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LABORATORY INVESTIGATION OF MAGNETIC SUSCEPTIBILITY OF HYDROCARBON CONTAMINATED SOIL.

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Abstract

Magnetic susceptibility (MS) monitoring of hydrocarbon contaminated soils and non-contaminated soils was carried out using Bartington MS2 magnetic susceptibility system with the aim of determining the suitability of magnetic susceptibility as a proxy for hydrocarbon pollution detection. Magnetic parameters viz. (MS & FD%) of both HC contaminated and non-contaminated soil sample were determined. The correlation coefficient between MS and its controlling factor such as duration and concentration of HC pollutant were investigated. Five samples of Sandy, Clay and sandy-loam each were collected at five different places at the depth of 5 cm each using soil auger. Each sample was subdivided into five (5) samples which amount to the total of seventy-five (75) samples all together and 25 samples per soil textual class. Three (3) representative samples of each soil textural class totaling 15 samples were used as control while the remaining 60 samples were subjected to varying (0.5 ml, 1 ml, 1.5 ml & 2 ml)degree of contamination of crude oil. The MS of all the contaminated and non-contaminated samples were measured at both low and high frequencies once every week over period of one month. The result of low frequency MS of the uncontaminated sandy, clay and sandy-loam ranged from 1.8-18.75 x $10^{-6}m^3kg^{-1}$, 7.85-61.75 x $10^{-6}m^3kg^{-1}$ and 5.625-11.15 x $10^{-6}m^3kg^{-1}$respectively while the result of low frequency MS of the contaminated sandy, clay and sandy-loam ranged from 1.2-18.2 x $10^{-6}m^3kg^{-1}$, 6.575-65.35 x $10^{-6}m^3kg^{-1}$and 4.95-10.55 x $10^{-6}m^3kg^{-1}$ with their mean value of 8.185 x $10^{-6}m^3kg^{-1}$, 18.2313 x $10^{-6}m^3kg^{-1}$ and 7.4738 x $10^{-6}m^3kg^{-1}$ respectively. The correlation of LF and HF magnetic susceptibility with degree of contamination of HC showed that 100% of sandy-loam sample showed strong correlation coefficient (R^2) value above 0.95 while only 40% of sandy and 60% of clay showed strong correlation coefficient value above 0.60 when the MS was measured with varying degree of crude oil contamination. 80% of sandy and clay showed good correlation coefficient when the MS was measured over the time while only 40% of sandy-loam showed good correlation coefficient which entails period of contaminant deposition could also affect the value of soil magnetic susceptibility. Therefore, magnetic methods may provide a quick and cost-effective way to assess HC contamination in soils.

***Keywords*:** Hydrocarbon**,** Soil Pollution, Magnetic Susceptibility, Frequency Dependent Susceptibility (FD%).

1 Introduction

Environmental problems are one of the major social problems in this century. Many academic and engineering societies therefore, have paid attention to the environmental issues in recent years. Environmental problems include many problems relating to human life such as natural disasters due to earthquakes and volcanic activities, and various accidents due to

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existing constructions as well as environmental pollutions. Pollutants may cause primary damage, with direct identifiable impact on the environment, or secondary damage in the form of minor perturbations in the delicate balance of the biological food web that are detectable only over long time periods. Environmental pollution is a problem both in developed and developing countries.

Petroleum hydrocarbons are becoming a global problem for the environment. They are highly persistent in the environment, toxic and present significant health risks to human [1], Sustainability of environmental systems largely depends on a sound soil ecosystem. Changes will occur in ecosystems if soils are polluted. Polycyclic aromatic hydrocarbons (PAHs) can remain in the environment for years. Even if the sources of PAHs are removed, residual PAHs may also pose long-term risks to the environmental system. Thus, PAHs accumulated in soil have attracted more attention because of the potential risk and adverse impact they cause in soil ecosystems [2]. The presence of PAHs in the environment is the source of infection and it poses a direct threat to all of the living organisms in the contaminated area [3][4]. Magnetic analysis of the samples indicates that hydrocarbon accumulation triggers geomicrobiological activity that forms magnetite in sediment with hydrocarbon fluctuation[5]. Magnetic methods have been used as one of hydrocarbon exploration surveys as several studies show the association of magnetic anomaly with the presence of hydrocarbon in subsurface [6].

In order to analyze Hydrocarbon contaminated sites and apply suitable remediation, rapid and cost-effective assessment methods are needed. Environmental magnetic methods have a high potential to serve as such a screening and monitoring tool for soil, water and air pollution, since they are fast and highly sensitive [7].

2. Materials and Methods.

2.1. Sampling and Analysis

The samples of Sand, Clay and sandy-loam each were collected at five different places at 5 cm depth each using soil auger which give total of fifteen (15) samples. All the samples were placed in well labeled polythene bags and taken to laboratory for analysis.

