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The Use of Portable Turbidity Meters in Developing an Erodibility Classification System for Iraqi Soils

Dr. Ghazi Maleh Mutter
Assistant Professor, Department of Environmental Engineering, Al-Mustansiriyah University, Baghdad, Iraq

ABSTRACT

This study aims to use portable turbidity meters in developing a quick dispersion ratio test (DR, %) to be used as an index of soil stability and erodibility. The work investigates; the use of many stabilizers (Bitumen, Lime and Cement) in the preparation of many artificially stabilized lead contaminated soils; the measurement of the scouring depth (SD, mm), critical shear stress (τ_c, pa) and then the erodibility coefficient (k_d, cm^3/kN.s) by a "Mini" Jet Erosion Test. Finally, the comparisons between the erodibility coefficient and dispersion ratio (DR, %) values of soils, as estimated by a portable turbidity meter and by the gravimetric method. The results showed that all stabilizers can markedly improve the stability of soil. In general, good correlations were found between the turbidity (NTU) and suspended solids (mg/l) of the stabilized soils (R= 0.99, 0.96 and 0.97) for bitumen, lime and cement respectively. The turbidity DR (%) appears to have a high correlation with the stabilizers percentages and with k_d of soils. This study proved that the turbidity DR (%) is a cost-effective method and can be easily utilized as a successful index of soil stability. Because this method is simple and quick and of reliable results, it may be recommended to be used in estimating the stability and then erodibility of Iraqi soils depending on a classification system developed according to the findings of this study.
Keywords: Portable, Turbidity meters, Erodibility, Classification system, Iraqi soils.

I. INTRODUCTION

Soil erodibility is usually determined in the field by measuring the true amount of eroded soil during natural rainstorms or under carefully regulated artificial water application. However, this is costly and time-consuming procedure. Low costs and quick methods are needed to give useful predictions. Recently in Iraq, Salah and Al-Madhhachi (2016) investigated the erodibility of lead contaminated cohesive soil using a newly "mini" JET method.

Globally, many attempts to define a proper index for soil erodibility by water, by both field and laboratory studies, have been conducted. For field studies, Chorly (1959) calculated an erodibility index by measuring both soil mean shearing resistance and soil permeability on the assumption that when both are high in soil, the soil has lower erodibility. Wischmeier et al. (1971) developed a monograph to determine the K factor depending on four soil properties: texture, organic matter, soil structure and soil permeability. The laboratory studies, however, fall in two general groups (Grieve, 1979). First, tests aimed at measuring intra-aggregate bond strength by special chemical procedures. These tests designed to measure the proportion of soil materials vulnerable to dispersion in water (usually clay and silt) by: dispersion ratio (Middleton, 1930; Loveland *et al.*, 1986), clay ratio (%sand+%silt)/%clay (Bouyoucos, 1935) and the amount of dispersed clay after the dispersion of certain amount of soil in water (Gupta et al., 1984; Mutter, 1989), soil aggregates "coherent test" in water (Emersion, 1967). Second, tests which subject aggregates to force designed to simulate fields under rain impact in the laboratory but in different rainfall tests (Woodburn, and Kozachyn, 1956), percentage of 0.5mm water stable aggregates after subjecting to rain simulation (Bryan, 1971), water drop test assessing percentage aggregates destroyed by Pre-selected number of impacts by a standard raindrop of a fixed height (Brauce-Okine and Lal, 1975), and the Wet Sieving method developed by Tulin in 1928 (Molope, 1985). Recently, the concentration of the dispersed materials has been estimated by colorimetric and light absorption meters. Allenn (1984) measured the percentage light transmission and the same procedure was also followed by Pojasc and kay, (1989). Mutter (1989), in a procedure modified from Gupta et al., (1984), has read the dispersed materials at 420 nm wavelength on a (4049 LKB) spectrophotometer.

The objective of this study is to develop a quick dispersion ratio test (DR, %), as an index of soil stability, and derive a stability classification system for Iraqi soils. The work includes; the use of many common soil stabilizers (cement, lime and bitumen) in the preparation of many artificially stabilized lead contaminated soil samples, the measurement of erodibility parameters by "Mini" JET device, suspended soil materials (as DR, %) in the suspensions (1:2 soil water mixtures) of treated soils by a water turbidity meter device first and then by a gravimetric method for the purpose of accurate comparisons.

