. < 2.84) identified in sand fraction of the soils under study are mainly composed of normal quartz, which constitutes a 83.4 to 94.6 % and undulose quartz in minute quantities (1.7 to 7.2 %). The quartz grains are predominantly present as single grains in different degrees of roundness and stained yellow by ferrugination material. Considering the distribution of quartz with depth, data show that the distribution pattern is almost similar within each profile and even in all the profiles studied. The predominance of normal quartz over other members of light fraction is a common indication of acidic plutonic parent rocks (mainly granitic rocks).

Data also show that other associated light minerals such as feldspars constitute only about 2 to 8.5 % of the light minerals. The members of feldspars can be arranged in the order of their abundance as plagioclase, orthoclase and microcline. The vertical distribution of these minerals and undulose quartz mineral shows a general increase trend with depth. This is well marked in soils formed from the recent and old alluvial sediments. Since undulose quartz grains are generally indicative of a metamorphic and igneous source rocks.

Also, the presence of feldspars could be taken as an indication of the weathering prevailing during soil formation which was not so drastic to cause a complete decay of feldspars minerals susceptible to weathering.

In addition, other minerals such as calcite and muscovite are detected and found to be equal or less than 2.0% in this fraction.

3.5.2. Heavy minerals

In the following a concise description of the frequency distribution of the heavy minerals recorded (opaques and non-opaques) of representative soil profiles for different landforms units as well as their distribution throughout the entire depth of each profile will be discussed in the same order of abundance as shown in table (6).

3.5.2.1. Opaque minerals

Data in table (6) show that the opaque minerals are generally the most abundant minerals in all the examined soils. They include hematite, magnetite and ilmenite. Their values vary over a limited range in the different landforms units, being 54.8 – 64.3%, 51.5 – 65.2% and 54.3 - 63.5% for gravelly sand plain, local depression and foot slope of plateau, respectively. Concerning the pattern of opaque distribution with depth, no specific trend in the studied profiles could be observed. Also, the occurrence of iron oxides in a pronounced content may have stress on the possibilities of enrichments from a basement source rock (Awadalla, 1998).

3.5.2.2. Non-Opaque minerals

Data in table (6) show also that the unstable minerals (pyroxenes, amphiboles and epidotes) dominate the non-opaque minerals in most of the studied samples followed by ultrastable minerals (zircon, rutile and tourmaline). However, the metastable minerals (staurolite, garnet, andalusite, sillimanite and kyanite) are detected in palpable portions.

To demonstrate the individual members of mineral groups of non-opaques and their frequency distribution, the results and discussion are presented under the following sub-headings:

3.5.2.2.1. Unstable minerals

Pyroxenes, amphiboles and epidotes constitute the unstable minerals which can be weathered and decay easily than other non-opaque minerals.

a) Pyroxene group: Pyroxenes are represented mainly by augite with less hyperthene and dioposide. Augite is present as yellowish green, greenish yellow, prismatic with sub-rounded edges. The relative high values of pyroxenes are recorded in the local depression followed by foot slope of plateau, while lower content is present in gravelly sand plain unit. Pyroxenes, in general, are recorded with considerable amounts in all the examined samples (ranging from 16.1 to 59.1% with an average of 36.4% of total non-opaqus).

As for pyroxene distribution with depth, table (6) shows an irregular distribution with depth in most soil profiles, however, a tendency for increase is noticed at the surface layers of some soil profiles Nos, (3, 7, and 8) representing the gravelly sand plain and local depression. Meanwhile, the nature of parent material, as well as the sedimentation regime seems to be the prime cause of such distribution.

b) Amphiboles group: Amphiboles are commonly associated with pyroxene, having the same mode of distribution in different units but with low quantities (ranging from 2.7 to 12.4% with an average of 9.2%. The dominant variety in the study area is hornblende followed by actinolite and/or glaucophane.

Three varieties of hornblende were recognized by the microscopic investigation. They show in a descending order: olive green, bluish green and dirty bottle green. Hornblende occurs as prismatic and tabular grains with rounded to sub-rounded edges.

c) Epidotes group: Epidotes are recorded in most of the examined samples (ranging from 0.0 to 4.1% with an average of 2%). They are mainly represented by pistachite. The pistachite grains are pale green, yellowish green and brownish yellow in color. In addition, the grains are sub-rounded to nearly rounded edges in shape. Soil profiles of foot slope of plateau comprise the least content of epidotes among the different landforms units.