In the laboratory, samples were air dry at room temperature for some days until constant mass was obtained to reduce the mass contribution of water and to avoid any chemical reaction. The samples were visibly screened to remove traces of hair, animal, and plant matter to ensure that the materials to be analyzed are not contaminated with foreign materials. The samples were then pounded using mortar and was sieved through a 2 mm sieve mesh [8], and stored in well labeled plastic containers for laboratory measurements. Each sample was subdivided into five (5) samples which amount to the total of seventy-five (75) samples

2.2 Particle size analysis.

50 g of all the air dry soil samples was put in 500 ml plastic bottle and 50 ml of $(NaPO_3)_6$ was added with 100 ml of distilled water and shake for 30 minutes on a shaking machine. The suspension was poured into 1000 ml measuring cylinder and water was added and with the hydrometer raised the volume of the suspension to 1000 ml mark.

The hydrometer was removed and the suspension was shaken vigorously. First temperature(T_1) and hydrometer (H_1) reading was taken after 40 seconds and second temperature(T_2) and hydrometer(H_2) reading was taken after 2 hours. The result was calculated using formula (1)

$$\%Sand = 100 - [H_2 + 0.2(T_1-20) - 2.0]2.0 \quad (1a)$$

$$\%Clay = [H_2 + 0.2(T_2-20) - 2.0]2.0 \quad (1b)$$

$$\%Slit = [100 - (\%Sand + \%Clay)] \quad (1c)$$

The result was interpreted for textural class using USDA Textural triangle

2.3 Magnetic Measurements

The mass specific magnetic susceptibility measurements were then carried out on the sieved samples packaged in a 10 ml plastic container at laboratory temperature. Measurements of magnetic susceptibility were made at both low (0.47 kHz) and high (4.7 kHz) frequencies using MS2 dual frequency susceptibility meter. All measurements were conducted at the 1.0 sensitivity setting. Each sample was measured five times with an air reading before and after each series for drift correction. The measured magnetic susceptibility was express as mass-specific susceptibility (χ), which was calculated from the following equation,

$$\chi = \frac{\kappa}{\rho} \quad (2)$$

where ρ is the density of the material. The values of χ was given in m^3kg^{-1}

The percentage of the mass-specific frequency dependent susceptibility was obtained from the relation[9]:

$$\chi^{fd\%} = \frac{\chi^{lf} - \chi^{hf}}{\chi^{lf}} \times 100 \quad (3)$$

Low-frequency (χ lf) and high-frequency (χ hf).Alternatively, mass specific dual frequency dependent susceptibility (χfd) is

$$\chi^{fd} = \frac{\kappa^{lf} - \kappa^{hf}}{\rho} \qquad (4)$$

where χfd is the mass specific frequency dependent susceptibility ($m^3 \, kg^{-1}$), ρ is the sample bulk density ($kg \, m^{-3}$).

3.0 RESULTS AND DISCUSSION

3.1 Result of Soil Particle Size Analysis

Table 1: Soil Textural Classes

SAMPLE	%Sand	%Silt	%Clay	TEXTURAL CLASS
A	87	10	3	Sandy
B	90	5	5	Sandy
C	92	3	5	Sandy
D	88	7	5	Sandy
E	88	6	6	Sandy
F	35	24	41	Clay
G	33	24	43	Clay
H	45	11	44	Clay
I	39	16	45	Clay
J	37	19	44	Clay
K	80	5	15	Sandy loam
L	72	16	12	Sandy loam
M	82	3	15	Sandy loam
N	78	12	10	Sandy loam
O	69	21	10	Sandy loam

3.4 Result Showing Linear Scatter Variation of Concentration with Magnetic Susceptibility

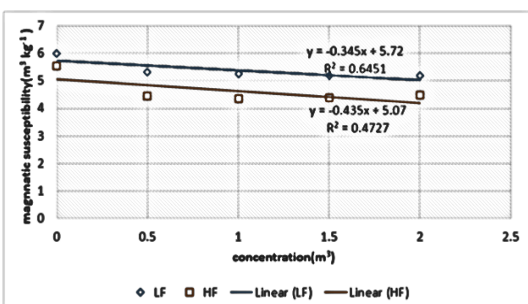

Fig. 1: Linear Scatter Variation of Concentration with Magnetic Susceptibility in Sample A