II. TURBIDITY AND DISPERSION RATIO

Turbidity is a measure of water suspended solids (SS). Turbidity can come from suspended sediment such as silt or clay, inorganic materials, or organic matter such as algae, plankton and decaying material. In addition to these suspended solids, turbidity can also include colored dissolved organic matter (CDOM), fluorescent dissolved organic matter (FDOM) and other dyes (Fink, 2005). Some turbid meters measure both of transmitted and scattered light intensity, and indicate a medium value. The word "turbid meter" means the whole range of photometers measuring turbidity.

The measurement of total suspended solids (TSS, in no filterable residue) is important in many turbid samples. Chemical or physical changes in the process may result in an increase in turbidity. Thus, solids analyses are usually completed by gravimetric methods; although it may be difficult to obtain a representative sample and it is time consuming and may take two or four hours or more to complete (Hach, 2009). The accuracy and precision of spectrophotometric method depends on three major factors: 1) instrumental limitations, 2) chemical variables and 3) operation skill. Under ideal conditions it is possible to achieve relative standard deviations in concentrations as low as about 0.5% which enables the determination in the range of micro quantities. The precision of spectrophotometric method also depends on concentration of the determinant (Engelhardt and Sadar, 2013).

The common but unrecognized problem in measuring the absorbance is stray light error. All wavelength isolation devices tend to produce some low intensity radiations at wavelength other than the desired one. This is usually due to the optical imperfections, or simply from scattered light due to dust particles on optical surfaces. Thus, the stray light errors will result in a negative bias for absorbance readings (Hach, 2013).

Dispersion ratio (DR) method is well known to give a reliable estimation for soil erodibility (Grieve, 1979; Morgan, 1985). The micro-aggregation or dispersion technique developed by Middleton (1930) has since been used as index of aggregate stability. The term "dispersion ratio" refers to matter suspended in water or in soil solution, and is related to the percentage of clay (<0.002mm) in soil sample. Dispersed solids include both total suspended solids; the portion of total solids retained by a filter, and total dissolved solids; the portion that passes through a filter (American Public Health Association, 1989). Dispersed solids can be measured by evaporating a soil-water mixture in a weighed dish, and then drying the residue in an oven at 103 to 105° C. The increase in weight of the dish represents the dispersed solids and hence soil erodibility.

III. MATERIALS AND METHODS

Lean clay (Silt Clay Loam, USDA classification) of clean and uncontaminated soil samples (Table I) were used to carry out the experiments; acquired from depths of (0.0 to 90 cm) from an orchard field near Al-Taji region, north of Baghdad city. The soil samples were tested and analyzed according to the ASTM standards (ASTM, 2006). Other soil properties, of the concern in this study, are also listed in Tables II to IV.

A. Soil Samples

Table 1. The Physical And Chemical Properties Of Studied Soil

							Chemical properties: soil suspension (1:2 soil:water)					
Soil properties	**Silt (%)**	**Clay (%)**	**Specific gravity**	**Organic Matter (%)**	**$CaCO_3$ (%)**	**$CaSO_4$ (%)**	**pH**	**EC, (mS/cm)**	**SAR**	**Pb, (ppm)**	**DR, (%)**
Value	57	30	2.48	1.09	0.3	0.6	7.4	1.03	7.11	19.5	7.03

B. Stabilizing Materials

Three common stabilizers were utilized in this study; cement, lime and bitumen which are all available in the local market as building materials. The cement is manufactured in Iraq, so it is considered an available material for stabilizing soils. The calcite is relatively high in Iraqi soil, which means that lime is an economically viable option commonly utilized in soil stabilization, and because of oil products are readily available from the refineries in Iraq, stabilization of local soil with bituminous material may be recognized as a solution for some soil construction problems.

The type of cement used in this study is the ordinary Portland cement (OPC) and the type of lime is the hydrated lime $Ca(OH)_2$, which is locally named as “Nora”. The bitumen used in this study, which is locally named as “flank coat” is an UAE product under the name “Prakcoat” which is made by the Oasis Grease & Lubricants Company. Bitumen features are: cold applied, easy to apply, adhere to (concrete, metal, wood), nonflammable, resist the chloride and sulphate salts attack in soil, and economical.