In view of the above, pyroxenes and amphiboles are chemically unstable in sediments and they dissolve at an early stage of soil formatin. Therefore, they are found only in either well-sealed ancient sediments or in younger deposits, but in both cases they are valuable indicators of origin (Mange and Maurer, 1992).

3.5.2.2.2. Ultrastable minerals (Index minerals)

They include zircon, rutile and tourmaline minerals and are named ultrastable or index minerals because of their resistance to weathering processes (Folk, 1980). These minerals represent one of the major constituents of the non-opaque minerals, but they are less abundant than unstable minerals (i.e., Pyroxenes, amphiboles and epidotes) and have a wide range in the study area (Table 6). The high percentages of these minerals are present in local depression unit followed by foot slope of plateau unit, while the lowest percent is present in gravelly sand plain unit.

a) Zircon: It is present as colorless, pale gray and has high relief bipyramidal and pyramidal termination with inclusions. However, some sub-rounded grains without inclusions are present. It's percent ranges from 5.8 to 42.3% with an average of 20% of the total non-opaques). The vertical distribution of the ultrastable mineral zircon indicates no consistent pattern, thus indicating discontinuity of zircon contents with depth. This reflects the multi - origin of parent material or its multi - depositional course or both.

b) Rutile: Its grains are mostly red or reddish brown in color with irregular sub rounded form. It is considered as the second abundant ultrastable minerals in most of the studied soil profiles (2.7 - 15% with an average of 8% of the total non-opaques). The distribution of rutile does not portray any specific pattern throughout the entire depth. The apparent discontinuity in the mineral distribution could be explained on the premise that the soils studied have multi-origin, i.e., are derived from multi parent material and / or show variation associated with depositional regime.

c) Tourmaline: It is characterized by different colours, e.g. pale brown, yellowish brown, green brown, yellowish green and green. However, pale brown and yellowish brown are the most common varieties. It occurs in form of prismatic grains having rounded edges and characterized by strong pleochroism. Tourmaline represents the third abundant ultrastable minerals in most of the studied samples (1.8% to 5.3% with an average of 3.1% of the total non-opaques). The mineral shows different irregular patterns of distribution downward the soil profiles.

Table 5: Frequency distribution of light minerals (%) in the sand sub fraction of the soil profiles representing the dominating landforms in the study area.