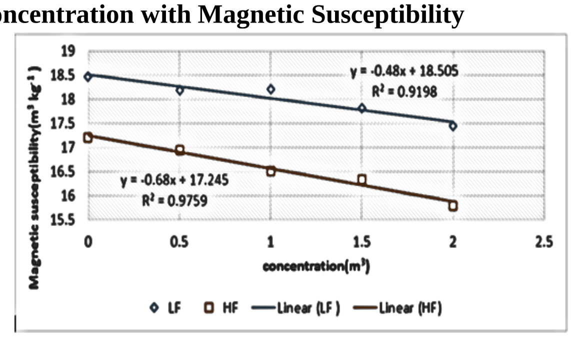

Fig.2: Linear Scatter Variation of Concentration with Magnetic Susceptibility in Sample B

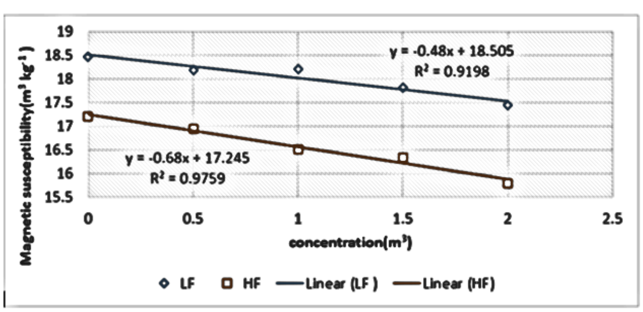

Fig 3: Linear Scatter Variation of Concentration with Magnetic Susceptibility in Sample C

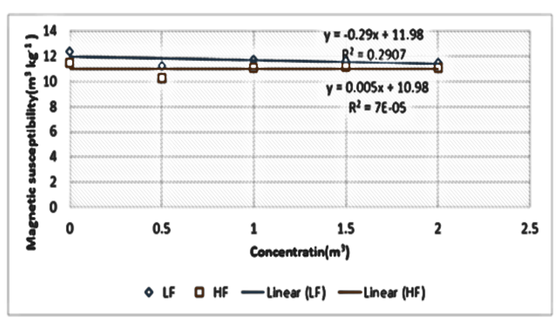

Fig 4: Linear Scatter Variation of Concentration with Magnetic Susceptibility in Sample D

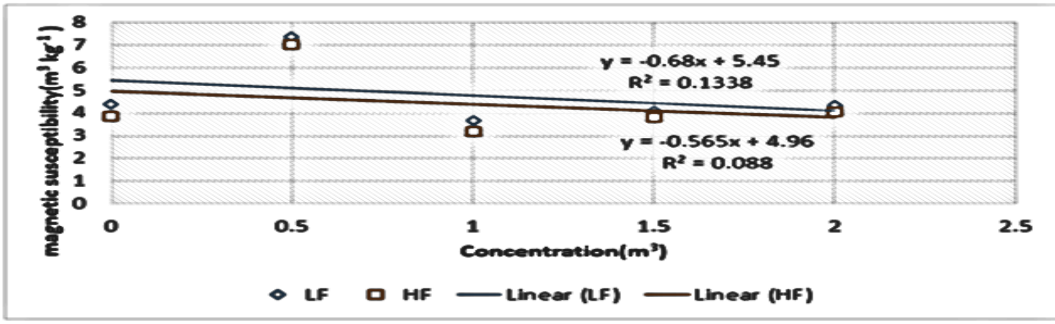

Fig.5: Linear Scatter Variation of Concentration with Magnetic Susceptibility in Sample E

The plots from A to E which are all sandy soil. Sample A, B & C shows very good correlation coefficient (**R^2**) both at LF and HF, With the exception of sample **A** which has R^2 =0.4727 at HF, D which has R^2=0.2907 and R^2=7E-05 at LF and HF respectively, E has R^2=0.1338 and R^2=0.088 at LF and HF also respectively. The very good correlation coefficient both at LF and HF depicts that the volume of concentration might be the factor that influence the changes in MS contaminatedsoil.

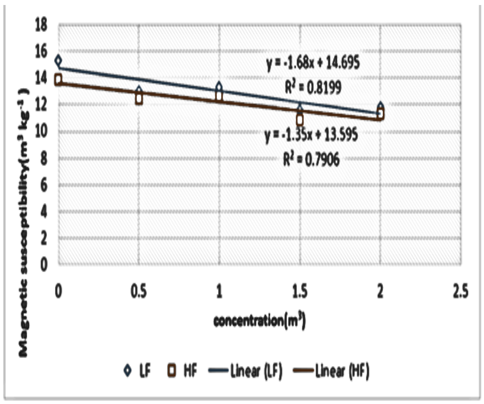

Fig 6: Linear Scatter Variation of Concentration with Magnetic Susceptibility in Sample F