IV. EXPERIMENTAL WORK

A. Soil Samples Tests

Most physical and engineering properties were determined at the Hydraulic laboratory of the Environmental Engineering Department, Engineering College, Al-Mustansiriyah University according to the ASTM standards (ASTM, 2006). However, scouring depth (SD), erodibility coefficient (k_d) and critical shear stress (τ_c) of soils were determined by a “mini” Jet Erosion device developed by Al-Madhhachi *et al.*, (2013).

The data obtained from the “mini” Jet were analyzed with a linear model using Blaisdell solution technique to derive τ_c and k_d. Digital Shore-D durometer (0.0 to 100 scale) was used for measuring the hardness of soil-stabilizer admixture, as it used by (Wang et al., 2015) to determine the hardness of cement-clay admixture, at the Materials Department laboratory, Engineering College, Al-Mustansiriyah University. Soil samples were prepared according to the following steps:

1. All the soil samples were air-dried, broken into small sizes and sieved through a 4.75 mm sieve according to ASTM standard. The sieving was performed to ensure that the soil was of uniform grade.
2. The artificial Pb-contaminated soil samples were prepared by mixing lead nitrate, as the source of lead (Pb), to produce a soil of 4000 mg/kg lead concentration in the natural soil. As a reminder, 300ppm in soil is the maximum acceptable Pb concentration in EU countries (Wild *et al.*, 1993).
3. Different percentages of stabilizers (0%, 3%, 6%, and 9%) by soil weight were added directly to a 2 kg of the lead contaminated soil and mixed by hand until the mixture seems to be homogeneous. The samples were then packed in special plastic (PVC) mold and compacted using Proctor test to be ready for the "mini" jet erosion tests, as described by Al-Madhhachi *et al.* (2013) and Mutter *et al.* (2017). It should be noted that all the JET erodibility tests were conducted after 7 days of curing time.

B. Soil Suspension Testing Methods

1) Chemistry of Soil: All tests on soil sample solutions were carried out at the Sanitary laboratory of the Environment Department, Engineering College, Al-Mustansiriyah University. The soil solution chemical properties, namely pH, EC, soluble Pb, and SAR, were measured in the filtered 1:2 soil solution prepared for this purpose. The pH was measured by a pH-meter, EC by an Electrical Bridge, soluble Pb (ppm), Na, Ca and Mg in (meq/l) by the Atomic Absorption Spectrophotometry. The sodium adsorption ratio was calculated by the following formula (USDA, 1954):

$$SAR=\frac{Na^{+1}}{\frac{\sqrt{Ca^{+2}+Mg^{+2}}}{2}} \quad (1)$$

Where: sodium, calcium and magnesium are in meq/liter.

Sodium adsorption ratio (SAR) is a measure of the suitability of water for use in irrigation to prevent soils from the sodium hazard. In general, the higher the sodium adsorption ratio, the less suitable the water is for irrigation. It is also an index of the soil sodicity and can be determined from the chemical analysis of the soil solution.

2) Dispersion Ratio (DR, %): The dispersion ratio was measured according to Middleton (1930) principles and by a quick method modified from CMG (2015). 25g of lead contaminated soil were mixed in 250ml conical flask with 50ml water to get a 1:2 soil water mixture. The mixture was shaken by hand for 1 minute, and then left for 2 hours. After 2 hours the soil particles greater than the clay (>0.002mm) may settle down. A10 ml of the suspension was transferred to a weighed beaker and put in the oven to determine the dispersed soil materials in suspension by the gravimetric method. For the clay content in the untreated original soil sample, the same above procedure is followed to determine the clay existing in the original soil sample. The gravimetric (DR, %) was calculated by the following equation:

$$\text{Gravimetric (DR, \%)} = \frac{\text{Weight of Clay in Treated Suspension}}{\text{Weight of Clay in Original Soil Suspension}} \times 100 \quad (2)$$

Field Portable Turbidity Meter (Micro-TPW, Scientific Inc. Ft. Myers, Florida, U.S.A) was used to estimate the suspended soil materials in (NTU units) of both treated and the untreated soil sample. The turbid metric DR (%) was calculated by the following equation:

$$\text{Turbidity (DR, \%)} = \frac{\text{NTU of Treated Suspension}}{\text{NTU of Original Soil Suspension}} \times 100 \quad (3)$$

V. RESULTS AND DISCUSSION

Due to the results obtained from this work and the findings of another related detailed study published by the same author (Mutter et al., 2017), all the stabilizers used have markedly improved all soil properties related to soil erodibility and stabilization. It should be noted, however, that a 9% of bitumen was needed for the best stabilization; compared with only 6% for both lime and cement.