Profile No.	Depth (cm)	Quartz			Feldspars				Others
		Normal	Undulose	Total	Plagioclase	Orthoclase	Microcline	Total	Mus. + Cal
Gravelly sand plain									
1	**0-30**	92.4	3.1	95.5	1.5	0.75	0.25	2.5	2
	30-90	88.7	4.8	93.5	3	1.5	0.5	5	1.5
	90-150	84.3	6.7	91	4.2	2.1	0.7	7	2
2	**0-40**	94.6	1.4	96	1.5	0.75	0.25	2.5	1.5
	40-80	88.9	4.1	93	3.3	1.65	0.55	5.5	1.5
	80-150	86.3	4.7	91	4.8	2.4	0.8	8	1
3	**0-40**	89.2	5.8	95	2.1	1.05	0.35	3.5	1.5
	40-80	89.5	3.5	93	3	1.5	0.5	5	2
	80-110	87.9	4.1	92	3.96	1.98	0.66	6.6	1.4
4	**0-20**	91	5	96	1.44	0.72	0.24	2.4	1.6
	20-80	85.5	6.5	92	3.6	1.8	0.6	6	2
	80-150	84.9	6.6	91.5	4.5	2.25	0.75	7.5	1
5	**0-30**	91.5	3	94.5	2.46	1.23	0.41	4.1	1.4
	30-70	88.4	4.6	93	3.6	1.8	0.6	6	1
	70-150	86.3	4.7	91	4.8	2.4	0.8	8	1
6	**0-50**	91.8	4.7	96.5	1.8	0.9	0.3	3	0.5
	50-75	88.5	5.5	94	2.7	1.35	0.45	4.5	1.5
	75-150	86	6	92	3.6	1.8	0.6	6	2
7	**0-30**	89	5	94	2.4	1.2	0.4	4	2
	30-90	85.8	6.2	92	3.9	1.95	0.65	6.5	1.5
	90-150	83.4	7.1	90.5	4.8	2.4	0.8	8	1.5
8	**0-50**	88.3	4.7	93	3.6	1.8	0.6	6	1
	50-100	87.9	5.6	93.5	3.3	1.65	0.55	5.5	1
	100-150	84.9	6.1	91	4.5	2.25	0.75	7.5	1.5
Local depression									
9	**0-20**	91	4.2	95.2	1.98	0.99	0.33	3.3	1.5
	20-70	88.4	5.1	93.5	3	1.5	0.5	5	1.5
	70-140	91.4	3.5	94.9	2.46	1.23	0.41	4.1	1
10	**0-30**	92.4	3.8	96.2	1.68	0.84	0.28	2.8	1
	30-100	92.4	4.1	96.5	1.2	0.6	0.2	2	1.5
	100-150	88.8	6.2	95	1.8	0.9	0.3	3	2
11	**0-30**	89.3	6.5	95.8	1.32	0.66	0.22	2.2	2
	30-100	90.9	3.7	94.6	2.34	1.17	0.39	3.9	1.5
	100-150	88.2	4.4	92.6	3.78	1.89	0.63	6.3	1.1
Foot slope of plateau									
12	**0-50**	84.2	7.2	91.4	4.56	2.28	0.76	7.6	1
	50-100	83.7	6.9	90.6	5.04	2.52	0.84	8.4	1
	100-150	86.2	4.7	90.9	4.56	2.28	0.76	7.6	1.5
13	**0-30**	86.2	6.8	93	3.3	1.65	0.55	5.5	1.5
	30-80	87.8	3.1	90.9	4.86	2.43	0.81	8.1	1
	80-150	87.1	3.9	91	5.1	2.55	0.85	8.5	0.5
14	**0-30**	91.8	4.2	96	1.8	0.9	0.3	3	1
	30-70	90	4.5	94.5	2.1	1.05	0.35	3.5	2
	70-120	90.9	4.1	95	2.1	1.05	0.35	3.5	1.5
15	**0-40**	90.4	5.6	96	1.5	0.75	0.25	2.5	1.5
	40-90	91.2	4.8	96	1.8	0.9	0.3	3	1
	90-150	88.3	6.7	95	2.4	1.2	0.4	4	1

Table 6: Frequency distribution of heavy minerals (%) in the sub sand fraction of the soil profiles representing the dominating landforms of the study area.

