American Journal of Engineering Research (AJER)
e-ISSN : 2320-0847 p-ISSN : 2320-0936
Volume-02, Issue-10, pp-205-213
www.ajer.org

Research Paper Open Access

Detection of Hazardous Elements in Foundation Layers in Carbonate Coastal plain, Port-Sudan – Suakin, Red Sea, Sudan

Al-Imam, O. A. O.; Elzien, S. M.; Mohammed A. A.; Elkrail, A.B.; & Mustafa A.A.
Faculty of Petroleum & Minerals, Al-Neelain University, Khartoum, Sudan

Abstract: - The area between Port-Sudan and Suakin is a carbonate coastal plain affected by climatic and environmental factors. Boreholes and trial pits were drilled to expose subsurface sediments and bore water samples from deferent depths. The samples were obtained for geochemical analyses which show interaction as ionic exchange in a complex process with sea water. The area has been subjected to both weathering and deposition process due to combination of factors. Sea water interaction, rainfall, evaporation rate and material supply by the drainage pattern.The Hydrochemical of the groundwater indicates dominance of the Cl^{-} and SO^{-2}_{4}, whereas, that of cation indicates the dominance of Na^{+} and Mg^{2+} ions. Consequently, four types of groundwater can be chemically distinguished: Na-Cl -facies; Mg-Na-Cl- facies, Na-Ca- Cl-faciesCa-Mg-Na-Cl –facies and Na-Ca-Cl - Facies. The dominance of Na^{+}, Cl^{-} and SO_4^{-2} ions with very high concentrations reflect an existence of sea water intrusion phenomenon.
The hazardous constituent of the foundation layer had been detected by weathering – deposition companion model.

Keywords: - *Port-Sudan and Suakin, carbonate coastal plain, sea water,subsurface sediments,and ionic exchange*

I. INTRODUCTION

The construction engineers are face real problems to decide the foundation layer in the Sudanese coastal plain, due seasonal and inter-seasonal subsurface characteristics changes. The rainfall, Evaporation, Sea water interaction with the subsurface and drainage pattern has significant influences in the foundation layers characteristics. Weathering and depositional products subjected to chemical change during transportation as ion exchange which were take place in pore water and subsurface sediments. The prevailing subsurface condition (Alkaline and Acidity environment) assists in form of activities and sinkholes in suchformation **(Al-Imam, 2005)**. Geological investigations were provided that several locations in Sudanese coastal plain characterized by different size of cavities and sinkholes filled by loose fine sediments **(Al-Imam, 2005)**.

Coastal reef limestone covered the area at depth (more than 60m) and mainly geologically formed of Aragonite, Calcite, Mg-Calcite and Dolomite. These carbonate minerals mostly refer to organic origin. The nature of carbonate distribution reflects the coral of carbonate mineralogy by the balance between the organic carbonate (mainly coarse grained constituents composed of aragonite and high Mg-Calcite) and terrigenous carbonate contribution (Calcite and Dolomite) **(Al-Zain& Al-Imam, 2002, 2004; Al-Zain, Al-Imam and AlShafie, 2005)**.

Sabkha along the coast between Port-Sudan and Suakin are super tidal surface which has been developed as result of sedimentation. **Al-Amoudi (1993)** reported that the Sabkha deposits appear to be cemented and the process of cementation are selective and varies with depth. At the present, the red sea has marks rainfall deficit (an excess of evaporation over precipitation personal communication), (Metrological Department-Port-Sudan office). The depth of ground water level in our Sabkha isaffected by continuous water evaporation process and chemically stable (dehydration of Gypsum ($CaSO_4.2H_2O$) to ($CaSO_4$).

Previous studies and literature is very scanty even. Managed realignment is one of several "soft" engineering options which may reduce the cost of coastal defense, providing a more natural response on the problem of rising sea level and at the same time deliver environmental especially natural conservation benefit **(Flemming and Delafonlaina, 2000: Watts et al., 2000 and Zheuhan et al., 2004)**. However, coastal geotechnical engineering as a field of investigation causing a lack of information so that engineering properties of coral reef limestone was ignored.

II. LOCATION AND SAMPLING

The area of study extends about 60Km from Port-Sudan to Suakin harbor bounded by coordinate lat. (19º 00' ; 19º 50' N) and long (37º 00' ; 37º 30' E) **Fig (1).**

Five sites were selected for sampling there are:

1- Tahlyia site: seven boreholes were drilled adjacent KhorSalalab of 40m depth in average to obtained subsurface sediments and pore water plus sea water sample.
2- DamaDama: about 7.0 km southern Port-Sudan. Two exploration boreholes of 40m depth for sediments and pore water samples plus surface and from 5.0m depth sea water samples.
3- Green area: (Southern Port) one trial pit of 0.6m on the back shore for sediments and pore water plus surface and one from 5.0m depth sea water samples.
4- Free Zone: about 37km from Port-Sudan toward Suakin. Two trial pits of 3m and 4m for sediments and pore water and one surface sea water samples.
5- Suakin: one trial pit of 1.0m on Sabkha flat and one surface sea water samples.