Table II shows the bitumen impact on the erodibility parameters of lead contaminated soil. A 9% of bitumen was required to get the best soil properties against erosion and lead movement. According to the correlation coefficient (R), bitumen has a significant impact on shear stress (τ_c, pa) and to some extent on the degree of hardness (DH). Hence the scouring depth (SD) was reduced from 24.5 to 0.38 mm and the erodibility coefficient (k_d) from 1090 to 0.1cm^3/kN.s. On the chemical properties, bitumen seems to have a positive impact on soil properties related to soil stability; by reducing the suspended solids from (10550 to 6725 mg/l).

The bitumen improvement of soil stability may be due to the increase in cohesive and load bearing capacity of soil particles which increases the resistance to the action of water. The soil particles may be covered and voids blocked with bitumen that prevent or slow the penetration of water (Onyelowe and Okafor, 2012). In soil stabilizing with bitumen, two basic processes are active: water proofing and adhesion (Stefan and Mustaque, 2003). Droplets in contact with clay minerals spread on the surface eventually displace the water film on the aggregate surface (Lesueur, 2000; Lesueur and Pott, 2004). When a contact happened between the bitumen emulsion and soil aggregates, adsorption of free emulsifier and soil particles may occur and the pH rises. This rise in pH leads to the flocculation of soil particles (Glet, 1997).

Table 2. Erodibility Parameters Of Lead Contaminated Soil In Relation To Bitumen Percentages

	Bitumen,%				
Erodibility parameter	**0**	**3**	**6**	**9**	**Correlation coefficient, R***
Degree of Hardness	76.5	92.3	93.35	97.75	0.90
Scouring Depth, mm	24.5	3.35	2.25	0.38	-0.84
Shear Stress (τ_c, pa)	0.05	4.13	5.09	7.74	0.97
Erodibility coefficient, (k_d, cm^3/kN.s)	1090	170	165	0.1	-0.85
Suspended Solids, (Gravimetric) mg/l	10550	7760	7100	6725	-0.91
Turbidity, NTU	592.4	356.3	265.6	188.7	-0.96

*R must equal 0.95 or 0.99 to be significant at 0.05 or 0.01 levels, respectively.

Table III shows the lime impact on the erodibility parameters of lead contaminated soil. Only 6% of lime was required to get the best soil properties against erosion and lead movement. According to the correlation coefficient (R), lime has a clear impact on shear stress (τ_c, pa) and on the degree of hardness (DH). Hence the scouring depth (SD) was reduced from (24.5 to 1.4 mm), and the erodibility coefficient (k_d) from (1090 to 170 cm^3/kN.s). On the chemical properties, lime seems to have a positive impact on soil properties related to soil stability; by increasing divalent cations (Ca and Mg) required for clay flocculation and hence granulation (Mutter, 1989). Emersion (1967) suggests that at least 0.6-2.0 meq/l divalent cation concentration is required in solution to inhibit clay dispersion. Hence, Lime succeeded in reducing suspended solids from (10550 to 2995 mg/l). The decreasing in k_d values with lime was due to the cementing products that strengthen soil layers (Quang and Chi, 2015). Note that the chemical reaction with lime required more time when compared with cement (Wild *et al.*, 1993).