Profile No.	Depth (cm)	Opaque	Non-Opaque minerals as 100%														
			Unstable Minerals				Ultrastable (Index) Minerals				Metastable Minerals						Biotite and others
			Pyroxenes	Amphiboles	Epidotes	Total	Zircon	Rutile	Tourmaline	Total	Staurolite	Garnet	Andalusite	Sillimanite	Kyanite	Total	
Gravelly sand plain																		
1	**0-30**	56.2	29.9	9.9	2	41.8	27	8.2	2.5	37.7	5.4	4.9	3.7	2.1	1.6	14.7	2.8
	30-90	56.9	36.4	6.4	1.8	44.6	21.6	11	3.2	36	4	4.5	3.2	2.3	2.7	16.7	2.7
	90-150	54.8	33.3	8.5	2	43.8	24.3	9	3.7	37	4	3.6	4	3.6	2.8	18	4.8
2	**0-40**	62.5	32.1	9	4.1	45.2	10.1	5.5	3.9	19.5	10	9.4	7.4	3.5	2.5	32.8	2.5
	40-80	64.3	28.4	8.4	3.4	40.2	10.1	4.8	4	18.9	11.6	10.4	9.2	4.3	3	38.5	2.4
	80-150	56.2	40.1	11	1.6	52.4	13.5	9.8	3	26.3	4.9	2.5	4.5	3.3	4.1	19.3	1.2
3	**0-40**	57.7	39.5	9.7	2.5	51.7	19.3	8.4	3	30.7	2.9	2.1	3.5	2.9	1.3	15.6	2
	40-80	57.5	25.7	8.1	1.9	35.7	27.2	15	4.7	47.1	5.3	3	3.8	1.9	1.5	15.5	1.7
	80-110	57.4	19.6	7.1	2.4	29.1	31.7	14	5	51.1	4.1	4.9	4.1	2	2	17.1	3
4	**0-20**	59.1	39.6	11	2.2	52.8	13.1	5.7	3.2	22	6.3	5.8	5.4	1.4	4.5	23.4	1.8
	20-80	54.8	20.5	12	2.2	34.7	29.3	12	4.1	44.9	4.4	4.1	3.6	3.6	2.5	18.2	2.2
	80-150	59.4	16.1	8.3	2.2	26.6	32.7	12	3.2	47.4	6.4	6	5.5	4.1	1.8	23.7	2.3
5	**0-30**	56.2	39.8	11	2.5	53.1	19.6	9.8	3.8	33.2	4.1	2.9	3.3	2	1.6	13.9	0.8
	30-70	60.8	39.9	11	2.8	53.8	17.8	9.1	3.3	30.2	2.9	4.3	2.4	3.4	1.9	14.9	1.1
	70-150	57.3	40	7.8	1.7	49.5	24.9	9.9	2.2	37	2.1	3.4	3	1.3	1.3	11.1	2.4
6	**0-50**	56.2	25.1	8.5	2.4	36	31.1	10	2.5	43.6	5.6	4	4.4	2.8	1.2	18	2
	50-75	63.4	46	10	2.4	58.5	5.8	2.7	2.9	11.4	8	5	8.1	4.7	1.3	27.1	3
	75-150	61.2	28.3	2.7	-	31.4	39.1	3.2	-	43.2	3.2	6.5	8.6	3.3	2.2	23.8	1.6
7	**0-30**	58	43.6	9.6	2.3	55.5	15.4	7.2	4.3	26.9	3.8	2.4	3.8	2.4	3.8	16.2	1.4
	30-90	56.2	40.1	11	1.6	52.4	13.5	9.8	3	26.3	4.9	2.5	4.5	3.3	4.1	19.3	1.2
	90-150	58.5	35.9	7	2.8	45.7	19.7	13	1.9	34.7	3.4	3.4	4.9	2.3	3.4	17.4	2.2
8	**0-50**	61.1	50.6	8.3	1.9	60.8	10.9	4.3	3.4	18.6	3.9	3.4	2.5	5.4	1.9	17.1	3.5
	50-100	59.2	45.1	9.9	1.8	56.8	12.7	7	3.8	23.5	3.8	3.7	4.7	3.3	1.9	17.4	2.3
	100-150	63.3	37.9	9.7	1.9	49.5	13.4	8	4.5	25.9	6.6	4.6	4.6	4.6	3	23.4	1.2
Local depression																		
9	**0-20**	59.3	53.7	11	1	66	12.4	4.7	1.9	19	3.6	2.6	3.1	2.6	1.6	13.5	1.5
	20-70	58.5	25.5	8.4	1.4	35.3	42.3	7.2	2.8	50.4	3.3	1.9	3.4	2.4	1.9	12.9	1.4
	70-140	53.4	28.7	10	2.2	41.1	28.3	8.1	3.1	39.5	4.1	3.4	3.7	3.3	3	17.5	1.9
10	**0-30**	59.8	49.5	12	1.4	63.3	13	5.8	2.8	21.6	3.3	2.9	2.9	1.4	1	11.5	3.3
	30-100	56.8	40.9	9.7	2.6	53.2	23.3	8.8	2.2	34.3	3.5	2.6	3.1	1.8	0.9	11.9	0.6
	100-150	59.4	35.9	8.6	1.8	46.3	28.1	8.7	2.7	39.5	2.8	1.8	4.6	1.8	1.4	12.4	1.8
11	**0-30**	65.2	59.1	10	2.4	70.6	7.9	4.3	3.9	16.1	3	3.1	2.4	1.2	1.8	11.5	1.8
	30-100	51.5	42.3	12	2.9	56.1	20.2	9.3	1.9	31.4	2.7	1.7	1.7	2.6	0.5	9.2	3.3
	100-150	53.7	38.1	9.1	1.6	48.8	21.7	6.2	2.9	30.8	4.3	4.1	4.9	2.9	2.9	19.1	1.1
Foot slope of plateau																		
12	**0-50**	58.9	41.9	9	0.9	51.8	14.9	4.5	1.8	21.1	6.3	5.9	6.7	3.2	2.2	24.3	2.8
	50-100	61.4	39.3	7.8	0.5	47.6	14.8	5.9	1.9	22.6	6.8	5.9	7.3	4.4	2.4	26.8	3
	100-150	60.4	46	9.1	2	57.1	14.4	5.1	1.9	21.4	4.6	4.1	5.1	2.3	2.6	18.7	2.8
13	**0-30**	57.5	29	9.3	1.7	40	23.5	11	3.8	38.6	5	3.4	5	2.5	2.1	18	3.4
	30-80	55.1	31.5	8.7	2.5	42.7	27.8	9.8	2.5	40.1	4.5	2.9	3.7	2.9	2	16	1.2
	80-150	54.4	21.1	7.2	1.5	29.6	30.6	13	2.8	46.4	4.4	4.1	5.6	3.7	4.4	22.2	1.8
14	**0-30**	63.5	39.5	7.9	1.4	48.8	22.2	5.8	2.3	30.3	6.3	3.4	4.3	1.9	1	16.9	4
	30-70	58.6	33.5	9.7	0.9	44.1	14.5	7	5.3	26.8	7.9	4.5	7	4.4	4	27.8	1.3
	70-120	59	43.1	9.4	1.8	54.3	13.5	4.5	3.2	21.2	8.1	5.8	4.5	3.6	1.4	23.4	1
15	**0-40**	59	40.7	11	2.1	53.7	11.4	5.3	2.1	19	7	6.1	6.2	4.1	2.1	25.5	1.8
	40-90	59.5	35.9	8.7	2.5	47.1	14.8	9.8	3.8	28.4	5.4	5.4	6.4	3.9	1.9	23	1.5
	90-150	54.3	28.8	10	1.7	40.9	16.2	6.9	4.9	28	8.2	6	9.5	4.3	2.2	30.2	0.9