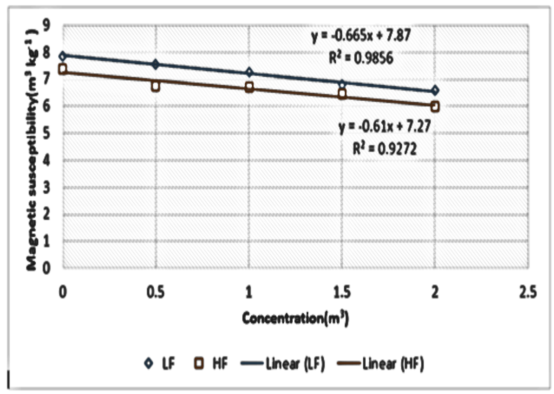

Fig 7: Linear Scatter Variation of Concentration with Magnetic Susceptibility in Sample G

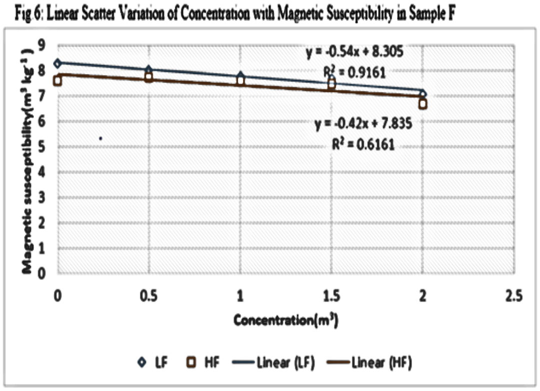

Fig 8: Linear Scatter Variation of Concentration with Magnetic Susceptibility in Sample H

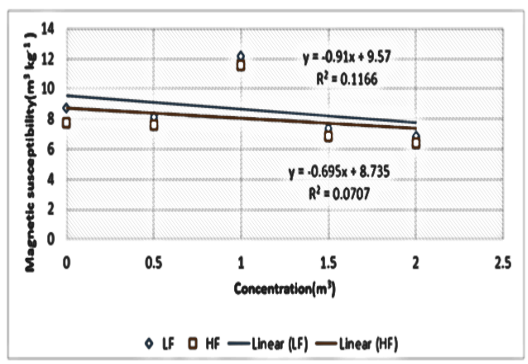

Fig 9: Linear Scatter Variation of Concentration with Magnetic Susceptibility in Sample I

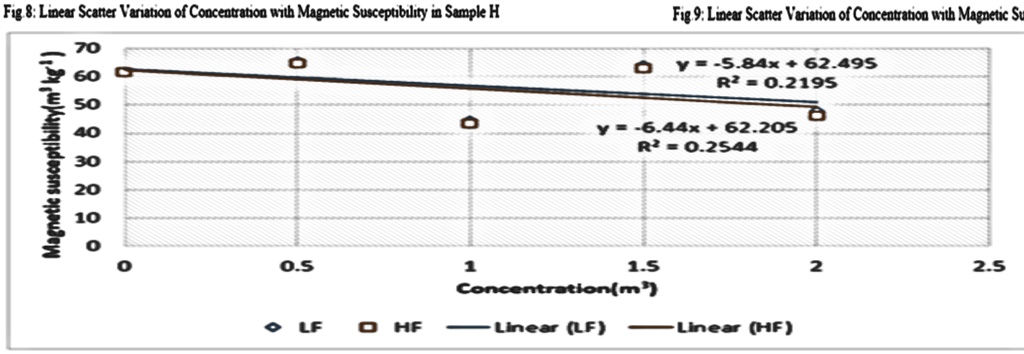

Fig.10: Linear Scatter Variation of Concentration with Magnetic Susceptibility in Sample J

The plots from sample **F** to **J** are all clay soil. The samples (F, G & H) shows very good correlation coefficient both at LF and HF with exception of sample I which has R^2=0.1166 and R^2=0.0707 LF and HF respectively, J which has R^2=0.2195 and R^2=0.0707 also t LF and HF respectively. From the result shown above, clay soil shows more correlation than sandy soil.

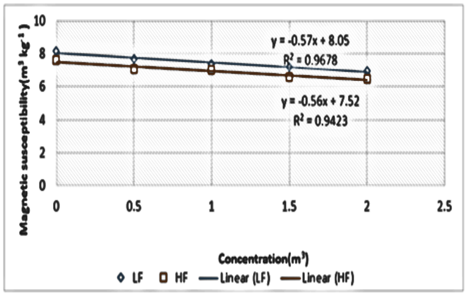

Fig. 11: Linear Scatter Variation of Concentration with Magnetic Susceptibility in Sample K