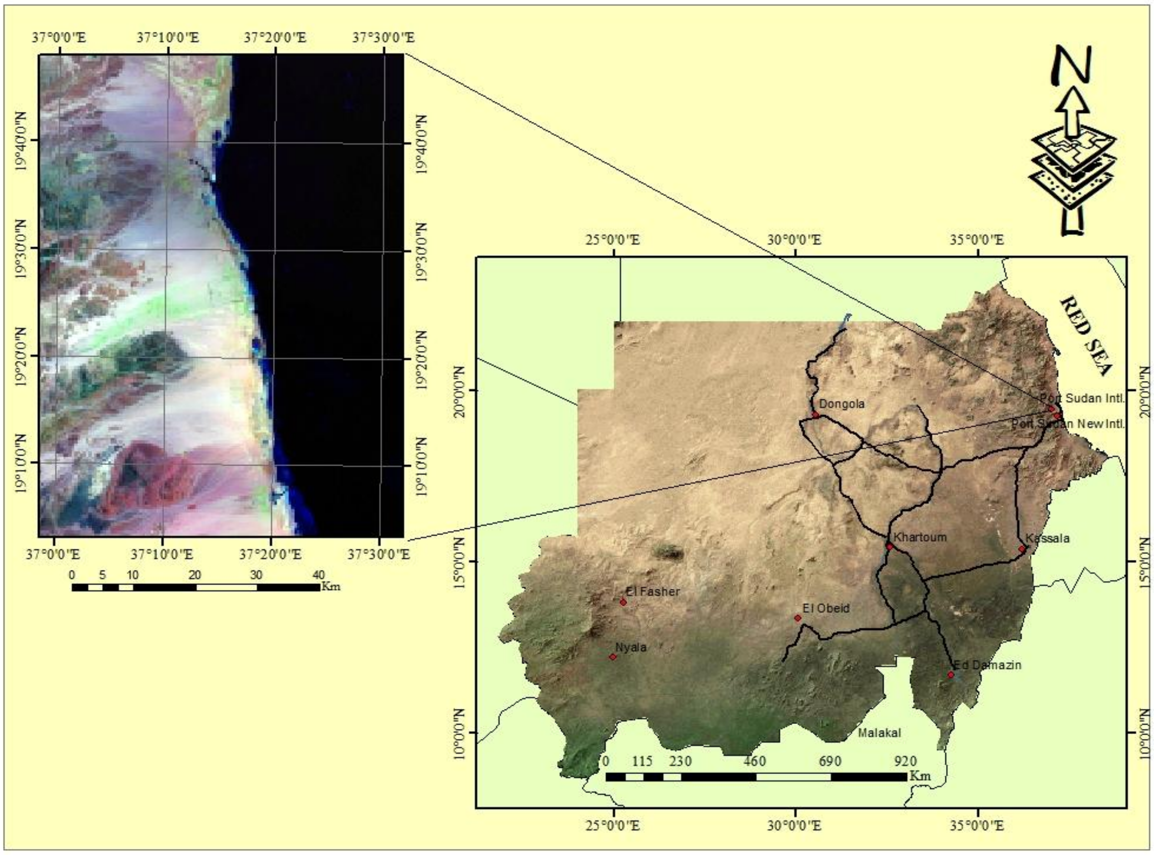

Fig. 1: Location Map of the Study area

III. GEOLOGY

The coastal plain of the red sea, Sudan, is located between the shore line and the Red sea hills. The basement rock occur over a large area in North- West Sudan of Pre- Nubian sand stone age which exhibit variable degree of metamorphism including sediments incorporate into complex sequence of igneous intrusive and extrusive suite **(Gass, 1981: Babikir, 1977: Vail, 1979: El-Nadi, 1984)**.

The igneous rocks cover a large area with unknown thickness of foliated and un-foliated granite and diorite **(El-Nadi, 1984)**. The meta-sedimentary inliers reaching the amphibolite metamorphic facies crop out in the Northern and Southern Red Sea Hills and West of Port-Sudan included a continental origin of the sediments **(El-Tom, 2002; Al-Imam, 2005)**. Volcanic sedimentary unit and green Schist assemblage's crop out NW Port-

Sudan and Suakin. However, the shield in the Red sea hills region had been more stable during most of lower and upper Paleozoic eras. Nubian sandstone is widely and in different continental environmentsdeposition of cretaceous. In the coastal plain, these Nubian form a wide part with other continental material reach the coastline particularly in the near shore zone **(Cowell et al., 2005; Punter, 1989)**.The widely spread Pre-Cambrian Afro-Arabian shield which had been available uplifted and eroded in the Red Sea region to produce three successive sequence of mixed carbonate and clastic sediments. The ultimate sedimentary phase was succeeded by period of large scale intrusion variously called the ring complexes are injection and red granite **(Krö ner, 1993)**.