In view of the above, the occurrence of ultrastable (index) minerals in the heavy fraction means either (1) the minerals are being reworked from older sediments or sedimentary rocks (Folk, 1980) e.g. the Miocene sandstone of the study area and/or (2) prolonged abrasion and/or chemical attach has occurred.

3.5.2.2.3. Metastable minerals

The metastable minerals (staurolite, garnet, andalusite, sillimanite and kyanite) are detected in palpable portions in the study soils. Foot slope of plateau unit has the highest percent followed by gravelly sand plain unit, while local depression unit has the lowest content (Table 6).

The metastable minerals, as their name implies, that they are derived mainly from the metamorphic rocks (e.g. schists, gneisses and metamorphosed argillaceous rocks) (Folk, 1980).

a) Staurolite: Staurolite is represented by subrounded or platy brownish yellow or straw yellow. It constitutes 2.1% to 11.6% and the high values are recorded in the sub surface layer of profile 2, while the low values are recorded in the deepest layer of profile (5). The distribution of Staurolite shows irregular pattern throughout the entire depth.

b) Garnet minerals*:* They are present as brown, colorless, yellow or as yellowish green with rounded to subrounded edges and pitted surface. They constitute 1.7 % to 10.4% with its highest value in profile (2) and its lowest content in the subsurface layer of profile 11. The frequency distribution of this mineral varies from one profile to another and also within profiles as revealed by the depth-wise distribution which revealed a tendency of increase downwards profiles (3, 6 and 8) at gravelly sand plain unit, 14 at foot slope of plateau with an irregular distribution in the rest of soil profiles.

c) Andalusite: It is detected as colorless to faintly yellowish pleochroic sub-angular or prismatic grains with rounded to sub-rounded edges. The content of andalusite varies from 1.7% to 9.5% of the non-opaques. The frequency distribution of andalusite shows irregular vertical distribution in most soil profiles except in some profiles where the mineral showed a slight increase downwards.

d) Sillimanite: It is recognized as colorless long prismatic or rectangular grains with irregular terminations and distinct vertical striations. It constitutes 1.2% to 5.4%. The highest value was recorded in the surface layer of profile 8, while the lowest value was found in the surface layer of profile (11). Its vertical distribution is irregular in all profiles except profiles 1, 4, 11, and 13 where sillimanite tends to increase with depth.