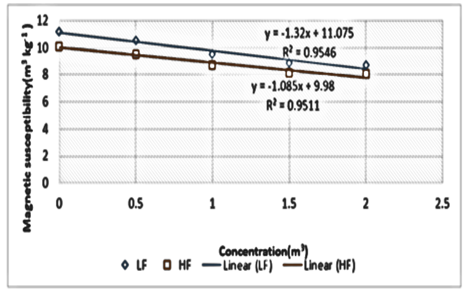

Fig. 12: Linear Scatter Variation of Concentration with Magnetic Susceptibility in Sample L

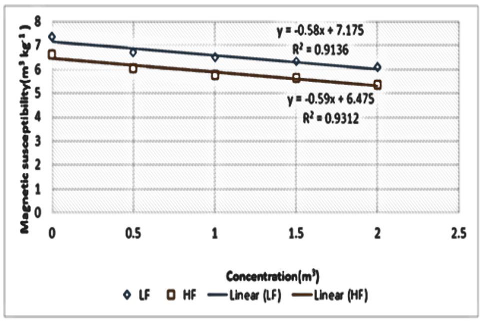

Fig. 13: Linear Scatter Variation of Concentration with Magnetic Susceptibility in Sample M

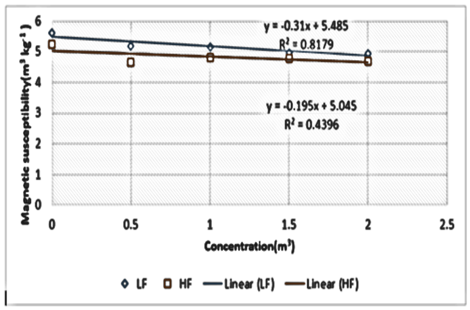

Fig. 14: Linear Scatter Variation of Concentration with Magnetic Susceptibility in Sample N

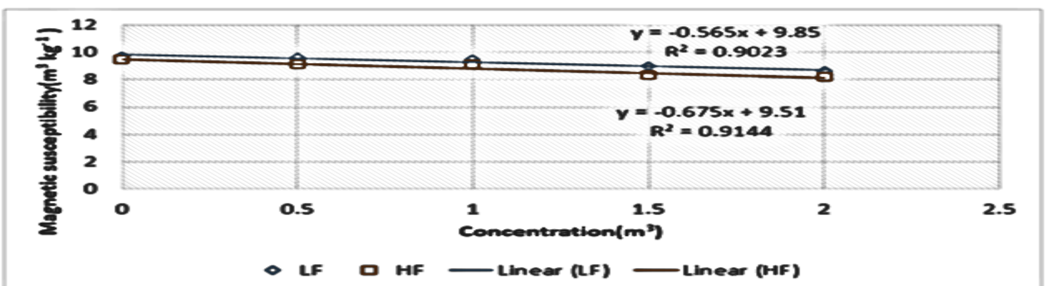

Fig. 15: Linear Scatter Variation of Concentration with Magnetic Susceptibility in Sample O

The plots from K to O which are all sandy-loam soil shows strong correlation coefficient both at LF and HF with exception of sample N which has R^2=0.4396 at HF. The strong correlation coefficient both at LF and HF depicts that the volume of concentration might be the factor that influence the changes in MS contaminated soil

3.5 Result Showing Linear Scatter Variation of Time with Magnetic Susceptibility

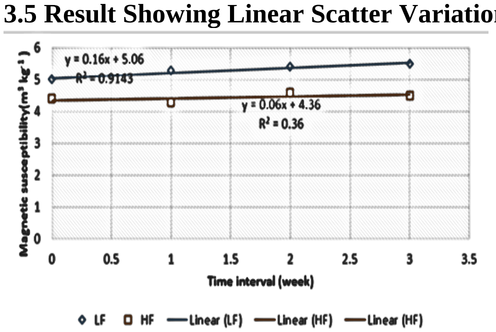

Fig. 16: Linear Scatter Variation of Time with Magnetic Susceptibility in Sample A

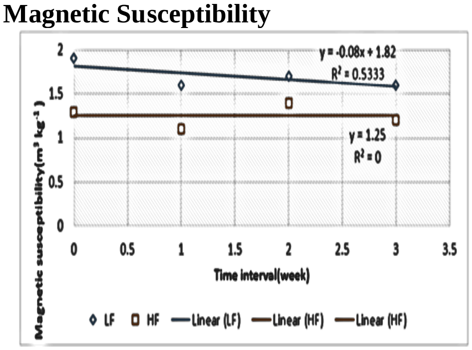

Fig. 17: Linear Scatter Variation of Time with Magnetic Susceptibility in Sample B