The Quaternary and Recent formation are classified as marine and continental sediments. The drainage system (Khors and Wadis) is filled by Quaternary continental sediments such as gravel, sand and silt varying in thickness. These depositions are alluvial deposits controlled by the configuration of the basement complex bed rock. Generally, Quaternary and Recent marine sediments are mainly composed of reef and reefal sand. Sabkha deposits and salt rocks mostly covered the back shore area **(Fig. 2).**

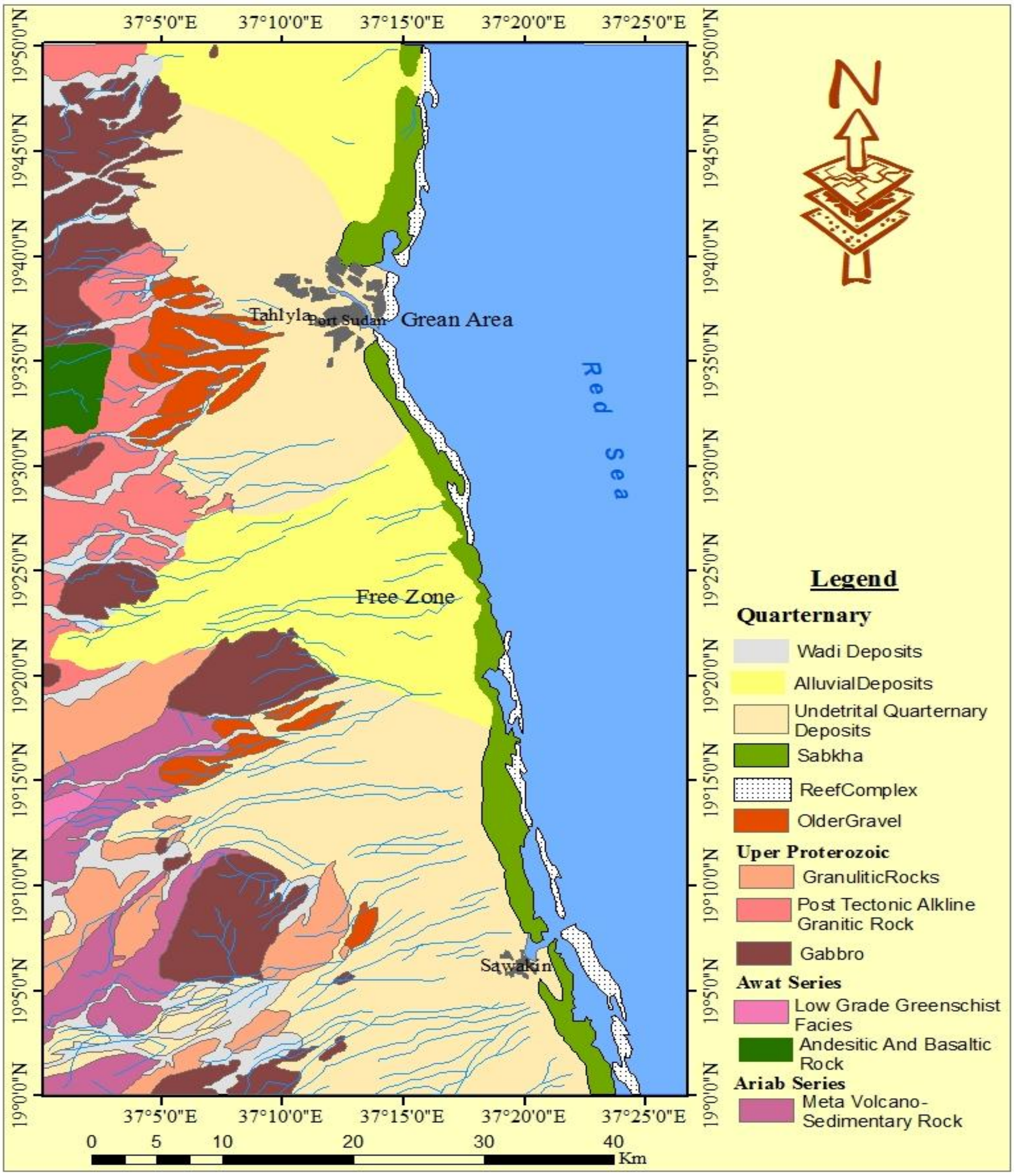

Fig. 2: Geological Map around the Study area

IV. REGIONAL TECTONICS AND SEDIMENTATION

Carbonate builds up on both tectonically passive active margins. Both were available in Sudanese coastal plain which had been subjected to tow different movements: vertically uplift and lateral displacement. However, reef complex may have originated grown over the uplift block resulting from faulting in the Pre-Pleistocene. Coral reef limestone terrace between Port-Sudan and Suakin has been uplifted 2.5m by vertical movement of the submerged coral bed rock. The lateral distribution of different facies in the Sabkha and reef flat has the same constituent and trend. Lateral shifting and depositional setting was frequent and could lead to lateral discontinuous shallowing upward **(Al-Zain and Al-Imam, 2002, 2004,Al-Zain; Al-Imam, and AlShafie 2005)**.

The onshore Pleistocene sediments are largely coarse graver and sand thought to have been derived from the basement complex. They reflect primarily rapid lateral attenuation siliciclastic deposits which may replace as such as in Green area. Back shore or any later overlain by carbonate as in Khor Salalab (Tahlyia site).Two separate groups of evidence that are related to deposition of alluvial wadi deposits and that to marine succession are involved. Marine sequence in particular are built up of sediments accumulations (mostly after reef), formed when sea level was higher than the highest point within the deposition. These are punctuated by erosion surface which may represent sea level or sub aerial surface. In Free zone, the coral reef assemblage height about 2.5m referring to sea-level while had with drawl simultaneously with uplift process. In contrast, compensation of these processes is represented in Suakin region at the entrance of main harbor which uplifted up to 3.0m.