e) Kyanite: It is detected in colourless varieties, having two perpendicular sets of cleavage. The mineral grains are generally subrounded in shape. It is the least abundant mineral among the metastable minerals. Kyanite constitutes 0.5% to 4.5% and the low values are recorded in sub surface layers of profile (11), while the high values are recorded in surface layer of profile (4). Frequency distribution of kyanite content varies from one profile to another and even within profiles layers as shown by its depth-wise distribution which shows two distinct patterns, a tendency of increase downwards profiles (1, 2, 3, 6, 9 and 12) and an irregular pattern in the rest profiles.

3.5.2.2.4. Biotite mineral

Biotite occurs mainly as reddish brown, yellowish brown and brown flaky varieties with common opaque minerals inclusions. Biotite is present in many of the examined soil profiles with low quantities. Biotite content ranges between 0.6% and 4.8% of the non-opaque minerals.

It is evident from results of this investigation that there is no fundamental mineralogical difference in the studied soils. Indeed, it appears that there is one distinct heavy mineral association characterizing all of these soils. This association is marked by the predominance of opaque minerals, unstable minerals, presence of appreciable quantities of ultrastable minerals, and less frequently metastable minerals. There is a noticeable variation in the quantity of the main heavy minerals in the different soil profiles of the study area.

The difference and random fluctuation in the distribution of heavy mineral associations in the sand fractions are mainly attributed to variations in nature of source rocks and environment of deposition. Also, the detected non-opaque, which are dominated by ferro-magnesium silicate minerals (pyroxenes, amphiboles, and epidotes) together with less pronounced amounts of parametamorphic ones (staurolite, garnet, andalusite, sillimanite and kyanite), indicate that these minerals were transported to the area mainly by water and recently by wind from the basement rocks which are considered the main sources of sand in sediments of the study area.

Moreover, the moderate content of ultrastable minerals (zircon, rutile and tourmaline) in study area may be derived from sedimentary rocks (mostly Miocene sandstone) enriched in these minerals.

3.6. Parent material uniformity assessment

In the current work, the parent material uniformity of the soils was indicated by applying different approaches, i.e. the vertical distribution of both index minerals and index figure (Barshad, 1964; El-kady, 1970 and Mitchell, 1975). The uniformity ratios were also applied i.e. ratios of zircon/tourmaline, zircon/rutile, zircon/(rutile + tourmaline) and (pyroxenes + amphiboles)/(zircon + rutile) for different layers of soil profile as suggested by Haseman and Marshall (1945) and Brewer (1964). They were applied to test the uniformity of Egyptian soils by El-Demerdash *et al.* (1972).

The distribution of the index minerals (Tables 6), the index figure and the uniformity ratio values (Table 7) in the studied soil profiles changed irregularly with no specific pattern with depth. This indicates that these soils are heterogeneous either due to their multi-sources and/or have undergone to a multi-depositional regime and therefore, they are considered young from the pedological point of view. These results are more or less consistent with the morphological characteristics and the granulometric analyses data.

3.7. Soil development and its maturity assessment

In the study area, the physical and chemical weathering processes on multi-sources parent materials lead to the prevalence of immature soil profiles. This is indicated by the irregular distribution of the ultrastable (index) minerals in the different landforms units and also by the irregular vertical distribution of such minerals. Also, the distribution of amphiboles and pyroxenes and index minerals (Table 6) indicate that the study soils are recent, poorly developed and immature from the pedogenic point of view. Moreover, the dominance of weatherable and resistant minerals in the majority of the studied soils can be considered as an indication of the immature conditions prevailing in this area. From the pedoginic point of view, the presence of pyroxenes and amphiboles in the study area indicate recent and poorly developed soils.

Ratio of the most susceptible weathered minerals (pyroxenes and amphiboles) and the ultrastable ones was used as a criterion for the efficiency of weathering process that prevailed, and consequently soil development (Hammad, 1968). In the light of the weathering ratio of the soils under study illustrated in table (7), it is worthy to mention that these soils are weakly developed.