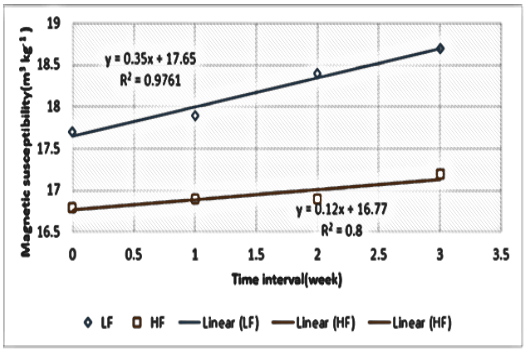

Fig. 18: Linear Scatter Variation of Time with Magnetic Susceptibility in Sample C

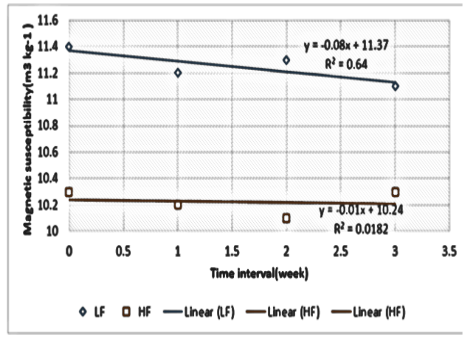

Fig. 19: Linear Scatter Variation of Time with Magnetic Susceptibility in Sample D

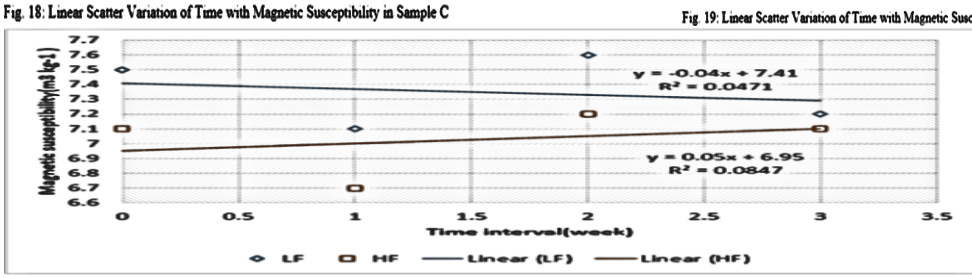

Fig. 20: Linear Scatter Variation of Time with Magnetic Susceptibility in Sample E

The plots from **A** to **E** are all sandy soil. The samples show relatively poor correlation coefficient at HF but good correlation coefficient at LF with exception of E which has R^2=0.0471 at LF . The result above depict that time might be a factor in MS variation but can be studied at LF if the study is observed within the long period of time. According to [10] the accumulation of the contaminant in soil triggers magnetic formation in soil, and the period of contaminant deposition could also affect the value of soil magnetic susceptibility or the relationship between these two parameters could be not linear.

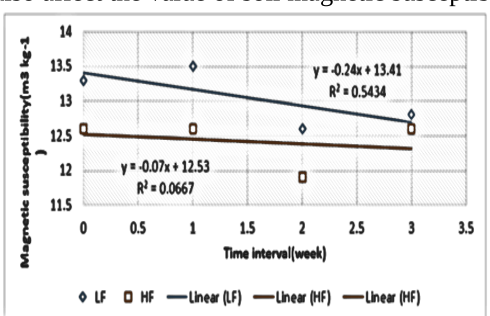

Fig. 21: Linear Scatter Variation of Time with Magnetic Susceptibility in Sample F

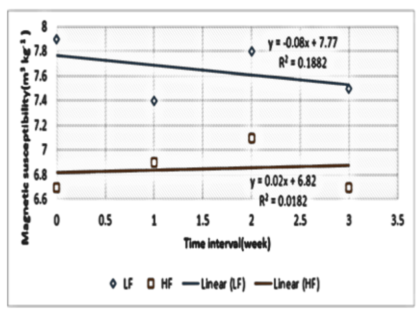

Fig. 22: Linear Scatter Variation of Time with Magnetic Susceptibility in Sample G

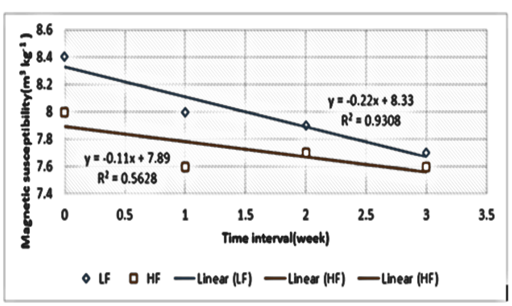

Fig. 23: Linear Scatter Variation of Time with Magnetic Susceptibility in Sample H