The coastal plain on which the drainage system run through have varied view of alluvial terrains deposits such as fan of Pleistocene debris spreading seaward a cross the coastal plain and have been dissected by more recent streams activity. In general, alluvial deposits are correlated with period of high rainfall. Recent sands, commonly coarse and arkosic are associated with heterogonous gravels. These are lateral gradation from unsorted screes to stratified and current-bedded sands and more grounded gravel. However, some of these alluvial deposits are resting on coral reefs, while others are laterally equivalent to carbonate.

V. HYDROGEOLOGICAL ANALYSIS

Sea water, pore water and trial pit sediments samples have been analyzed to measure the hazardous cations and anions using **HASH (1989)** method. Results of different waters are compared with sea water which used as standard content

Table 1: Hydrochemical Facies of the Water from Port Sudan-Suakin area

Sampl e No.	unit	Na+	K	Ca	Mg	Cl	F	SO4	HCO3	NO2	NO3	NH3	pH	W. Facies
TBw-1	Ppm	13616	1953.5	96	97.2	24850	2.4	5956.6	597.8	6.6	30.8	NA	6.74	Na-Cl water Facies
TBw-2	Ppm	14490	1531.5	14	17.1	21655	3.2	3259.08	143.6	13.2	28.6	NA	7.22	Na-Cl water Facies
TBw-3	Ppm	23000	2429.5	19.2	23.13	40115	3.2	3885	533.8	3.3	39.6	NA	7,17	Na-Cl water Facies
TBw-4	Ppm	22599	2130.5	18.4	28.2	33015	3.2	3212.6	512.4	0	16.5	NA	7.33	Na-Cl water Facies
TBw-5	Ppm	24150	1870	18.4	27.7	33015	5	5077.7	439.2	3.3	28.6	NA	7.35	Na-Cl water Facies
TBw-6	Ppm	23000	1943	15	30.1	37275	3.2	5205.7	463.6	3.3	29	NA	7.42	Na-Cl water Facies
TBw-7	Ppm	18400	2090.5	16	29.2	31595	3.2	4964	916	3.3	23.1	NA	7.35	Na-Cl water Facies
Tsw-1	Ppm	11040	1999.5	480	1044	21535	2	3188.7	158	N.A.	8.36	NA	7.45	Na-Cl water Facies
DBw-1	Ppm	23654	2368	1240	2056.5	41712.5	5	7778.5	170.8	3.3	7.9	NA	6.8	Na-Cl water Facies
DBw-2	Ppm	32500	2160	1080	1992.5	60350	5	7375.6	170.8	16.5	10.56	NA	6.9	Na-Cl water Facies
DPw-1	Ppm	15318	1985.5	500	466.4	25602.5	2	4430	97	0	14.5	NA	7.45	Na-Cl water Facies
Dsw-1	Ppm	15318	1833	480	1020.6	31950	2	3424.9	170.8	Na	4	NA	7.98	Na-Cl water Facies
Dsw-2	Ppm	11500	1438	480	874.8	22035	2	3831.1	119.56	3.3	8.36	NA	8.05	Na-Cl water Facies
Gpw-1	Ppm	30015	2325.5	640	1142.1	51475	3	5280	195.2	NA	16.2	NA	7.76	Na-Cl water Facies
Gsw-1	Ppm	227.6	5	40	777.8	300.3	2	34.5	73.2	NA	6.16	NA	7.86	Mg-Na-Cl water facies
Fpw-1	Ppm	1.695	1009.5	6080	1625.4	3342.5	2	1499.7	73.2	NA	24.6	NA	6.7	ca-mg-na-cl -water facies
Fpw-2	Ppm	5750	880.5	4160	777.8	18825	3	1959.6	73.2	NA	26.8	NA	6.86	Na-Ca-Cl water Facies
Spw-1	Ppm	20700	2156.5	880	1069.2	38870	4	5606	134.2	6.6	12.76	NA	7.48	Na-Cl water Facies
Ssw-1	Ppm	15571	1810.5	480	899.1	27475	2	3404.9	219.6	3.3	7.48	NA	8.02	Na-Cl water Facies

