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# Aspects of Geo-mathematical Diagnoses and Prognoses from Physiochemical Analyses in Landfills and other Areas of Lagos, Nigeria

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***KEYWORDS*:** Composite correlation tables, coefficient of determination, attenuation, pollution.

**ABSTRACT:** Upon physiochemical analyses of groundwaters samples in active government operated landfills and other areas of Lagos, geomathematical evaluations were undertaken to ascertain the roles of the municipal solid wastes (MSW) in the differentials in concentrations with depth and / or distances away from the suspected causal mode. Novel transpositions of the correlation tables to produce composite tables revealed striking interactions amongst the analytes at depth and / or distances. The correlations between the anions and cations were essentially excellent except for K & Mn. The likely substitutions of K/Mn in the groundwater are in the sequence: Cd > Cr >Ni >Hg >Fe >Zn > Pb > As >K/Mn. Using the regression plots in the Olusosun groundwater, Cd showed that it required the most distance (802m) away from the landfill for complete attenuation among the cations while chloride required the most distance (570m) amongst the anions. The results show that attenuation is exponentially higher for depth relative to distance. Corollary, it takes a factor of 1:55 (depth : surface distance) to produce a unit change in pH, electrical conductivity- 1:117 , DO- 1:47, chloride- 1:68, nitrate/phosphate-1:107, sulphate- 1:100; and 1:37,85,64,63,40,64,89,56,37,117 for K, Zn, Fe, Ni, Cd, Hg, Pb, Cr, Mn, & As respectively. Overall, the sequence indicates attenuation of pollution away from the landfills with clayey/ lateritic lithology. The physiochemical results of areas extraneous to MSW operations implicate the landfills as major contributors to pollution in the Lagos landfill area of Nigeria. © JASEM

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*Introduction:*
Correlation and regression analyses are increasingly becoming more veritable geomathematical tools for prediction, and for in-depth assessment in environmental studies.

Using Microsoft Excel 2007, data acquired from the physiochemical analyses of groundwater in and around landfills and other areas in Lagos were subjected to geomathematical evaluation. This was in order to expound on the level of contributions of the emplaced municipal solid waste (MSW), vehicular traffic and other anthropogenic activities to the observed concentrations in the aforementioned environment.

A number of additions to knowledge are here embodied. They include the novel transposition of correlation tables with the original values to form composite tables. Various predictive models were also devised for environmental prognoses. These may form useful aids for future works on attenuation-based remediation using geomathematics.

*Location of the Study Areas:* The study was undertaken in and around all the current Lagos Waste Management Agency (LAWMA) operated landfills areas, Badagry (control area) and Oshodi in Lagos State of Nigeria (fig. 1).

*Geological Settings:* The geology of the landfill areas is essentially that of the Oligocene to Pleistocene Coastal Plain Sands (CPS) except for that of Epe landfill area and Badagry, which are of Recent Littoral and Lagoonal Deposit. The name Coastal Plains Sands was introduced by Tattam (1943) to indicate the extensive red earths and loose, ill-sorted sands underlying the Recent deposits of the Niger Delta and overlying the Eocene Bende-Ameki group. The name is now well—established in the stratigraphy of the Delta and it has been retained in the south—western coastal sedimentary basin, although the abundance of clays in the formation In this area do not make it entirely appropriate (Jones H. A, et al. 1964).

The Recent sediments are underlain by the CPS while the CPS overlay a thick clay layer, the Ilaro Formation. The CPS consists of thick bodies of yellowish and white sands and gravels. The Formation is poorly sorted and has local shale interbeds, lenses of clays and sandy clay with lignite.