4. Conclusions

In view of the former finding, one can conclude that the samples studied occur in median sand, sometimes close to fine sand grade. These samples are moderately sorted to poorly sorted, strongly coarse skewed to fine skewed and very platy kurtic to very lepto kourtic.

The difference and random fluctuation in the distribution of light and heavy minerals associations in the sand sub fractions are mainly attributed to variations in nature of provenance, and environment of deposition. The source rocks of sand in the study area are mixture of igneous, sedimentary and metamorphic rocks.

The soil minerals were mainly transported to the area by water from southern basement rocks. The results show that the obtained values are highly reflecting the effect of weathering processes on these soils due to their relatively high content of less stable minerals of pyroxenes and amphiboles. The variations in weathering ratio among the soil profiles and also between the layers in each profile emphasis that these soils are formed from multi-origin and/or due to multi-sedimentation regimes.

Table 7: Indez figure and Uniformity and weathering ratios of soil profiles representing the dominating landforms of the study area.

Profile No.	Depth (cm)	Index figure	Z/R*	Z/T	Z/(R+T)	(A+P)/(Z+R)
			Gravelly sand plain			
1	**0-30**	0.064	3.29	10.80	2.52	1.13
	30-90	0.02	1.93	6.75	1.50	1.30
	90-150	0.069	2.70	6.57	1.91	1.26
2	**0-40**	0.033	1.84	2.59	1.07	2.63
	40-80	0.042	2.10	2.53	1.15	2.47
	80-150	0.043	1.38	4.50	1.05	2.18
3	**0-40**	0.06	2.30	6.43	1.69	1.78
	40-80	0.092	1.79	5.79	1.37	0.80
	80-110	0.095	2.20	6.34	1.63	0.58
4	**0-20**	0.062	2.30	4.09	1.47	2.69
	20-80	0.099	2.55	7.15	1.88	0.80
	80-150	0.071	2.84	10.22	2.22	0.55
5	**0-30**	0.062	2.00	5.16	1.44	1.72
	30-70	0.053	1.96	5.39	1.44	1.90
	70-150	0.044	2.52	11.32	2.06	1.37
6	**0-50**	0.09	3.11	12.44	2.49	0.82
	50-75	0.046	2.15	2.00	1.04	6.60
	75-150	0.027	12.22	-	-	0.73
7	**0-30**	0.071	2.14	3.58	1.34	2.35
	30-90	0.043	1.38	4.50	1.05	2.18
	90-150	0.08	1.50	10.37	1.31	1.31
8	**0-50**	0.043	2.53	3.21	1.42	3.88
	50-100	0.03	1.81	3.34	1.18	2.79
	100-150	0.022	1.68	2.98	1.07	2.22
			Local depression			
9	**0-20**	0.059	2.64	6.53	1.88	3.80
	20-70	0.056	5.88	15.11	4.23	0.68
	70-140	0.062	3.49	9.13	2.53	1.07
10	**0-30**	0.045	2.24	4.64	1.51	3.29
	30-100	0.039	2.65	10.59	2.12	1.58
	100-150	0.036	3.23	10.41	2.46	1.21
11	**0-30**	0.085	1.84	2.03	0.96	5.67
	30-100	0.037	2.17	10.63	1.80	1.82
	100-150	0.058	3.50	7.48	2.38	1.69
			Foot slope of plateau			
12	**0-50**	0.033	3.31	8.28	2.37	2.62
	50-100	0.029	2.51	7.79	1.90	2.28
	100-150	0.066	2.82	7.58	2.06	2.83
13	**0-30**	0.03	2.08	6.18	1.56	1.10
	30-80	0.036	2.84	11.12	2.26	1.07
	80-150	0.044	2.35	10.93	1.94	0.65
14	**0-30**	0.073	3.83	9.65	2.74	1.69
	30-70	0.061	2.07	2.74	1.18	2.01
	70-120	0.056	3.00	4.22	1.75	2.92
15	**0-40**	0.089	2.15	5.43	1.54	3.09
	40-90	0.093	1.51	3.89	1.09	1.81
	90-150	0.071	2.35	3.31	1.37	1.70

*Z: Zircon, R: Rutile, T: Tourmaline, A = Amphiboles, P = Pyroxenes

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