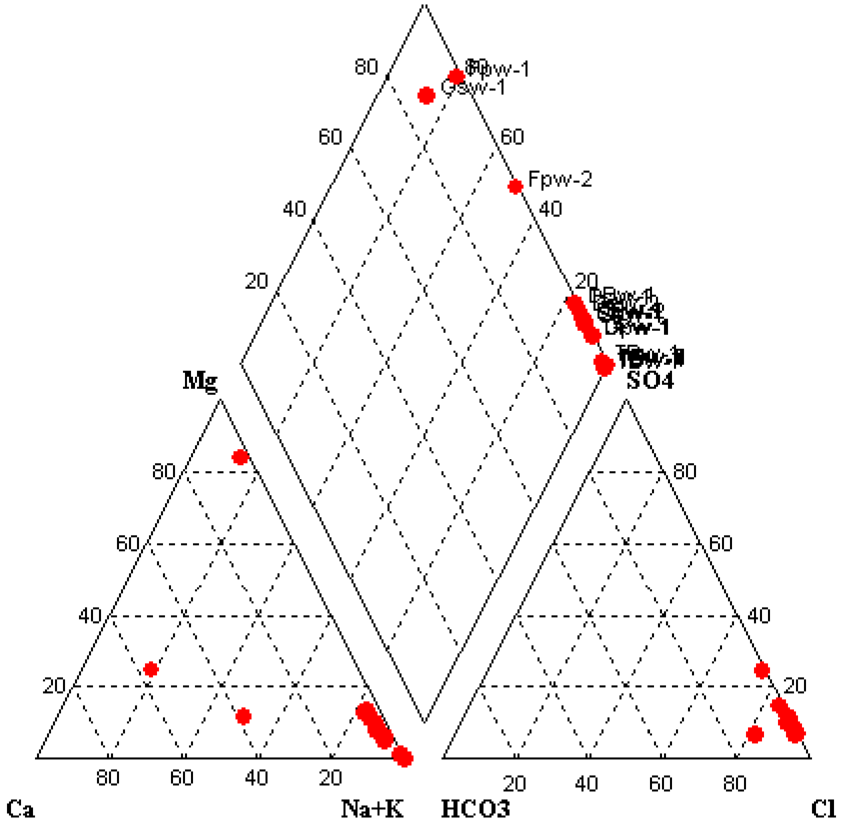

Fig.3: Piper Diagram for Coastal groundwater from Port Sudan to Suakin (Piper, 1953)

The results of the chemical analyses of the total wells in the study area were plotted on Piper diagram **(Fig. 3)** for hydrochemical facies. As results, groundwater is significantly dominated by Na^+, and Cl^- , ions**(Table 1).** The content of cations and anions give an indication of increasing salinity of pore water.
However, the sub surface stratigraphic facies, geomorphological feature, structural and tectonic provide that the area is well developed karsts formation. Such formation consist of carbonate minerals e.g. Calcite $CaCO_3$ and Dolomite Ca Mg $(CO_3)_2$.

In Tahalyia, pore water, Na^+ has excess content in range of 10.58% - 16.85% where K^+ (2.57% - 6.95%), Ca^{2+} (1.34 % - 3.21%) and Mg^{2+} (0.97% - 7.08%) are less in average values. In contrast, a complexity in the distribution of the anions concentration reflects the inland interaction. NH_3^- is completely absent; where NO_2exceed by 0.01% to 0.13% in content than that of the sea water, but there is not recorded in boreholes numberTBw–4;TBw–5 and TBw–7. The distribution of content of NO_3 is approximately similar to that of NO_2. Bicarbonate (HCO_3) and sulphate (SO_4^{2-}) recorded more concentration than sea water by 0.45% to 1.8% and 4.11% to 3.46% respectively. Cl^- has regular distribution with less concentration, except in borehole No. TBw–3 and TBw–6 where is associated with high concentration of SO_4^{2-} (3.47% and 0.21% respectively). Most of pore water have the same content of fluorite but generally reflected as high content.

In Dama Dama, generally, K^+ has less concentration by 1.99% than sea waters where other cations are increasing. The difference between DBw-1and DBw-2 in Na^+ concentration is 5.67% but in DBw-2 K^+, Ca^{2+} and Mg^{2+} recorded more than these in DBw-1. Although these boreholes are located in the same environment, Cl^- is decreasing in DBw-1 by 0.78 % and increase by 5.09% in DBw-2 with reverse content of SO_4^{2-}.
Very wide variation in concentration of both cations and anions in Green area (GPw-1) compared with sea water, where Na^+contents is 17.1% and K^+ is 3.44% respectively increasing, while, Ca^{2+} 10.57% and Mg^{2+} 4.78% decrease. All anions have excess concentration in different percentage: 18.2% Cl^-, 0.98% SO_4^{2+}, 0.43% F, 17.25% HCO_3 and No_3 1.45%.

The result of (FPW-1) pore water shore that all anions and cations have less content than sea water, except Cl^- which approximately equal of that of sea water. The coastal (SPw-1) in Suakin is characterized by high concentration of Na^+ and Ca^{2+} compared to sea water. They have 0.45% and 0.99% while K^+ and Mg^{2+} decrease by 0.96% and 0.48% respectively.

The pH values of sea water and most of pore water are in ranges 7.0 to8.0 where some other pore waters are less by (6.7-6.9). Although Na^+ is high concentration in pore water, the pH values are less than sea water referring to the anions balance between them (sea water and pore water). SO_4^{2+}, HCO_3 and Na^+ cause the acidity in some pore water.

VI. GEOCHEMISTRY OF SUBSURFACE SEDIMENTS

Result of chemical analyses of samples of water obtained using atomic absorption spectrophotometer (A.A.S) as shown in **(Table 2).**Cl^- and SO_4^{2-}content in Tahalyia subsurface sediments varies between (1.26%-1.86%) and (0.43%-2.7%) respectively. It is very low content when compared with pore water. Although the trial pits consist of different types of sediments, they have more or less the same content of Tahalyia subsurface sediments. However, any consist in content of anions in the sediments is due to the leaching from pore water certainly in Sabkha deposits (GPs-1), FPs-1, FPs-2 and SPs-1). In deeper depths where clastic deposits occur, the content in percentage of Cl^- is more than carbonate (TBs-1, TBs-2 and TBs-4). In Sabkha deposits, where pits are located, Cl^- is high indicating the nature of Sabkha and salt marshes.

The content of anions generally, decreasing in pore water than in sediments. Clastic deposits are richer in Na^+ than in carbonate. This high concentration of Na^+ as well as K+ in the first sample of DBs-1 as a resultant of mixture with alluvial deposits on the surface in which Na^+ and K^+ have the same behavior of content disruption. Subsurface clastic deposits facies process, mostly rich in Na^+ and K^+ as sodic and alkaline sediments where other elements predicated in carbonate pore water.