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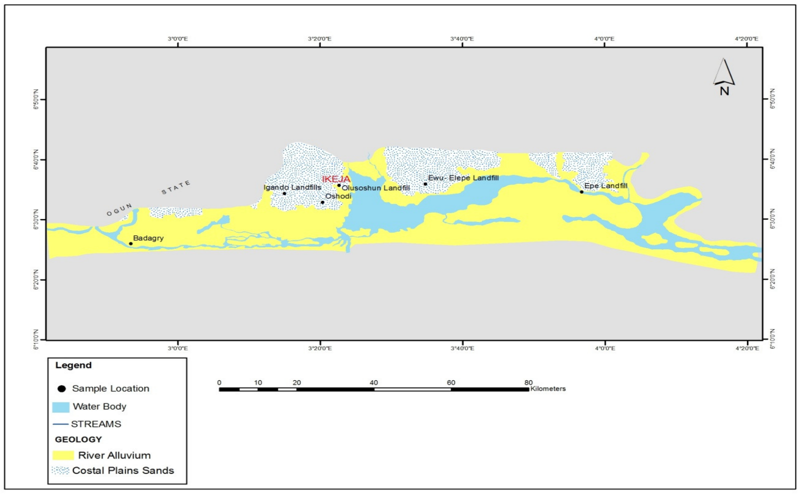


**Fig. 1:** Geological Map of Lagos State showing the landfill locations and other areas.

*Methodology*: Reconnaissance geological surveys were first undertaken and recorded on reaching the field. One litre clean sample containers (high density polyethylene-HDPE bottles) were used with the tips of the taps from which samples were collected sterilized with ethanol to remove/ reduce the microbial load at the tips of the taps. These containers were filled to the brim to prevent trapping bubbles of oxygen which may affect the correct determination of dissolved oxygen (DO). The in-situ parameters were immediately analyzed in the field.

Analyses were conducted in line with standard procedures (as devised by American Public Health Association -APHA, 1995) at Schmidt Research Laboratories with assistance from LASEPA laboratories (Lagos). Microsoft Excel (2007) was used for statistical analyses.

## RESULTS AND DISCUSSIONS

**Table 1**: Correlation with distance: heavy metal vs. heavy metal

| | *Fe* | *Ni* | *Cd* | *Hg* | *Pb* | *Cr* | *Mn* | *As* |
|---|---|---|---|---|---|---|---|---|
| Fe | 1 | | | | | | | |
| Ni | 0.969731 | 1 | | | | | | |
| Cd | 0.988471 | 0.995522 | 1 | | | | | |
| Hg | 0.87142 | 0.96482 | 0.935646 | 1 | | | | |
| Pb | 0.998456 | 0.981798 | 0.995356 | 0.897325 | 1 | | | |
| Cr | 0.992065 | 0.992736 | 0.999664 | 0.92618 | 0.997517 | 1 | | |
| Mn | 0.986979 | 0.99638 | 0.999954 | 0.938976 | 0.99439 | 0.99937 | 1 | |
| As | 0.966823 | 0.875186 | 0.917001 | 0.717204 | 0.95114 | 0.927034 | 0.913146 | 1 |

**Table 2**: Composite correlation with distance at Ewu-Elepe: heavy metal vs. heavy metal

| | Fe | Ni | Cd | Hg | Pb | Cr | Mn | As |
|---|---|---|---|---|---|---|---|---|
| Fe | 1 | 0.96973 | 0.98847 | 0.87142 | 0.98818 | 0.992065 | 0.986979 | 0.966823 |
| Ni | 0.96973 | 1 | 0.99552 | 0.96482 | 0.920838 | 0.992736 | 0.99638 | 0.875186 |
| Cd | 0.98847 | 0.99552 | 1 | 0.93565 | 0.953577 | 0.999664 | 0.999954 | 0.917001 |
| Hg | 0.87142 | 0.96482 | 0.93565 | 1 | 0.785923 | 0.92618 | 0.938976 | 0.717204 |
| Pb | 0.98818 | 0.92084 | 0.95358 | 0.78592 | 1 | 0.961065 | 0.950655 | 0.994555 |
| Cr | 0.99207 | 0.99274 | 0.99966 | 0.92618 | 0.961065 | 1 | 0.99937 | 0.927034 |
| Mn | 0.98698 | 0.99638 | 0.99995 | 0.93898 | 0.950655 | 0.99937 | 1 | 0.913146 |
| As | 0.96682 | 0.87519 | 0.91700 | 0.71720 | 0.994555 | 0.927034 | 0.913146 | 1 |

The use of composite correlation gave far better understanding of the interactions amongst the analyzed components as shown in tables 1 & 2. All the parameters in the Olusosun groundwater showed attenuation with distance except total acidity and hardness, DO, K, Mn and As. The implication for DO is that it improves away from the landfill. K, Mn increasing away from the landfill may indicate that their inherent natural concentrations were reduced by the effects of the landfill. It is possible that some of the sites of K, Mn, and As in the natural soils were substituted by other chemical species from the landfill.