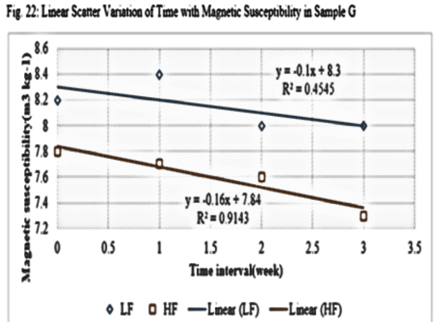

Fig. 24: Linear Scatter Variation of Time with Magnetic Susceptibility in Sample I

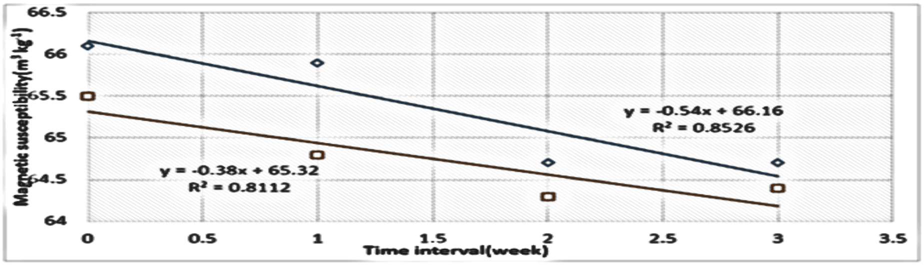

Fig. 25: Linear Scatter Variation of Time with Magnetic Susceptibility in Sample J

The plots from **F** to **J** which are all clay soil also shows relatively good correlation coefficient at different frequencies with exception of sample G which has R^2=0.1882 and R^2=0.0182 at LF andHF respectively also sample **I** have R^2=0.4545 at LF.

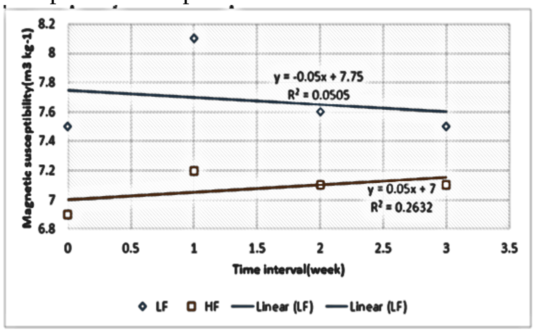

Fig. 26: Linear Scatter Variation of Time with Magnetic Susceptibility in Sample K

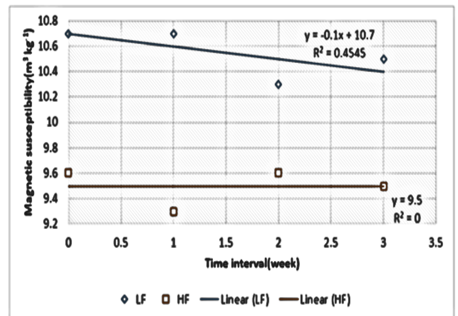

Fig. 27: Linear Scatter Variation of Time with Magnetic Susceptibility in Sample L

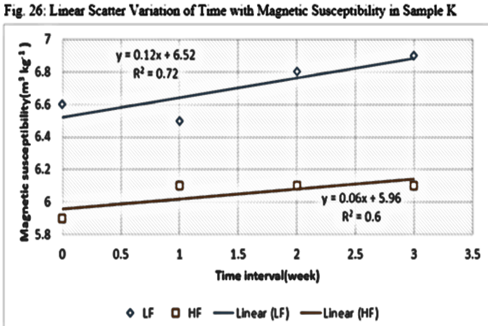

Fig. 28: Linear Scatter Variation of Time with Magnetic Susceptibility in Sample M

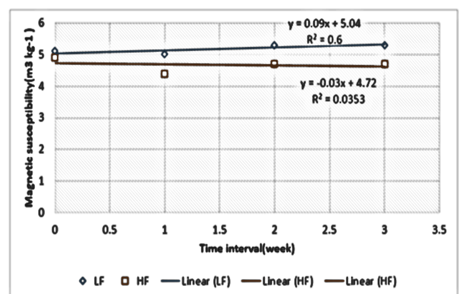

Fig. 29: Linear Scatter Variation of Time with Magnetic Susceptibility in Sample N

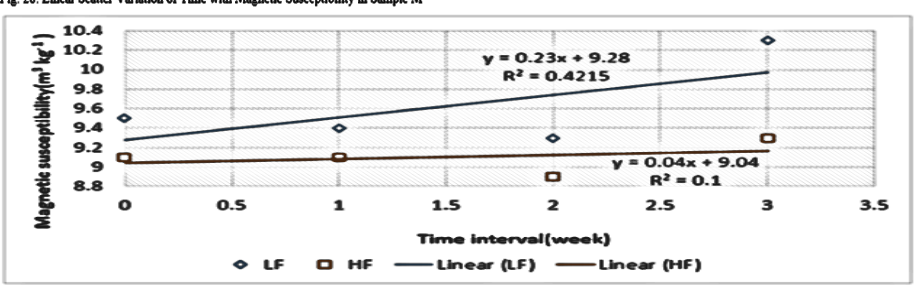

Fig. 30: Linear Scatter Variation of Time with Magnetic Susceptibility in Sample O