Table 2: Chemistry of subsurface Sediments

Code	No.	Depth (m)	Cr %	So_4^{2-} %	Na^+ %	K^+ %	Ca^{2+} %	Mg^{2+}	Type of Sediments
TBs-1	1 2	18 41	1.56 1.86	* *	1.25 3.45	0.61 1.40	30.19 3.25	0.45 0.59	Limestone Clastic Deposits
TBs-3	1 2	38 46	1.52 1.54	2.13 2.00	4.06 4.05	1.63 1.60	16.11 6.41	1.38 1.19	Carbonate sandy Mud Clastic Deposits
TBs-6	1 2 3	10 31 40	1.38 1.79 1.67	0.59 * 1.66	3.94 1055 3.38	0.71 4.21 1.60	31.92 10.78 428	0.93 2.56 9.78	Limestone Clastic Deposits Clastic Deposits
TBs-9	1 2	14 38	1.71 1.27	* 2.77	1.72 2.92	0.76 1.32	28.30 3.92	0.75 1.30	Carbonate Sandy Mud Clastic Deposits
DBs-1	1 2 3	11 23 48	1.23 1.60 1.36	0.44 1.00 0.43	6.75 3.85 3.85	1.40 1.10 0.81	23.29 32.17 32.34	1.09 0.72 0.81	Limestone Sandy limestone Limestone
DBs-2	1 2 3	26 39 49	1.57 0.43 1.41	0.40 1.72 0.52	2.57 1.82 2.66	0.67 0.62 0.79	33.47 28.79 31.08	0.70 0.52 0.81	Limestone Limestone Limestone
DBs-1	1 2	1.01.5	1.55 1.80	0.28 0.28	0.94 0.92	0.09 0.25	32.08 42.21	0.53 0.45	Coral reef Coral &clay
GPs-1	1	0.6	1.60	0.52	1.25	0.43	27.93	0.53	Sand,shel Fragment
FPs-1	1	2.5	2.48	*	2.50	1.39	5.80	0.56	Sabkha, muddy Sand
FPs-2	1 2	2.0 3.5	1.74 1.87	1.08 *	2.57 2.54	1.84 1.83	4.06 4.32	0.45 0.48	Sabkha, muddy Sand
SPs-1	1	1.5	1.67	*	1.21	0.72	31.18	0.40	Coral fragment

VII. DISCUSSION

Arid and semi-arid climatic factors have direct effect on different environment processes. Temperature, moisture and humidity are affecting the physical and chemical properties of surface and subsurface sediments. Geology, geomorphology and drainage system patterns play an important role in controlling effective factors and mechanism of reaction. The capability ofdrainage patterns to carry a dense load and a large amount of clastic material as meta-sediments and meta-volcanics which are deposited over tertiary deposits toward the sea. However, stratigraphy and geophysical studies show deep weathering to depth of 40m **(Al-Imam, 2005)**. As the sea water effected on pore water and surface sediments it is also directly influences directly subsurface layer. These change due to the sea water seepage and interaction cause ionic exchanges with constituents of layers. Carbonate rock and evaporation rate in such regionexceeding increasing content of Na^+ and Cl^- in pore water and/or in the sediments. Clastic clay which is delivered from surrounding highlands and milky white materials which originate from carbonate rock filled joints and fractions in form of kaolinite, bicarbonate, silicic acid and release Na^+, Ca^+ and Mg^{2+}. This condition stimulate the weathering reaction and causes Na^+ to be release with exchange of H^+ due to the excess of Na^+ and high HCO_3 concentration in shallow water table and deep pore water in the subsurface layers. Formation of HCO_3 causes depletion of H^+ and CO_2^{2-} leading to decrease in grade of weathering process which require substantial amount of sea water to convert the alternated terrigenous and clay minerals as biotite and K-feldspar to kaolin, silicic acid and bicarbonate. However, the weathering processes are progressive and proceeds downward erosion through the layers. Newly formed minerals will be transformed into other mineral assemblages by exceeding rate of evaporation **(Salama et al., 1999)**.

As well as sea water sprays, Chlorite content in the rainfall decreases with increasing distance from the sea. Different type of rocks in the Red Sea hills weather by rainfall. In the produce subjected to chemical exchange during transportation through the carbonate coastal plain. Two process of water movement take place in the coastal plain: 1- rain water percolation downward during winter (rainy season) and 2- evaporation by capillary rise of hyper saline pore water during the year. The second process has more influence than of the first one. Hereinafter, the formation of carbonic acid, bicarbonate and carbonate dissolution or precipitation involves equilibrium with setting sequence of carbonate:

$CO_2 + H_2O$ ------ H_2CO_3 ………………………………………………….... (1)

$HCO_3 + H^+$ ------- H_2CO_3 ………………………………………………….... (2)

and from weathering:

$H^+ + CO_3$ ---------HCO_3 ………………………………………………….. (3)

$Ca^{2+} + 2HCO_3$ ------------$CaCO_3 + CO_2 + H_2O$ ……………………………….. (4)

As a result of exchange between pore water and subsurface sediments with increasing alkalinity and Mg^{2+} in pore water, dolomite will precipitated.