Most of the measured indices correlated strongly and negatively with distance. Correlation analysis of the metals showed that all the heavy elements correlated strongly with one another except As which was poor. Mn correlated negatively amongst the metals suggesting that its concentration in groundwater reduced towards the landfill unlike the other metals. It is possible that the natural concentration of Mn in the groundwater was substituted by other metallic contaminants from the sphere of the landfill. At depth, the trend of correlation was virtually replicated.

The correlations between the anions and cations were excellent except for K & Mn. The negative values derived for K and Mn seems to re-iterate the assumption that the concentrations of these metals in the groundwater is more related to nature and are reduced towards the landfill foci. In terms of the interactions of anions with the metals to groundwater at both depth and distances: sulphate >nitrate =phosphate>chloride. Whereas, in terms of interactions of anions only to groundwater at both depth and distances: chloride> sulphate >nitrate =phosphate.

**Table 3**: Composite correlation table (at distance in Olusosun): metal vs. metal

| | **K** | Zn | Fe | Ni | Cd | Hg | Pb | Cr | Mn |
|---|---|---|---|---|---|---|---|---|---|
| K | **1** | -0.5331 | -0.7772 | -0.7961 | -0.9971 | -0.7831 | -0.498 | -0.8792 | 0.999989 |
| Zn | **-0.5330** | 1 | 0.9467 | 0.9364 | 0.5960 | 0.9436 | 0.9992 | 0.8718 | -0.52911 |
| Fe | **-0.7771** | 0.9467 | 1 | 0.9995 | 0.8229 | 0.9999 | 0.9328 | 0.9831 | -0.77424 |
| Ni | **-0.7960** | 0.9364 | 0.99953 | 1 | 0.8399 | 0.9998 | 0.9214 | 0.9883 | -0.79324 |
| Cd | **-0.9970** | 0.5960 | 0.82292 | 0.8399 | 1 | 0.8283 | 0.5629 | 0.9130 | -0.99672 |
| Hg | **-0.7831** | 0.943609 | 0.999955 | 0.999777 | 0.828256 | 1 | 0.929381 | 0.984805 | -0.78019 |
| Pb | **-0.4982** | 0.999174 | 0.932833 | 0.92137 | 0.562928 | 0.929381 | 1 | 0.851157 | -0.4942 |
| Cr | **-0.8792** | 0.871779 | 0.983118 | 0.988257 | 0.912982 | 0.984805 | 0.851157 | 1 | -0.87697 |
| Mn | **0.99998** | -0.52911 | -0.77424 | -0.79324 | -0.99672 | -0.78019 | -0.4942 | -0.87697 | **1** |

The low interaction of K, Mn with depth and distance may indicate their substitution by other metals, first from leachates development and then in the aquifer body. This was also buttressed by their inverse relationship with other metals (tables 3). When the sums of all the values are considered without the directional impact, Pb and Zn showed the best interaction with the other metals. From the correlation with distance, using the coefficient of determination, one can postulate that the substitution of Mn in the groundwater is likely to be in the sequence: Cd > Cr >Ni >Hg >Fe >Zn > Pb > As >K. The likely substitution of K is: Cd > Cr > Ni > Hg > Fe > Zn >Pb >As >Mn.