The plots from sample **K** to **O** which are all sandy-loam soil too shows relatively poor correlation coefficient with exception of sample **M** which has R^2=0.72 and R^2=0.6 at LF and HF respectively, Sample **N** which has R^2=0.6 at LF. The sample **M** which has shown good correlation coefficient at both frequencies.

4.0 Summary and Conclusion

This paper presents preliminary results of laboratory investigation of magnetic susceptibility of hydrocarbon contaminated soil. The result of low frequency MS of the uncontaminated sandy, clay and sandy-loam showed values ranging from 1.8-18.75 x $10^{-6}m^3kg^{-1}$, 7.85-61.75 x $10^{-6}m^3kg^{-1}$ and 5.625-11.15 x $10^{-6}m^3kg^{-1}$respectively while the result of low frequency MS of the contaminated sandy, clay and sandy-loam showed values ranging from 1.2-18.2 x $10^{-6}m^3kg^{-1}$, 6.575-65.35 x $10^{-6}m^3kg^{-1}$and 4.95-10.55 x $10^{-6}m^3kg^{-1}$ with their mean value of 8.185 x $10^{-6}m^3kg^{-1}$, 18.2313 x $10^{-6}m^3kg^{-1}$ and 7.4738 x $10^{-6}m^3kg^{-1}$ respectively. From this analysis, we assume that, the volume of the hydrocarbon content in soil and the period of petroleum hydrocarbon deposition in soil could differently increase the soil magnetic susceptibility. This correlation could be used to determine which treatment could be best to be applied for soil remediation inhydrocarbon polluted soil. The measured magnetic parameters showed enhancement when contaminated with crude oil. Therefore, magnetic methods may provide a quick and cost-effective way to assess HC contamination in soils.

References

[1] Hentati, O., Lachhab, R., Ayadi, M. & Ksibi, M. (2013). Toxicity assessment for petroleum contaminated soil using terrestrial invertebrates and plant bioassays. *Environmental Monitoring and Assessment*,185(4),2989–2998.

[2] Xu, J., Wang, H., Sheng, L., Liu, X. & Zheng, X. (2017). Distribution Characteristics and assessment of Polycyclic Aromatic Hydrocarbons in the Momoge Wetland, China.*Int. J.* Risk *Environ. Res. Public Health*, 14, 85.

[3] Maliszewska-Kordybach, B. (1999). Persistent organic contaminants in the environment: PAHs asa Case Study.*Environment,64,* 3-34.

[4] Wang, W., Huang, M., Kang, Y., Wang, H., Leung, A., Cheung, K. & Wong, M. (2011).Polycyclicaromatic hydrocarbons (PAHs) in urban surface dust of Guangzhou, China: status, sources andhuman health risk assessment. *Sci Total Environ*, 409,4519–4527.

[5] Rijal, M.L, Appel, E., Petrovsky, E. &Blaha, U. (2010). Change of magnetic properties due Tofluctuations of hydrocarbon contaminated groundwater in unconsolidated sediments. *Environmental Pollution***,** 158(5), 1756-1762.

[6] Piskarev, A. L. &Tchernyshev, M. Y. (1997). Magnetic and Gravity Anomaly Patterns related to Hydrocarbon Fields in Northern West Siberia *Geophysics.* 62,831-841.

[7] Petrovský E. & Ellwood B.B. (1999). Magnetic monitoring of air, land and water pollution. in Maher B.A. and Thompson R. (Eds.), *Quaternary Climates, Environments and Magnetism*. U.K., Cambridge University Press, pp279-322.

[8] Kanu, M.O. (2014). Application of environmental magnetism techniques for pollution Assessment and monitoring in some selected urban towns in Taraba state, North-eastern Nigeria (Unpublished Ph.D. Dissertation, Modibbo Adama University of Technology, Yola, Nigeria).

[9] Dearing, J. A., Dann, R. J. L., Hay, K., Lees, J. A., Loveland, P. J., Maher B. A, &O’Grady, K. (1996). Frequency Dependent Susceptibility Measurements of Environmental Materials. Geophysics. J. Int., Vol. 124, 228 – 240.

[10] Kirana K, Aufa N, Huliselan, E. &Bijaksana S. (2011). Magnetic and Electrical Properties of Leachate.*ITB Journal of Sciences,* 43,165-178.