$Mg^{2+} + 2HCO_3 + CaCO_3$ -------- $CaMg(CO_3)_2 + CO_2 + H_2O$…………………. (5)

As Ca^{2+} is removing, the Mg/Ca ratio is increases. At ratio of (6) or grater $CaCO_3$ as aragonite in the sediments possibly convert to dolomite conditioning by increasing evaporation and precipitation of Mg^{2+}**(Drever, 1982)**. Similarly, this process in Sabkha and salt marshes environments:

$2CaCO_3 + Mg^{2+}$ ---------- $CaMg(CO_3)_2 + Ca^{2+}$…………………………...… (6)

The free Ca^{2+} associate with SO_4^{2-}, with increase salinity to form Gypsum:

$Ca^{2+} + SO_4^{2-} + 2H_2O$ ---------$CaSO_4.2H_2O$…………………………….…. (7)

When HCO_3 is more and CO_2 dissolved in water and reacts with Ca^{2+}, Calcite will form (eq. 4). If weathering process is reserved, silicic acid and sepiolite will form and other cations which are produced during weathering process percolate downwards:

$Mg^{2+} + 2HCO_3 + 4H_4SiO_4$ ------------- $Mg_2Si_3O_6(OH)_2 + 2CO_2 + 6H_2O$……… (8)

The clay minerals (Alumino-silicates) are precipitated when degradation takes place in clays:

$K^+ + 2Al^{3+} + 1.5H_4SiO_4 + 5H_2O$ --------- $KAl_2O_3(SiO_2)1.5(H_2O) + 6H^+$…….. (9)

The position of the groundwater samples in the anion triangle indicates dominance of the Cl^- and SO^{-2}_4, whereas, that of cation indicates the dominance of Na^+ and Mg^{2+} ions.Consequently, four types of groundwater can be chemically distinguished: Na-Cl -facies; Mg-Na-Cl- facies, Na-Ca- Cl-facies Ca-Mg-Na-Cl –facies and Na-Ca-Cl - Facies. The dominance of Na^+, Cl^- and SO_4^{-2} ions with very high concentrations reflect an existence of sea water intrusion phenomenon.

VIII. CONCLUSION

The precipitation of clay minerals fills the fissure fractions, cracks, voids and cavities. This process may lead to sliding of buildings which are proposed to be constructing on such foundation layer and may also causing settlement of foundation**(Fig. 4).**

Moreover, carbonic acid and silicic acid are may attack the concentrate and the reinforcing steel of foundation causing corrosion and damage to foundation structures.

The equilibrium between the alkalinity and acidity in such environment is requiring as a factor in subsurface constructions. The sulphate minerals in Sabkha environment such a Sepiolite and Gypsum are directly precipitated in foundation layers associated with carbonic acid. To avoid the hazardous chemical components, the pH value, type of building materials (type of cement, aggregate, brats..…..etc.) and foundation design are very important and care should has been taken.