All the observed trends using distance were replicated using depth. The import of the above proposed substitutions by the metals is clearer when it is noted from the coefficient of determination that about 99% of the variations of Mn with depth is impacted by changes in Cd. Whereas 77% , 63% , 61%, 60%, 28%, 24%, (-14%, -100%) of the variations in Mn are attributable to changes impacted by Cr, Ni, Hg, Fe, Zn, Pb, As & K respectively. It also means that K is almost never substituted by Mn and this seems chemically permissible. The low concentration of Hg reduces its potency for interaction. Overall, it means that the Mn in the groundwater is majorly substituted by Cd, Cr, & Ni that make it to the groundwater. The reverse correlation of K, As and Mn indicates that their concentration increases away from the landfill and may be more influenced by the mineralogy of the lithology.

The other measured parameters (except DO) correlated negatively with depth / distance. They also correlated positively with one another inferring that they are all influenced by a common factor – the landfill. Overall, the decreasing concentrations of most of the analytes away from the landfills implicate the latter as the causal mode.

Using groundwater at Oshodi, correlation at both depth, and distance was inconsistent. This suggests that the transfer loading station (TLS)- bearing an impervious concrete pavement, is not the major contributor to the observed concentrations. The relationships among the measured parameters were almost counter-balanced by the direction of influence as indicated by the positive and negative correlation values. Analytes in the Badagry samples infer near pristine conditions.

In the Soluos 2 & 3 area, all the measured parameters negatively correlated with distance except DO. Most were also strongly correlated. This means that as distances increased, the concentration of the measured parameters decreased. Further consideration of the DO indicates 90% of the variations in this parameter are attributable to changes in distance.

Using distance, Pb correlated the most with other measured heavy elements thus Pb > Cd >Ni >Hg > Cr >Mn > As > Fe. The anions and cations related excellently and trended in the same negative direction indicating that the causation is similar. Conversely, Fe and K point more to nature given their reverse directions. In terms of anions contributions, nitrate > chloride > phosphate > sulphate.

From the regression analyses, at mean groundwater depth of about 18m, the estimated Cr was 0.05733mg/l whereas the observed value was 0.062mg/l (Table 5).

**Table 5:** Using the intercepts and slopes of the regression equations of the Olusosun landfill areas to estimate concentration metals

| | K | Zn | Fe | Ni | Cd | Hg | Pb | **Cr** |
|---|---|---|---|---|---|---|---|---|
| a | -2.2953 | 0.033286 | 6.535786 | 0.157643 | 0.111929 | 0.018112 | 0.337714 | **0.236071** |
| b | 0.15471 | -0.00171 | -0.33721 | -0.00736 | -0.00307 | -0.00094 | -0.01729 | **-0.00993** |
| y=0 | -14 | -19 | -19 | -21 | -36 | -19 | -19 | **-23** |

Example:
Estimation of concentration of Cr at a depth of 18m:

$Y= a + bx$
(where y= concentration of analyte & (y=0)= nil contaminant/ pollutant concentration
a = y intercept/ constant
b=slope
x= depth)

$Cr = 0.236071 + (-0.00993) \times 18$
$Cr =0.23607 + 0.17874$
Cr= 0.057331mg/l

The results show that attenuation is exponentially higher for depth relative to distance. For instance, it takes a factor of 1:55 (depth : surface distance) to produce a unit change in pH, electrical conductivity- 1:117 , DO- 1:47, chloride- 1:68, nitrate, phosphate- 1:107, sulphate- 1:100, 1:37,85,64,63,40,64,89,56,37,117 for K, Zn, Fe, Ni, Cd, Hg, Pb, Cr, Mn, & As respectively.

More explicitly stated, it means for instance that in the Olusosun landfill area if it will take 1m of soil thickness to completely adsorb Ni, a surface distance of 63m will be required ( assuming the leachate flows only on the surface gently -like groundwater to permit adsorption). This argument is only a rule of the thumb as in actuality a plethora of factors inter-play. The values obtained in this regard from Soluos 2 & 3 compares well with Olusosun while the minor disparities may be attributable to lithology, type of waste-load, etc ( which though similar are not completely same). However, the Ewu-Elepe gradient of depth versus distance gave very low values of between 1:2 and 1: 7. It is possible that the interactions of the leachate with the soil are still at its infancy given the relative nascence of this landfill, lower waste volume, amongst other contributory factors..