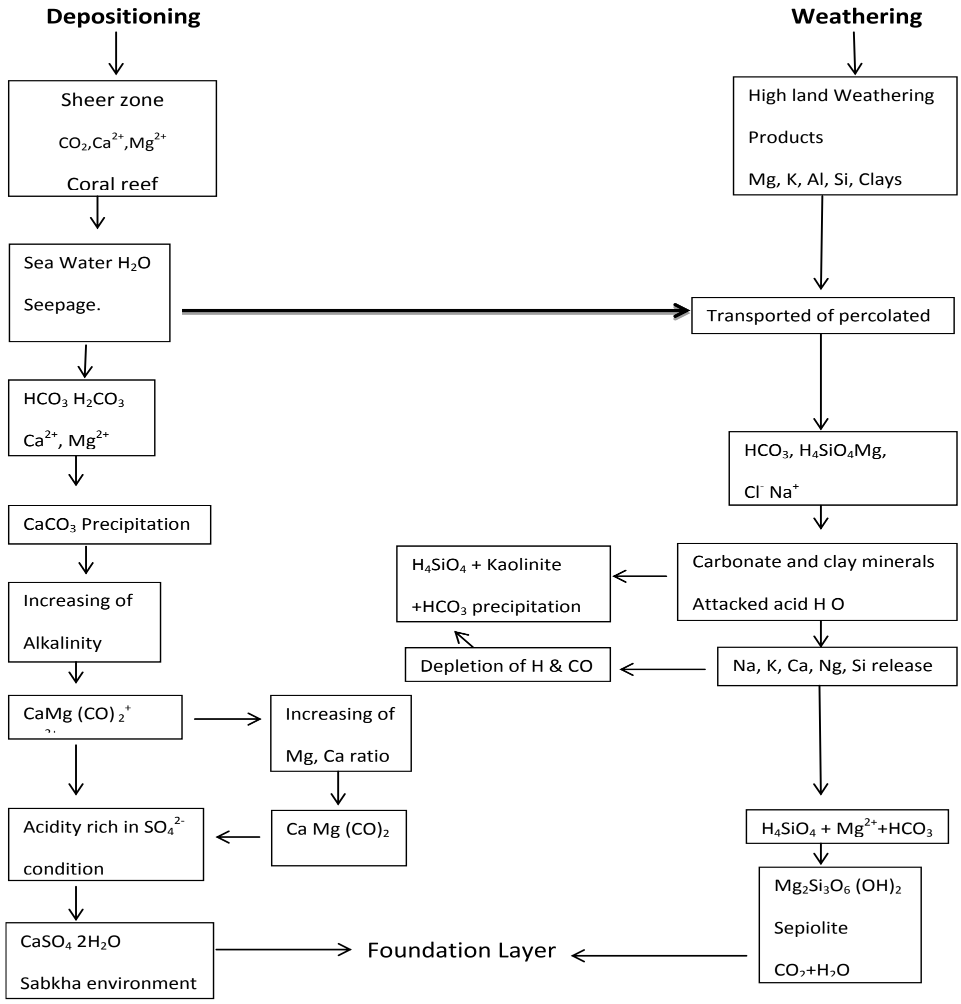

Fig.4: Weathering depositions companion model

REFERENCES

[1] **Al-Imam, O.A.O., (2005).**Coastal Geotechnical Properties and Pilling Foundation Design area between Port Sudan and Suakin, Red Sea, Sudan. Ph.D. Thesis, Alneelain University 300p.

[2] **Al-Zain, S.M.& Al-Imam, O.A.O., (2002).** Carbonate Minerals diagenesis in Towaratit Coastal Plain, south Port-Sudan, Red Sea, Sudan. Nile Basin Research Journal.Alneelain University, Khartoum, Issue No. 4, Vol. II p35 – 58.

[3] **Al-Zain, S.M.& Al-Imam, O.A.O., (2004).**Sea Level Changes and Evolution of Towaratit Coastal Plain south Port-Sudan, Red Sea, Sudan.Nile Basin Research Journal.Alneelain University, Khartoum, Issue No. 6, Vol.III, p 32-54.

[4] **Al-Zain, S.M.; Al-Imam, O.A.O., and AlShafie A.I.,(2005).** Surface Textural Characteristics of the sediments in Towaratit Coastal Plain, south Port-Sudan Red Sea, Sudan, Natural Science Magazine, Higher Education, Khartoum. SJBS (G), 6:149-167.

[5] **Al-Amoudi, O.S.B., (1993).** Chemical Stabilization of Sabkha soils at high moisture contents. Eng. Geol., 36:279-291.

[6] **Babikir, I.M., (1977).**Aspects of the Ore Geology of Sudan. Ph.D. Thesis. University College og Cardiff. U.K.

[7] **Cowell, P.J.; Stive, M.J.F.; Niedoroda, A.W.; De Vriend, H.J.; Swift, D.J.P.; Kaminsky, G.M.; Capobianco, M., (2005).** The coastal tract (Part I): A conceptual approach to aggregated modeling of low-order coastal change. Spec Issue, Jour. Coast.Res.

[8] **Drever, I.J., (1982).**The geochemistry natural waters.Prentice Hall, Englewood, Cliffs, NJ.

[9] **El Nadi, A.H., (1984).**The geology of the Precambrian metavolcanics. Red Sea Hills, NE Sudan. PhD. Thesis. University of Nottingham, England, UK.

[10] **El Tom, A.M., (2002).**Water resources development and management, Red Sea State, Port – Sudan area. Ph.D. Thesis. Alneelain University, Khartoum, Sudan.

[11] **Flemming, B.W.; Delafontaine, M.T., (2000).** Mass physical properties of muddy intertidal sediments: Some applications, misapplications and non-applications. Continental Shelf Research, 20:1179 – 1197.

[12] **Gass, I.G., (1981).**Pan-African (upper Proterozoic) Plate tectonics of the Arabian-Nubian Shield.In: A. Kröner (ed) Precambrian Plate tectonic. 387-405.

[13] **HASH (1989).**Standard methods for the examination of water and waste water. 17^{th} (ed). Rand, M.C. and et al., New York U.S.A.

[14] **Kröner, A., (1993).** The Pan- African Belt of north-eastern and eastern Africa. Madagascar, southern India, Sri Lanka and east Antarctica: Terrane amalgamation during formation of the Gondwana supercontinent. In: Thorweihe, U., and Schandelmeier, H. (ed): Geoscientific Research in northeast Africa, S3-9, Rotterdam (Balkema).

[15] **Piper, A.M., (1953).**A graphic procedure on geochemical interpretation of water analysis.U.S. Geol. Surv.Groundwater, Note 12.

[16] **Putner, Majid (1989).** The Sudanese Red Sea: I, new developments in stratigraphy and petroleum – geological evolution. J. of Pet. Geol. 12 (2): 145-166.

[17] **Salama, R.B., Otto, J., and Fitzpatrick, W., (1999).**Contribution of groundwater conditions to soil water salinization Jour. Of Hydrol. 7: 46-64.

[18] **Vail, J.R., (1979).** Outline of Geology and mineralization of the Nubian shield east of the Nile Valley, Sudan. In: Tahoun, S.A., (ed). Evolution and Mineralization of the Arabian Shield. 1: 97-107.

[19] **Watts, C.W.; Tolhurst, T.J.; Black, H.S., and Whitmore, A.P., (2000).** In situ managements of erosion shear stress and geotechnical shear strength of the intertidal sediments of the experimental managed realignment scheme at Tollesbury, Essex, U.K. Estuarine, Coastal and Shelf Science, 58: 611-620.

[20] **Zhenhan, Wu; Patrick, J.; Daogong Hu; Zhonghai Wu; Xitao Zhao; Peisheng Ye and Wan Jiang (2004).** Hazard posed by active major faults along the Golmud-Lhasa railway route, Tibetan Plateau, China. Eng. Geol., 74: 163-182.