**Table 6 :** Deduction of ratios using slopes for groundwater at the Olusosun landfill area

| Olusosun | | PH | EC | TSS | T. acd | T.alk | DO | Chlori |
|---|---|---|---|---|---|---|---|---|
| | $\Delta_{depth}$ | -0.65 | 471 | 6.357 | 7.1429 | -6.5 | 0.5 | 2.286 |
| | $\Delta_{dist}$ | 0.01167 | -4 | 0.0833 | 0.266667 | 0.09667 | 0.010667 | 0.0333 |
| | Ratio | 55 | 117 | 76 | 26 | 67 | 46 | 68 |

| | | Nitrat | Phosp | Sulp | K | Zn | Fe | Ni |
|---|---|---|---|---|---|---|---|---|
| Olusosun | $\Delta_{depth}$ | -1.57143 | -0.02607 | -2.1 | 0.154714 | -0.00171 | -0.33721 | -0.00736 |
| | $\Delta_{dist}$ | -0.01467 | -0.00024 | -0.021 | 0.00416 | -0.00002 | -0.00522 | -0.00012 |
| | Ratio | 107 | 107 | 100 | 37 | 85 | 64 | 63 |

| Olusosun | Cd | Hg | Pb | Cr | Mn | As |
|---|---|---|---|---|---|---|
| $\Delta_{depth}$ | 0.00307 | 0.00094 | 0.01729 | 0.00993 | 0.001357 | 0.00629 |
| $\Delta_{dist}$ | -7.7E-05 | -1.5E-05 | 0.00019 | 0.00018 | 3.67E-05 | 5.33E-05 |
| Ratio | 40 | 64 | 89 | 56 | 37 | -117 |

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**Table 7:** Ratio of the slope of depth vs slope of distance for the measured parameters in groundwater in some of the study areas.

| | pH | EC | TSS | T. acidt | T.alkalinty | DO | Cl | $NO_3$ | $PO_4$ | $SO_4$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **Soluos** | 23 | 86 | 37 | 45 | 45 | 13 | 54 | 81 | 103 | 81 |
| **Oshodi** | -950 | -950 | -158 | -94 | -158 | -95 | -86 | -282 | -189 | -217 |
| **Olusosun** | 55 | 117 | 76 | 26 | 67 | 46 | 68 | 107 | 107 | 100 |

| | K | Zn | Fe | Ni | Cd | Hg | Pb | Cr | Mn | As |
|---|---|---|---|---|---|---|---|---|---|---|
| **Soluos** | 422 | 55 | 59 | 55 | 59 | 86 | 63 | 77 | 101 | 7 |
| **Oshodi** | -950 | -950 | -158 | -94 | -158 | -190 | -95 | -86 | -282 | -189 |
| **Olusosun** | 55 | 117 | 76 | 26 | 67 | -4.7E+17 | 46 | 68 | 107 | 107 |

It is also possible to predict theoretically, the position at which the effects of pollutants/ contaminants may cease to exist through the soil to the groundwater because of attenuation (i.e. at y=0). For instance, although from the regression plots, hardness in the Olusosun soil is expected to continue indefinitely (meaning that the hardness is majorly impacted by mineralogy and/ or factor outside the landfill), Cd showed that it required the most distance (802m) away from the landfill for complete attenuation among the cations while chloride required the most distance (570m). However, total acidity, DO, K, Mn, As increased with distances away from the landfill. Similarly, Cd showed it required the most depth (26m) and Chloride (25m). Mn increased with depth and may suggest natural imbuement.

*Conclusion:* The correlation and regression values establish a case to implicate anthropogenic activities for the despoliation of the landfill environment even though the specific individual quanta of contributions from the municipal solid wastes and the various human activities are yet unknown. The use of geomathematical evaluation shows clearly that the municipal solid wastes in the landfills are major contributors to the imbuement of the environment with pollutants. This work also highlights the possibility of creating invaluable models for diagnoses and prognoses in environmental studies such as elemental substitutions and attenuative effects.

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