Table 3. Erodibility Parameters Of Lead Contaminated Soil In Relation To Lime Percentages

	Lime, %				
Erodibility parameter	**0**	**3**	**6**	**9**	**Correlation, coefficient, R***
Degree of Hardness	76.5	89.1	93.5	94	0.90
Scouring Depth, mm	24.5	2.93	1.45	1.40	-0.80
Shear Stress (τ_c, pa)	0.05	4.6	6.2	5.9	0.89
Erodibility coefficient, (k_d, cm^3/kN.s)	1090	180	150	170	-0.78
Suspended Solids, (Gravimetric) mg/l	10550	3895	3135	2995	-0.83
Turbidity, NTU	592.4	343.4	194.0	104.9	-0.98

*R must equal 0.95 or 0.99 to be significant at 0.05 or 0.01 level, respectively.

Table IV shows the cement impact on the erodibility parameters of lead contaminated soil. A 6% of cement was required to get the best soil properties against erosion and lead movement. According to the correlation coefficient (R), cement has a big impact on shear stress (τ_c, pa) and on the degree of hardness (DH). Hence the scouring depth (SD) was reduced from (24.5 to 0.38) mm and the erodibility coefficient (k_d) from (1090 to 0.0) cm^3/kN.s. On the chemical properties, cement seems to have a significant impact on soil properties related to soil stability; by reducing the suspended solids from (10550 to 1995 mg/l). The greater decreasing in k_d with cement was due to the cement chemical composition, especially in the existence of divalent and trivalent oxides, and the adhesive and cohesive property that make it capable of flocculating clay and binding fragments of mineral (Onyelowe and Okafor, 2012). When Portland cement is mixed with water, it will hydrate forming strong cementing compounds of calcium-silicate-hydrate, calcium-aluminum-hydrate as well as calcium hydroxide (Lee *et al.*, 2003).

Table 4. Erodibility Parameters Of Lead Contaminated Soil In Relation To Cement Percentages

	Cement, %				
Erodibility parameter	**0**	**3**	**6**	**9**	**Correlation coefficient R***
Degree of Hardness	76.5	92.5	96	98.2	0.90
Scouring Depth, mm	24.5	3.35	2.25	0.38	-0.84
Shear Stress (τ_c, pa)	0.05	4.49	7.37	7.74	0.94
Erodibility Coefficient, (k_d cm^3/kN.s)	1090	170	0.1	0.0	-0.85
Suspended Solids, (Gravimetric), mg/l	10550	6275	2740	1995	-0.96
Turbidity, NTU	592.4	213.4	121.8	97.3	-0.87

*R must equal 0.95 or 0.99 to be significant at 0.05 or 0.01 level, respectively.

Figure 1 shows that there is a high and good relationship between turbidity and suspended solids of soil solution and stabilizers percentage. The figure indicates that whenever the stabilizers percentage increase in the soil, the turbidity and dispersed solids of soil solution decreased which means that soils are under better stabilization conditions. Cement appears as the best stabilizer in reducing both suspended solids and turbidity of soil solution, followed by lime and then bitumen, due to the same reasons mentioned above in the discussions of the tables. These results agree with the results of Sivapalan (2005) who found that the application of small quantities of such soil stabilizers may improve the soil aggregate stability, enhance the infiltration, reduce runoff and overcome the water turbidity problem in water resources. Hannouche *et al.* (2011) confirmed the possible successes of using turbidity in assessing TSS within a combined sewer system.

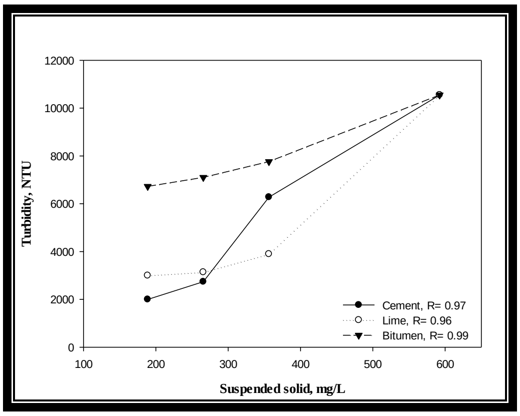

Figure 1. Relationships between suspended solids in (1:2 soil:water) soil suspension (mg/l) and Turbidity (NTU) of different soil stabilizers.

Figure 2 shows a clear relationship between the dispersion ratios of the lead contaminated soil and the stabilizers percentage. The figures indicate that there is a high correlation between the DR and the amounts of stabilizers, and whenever the stabilizers percentage increase in soil, the dispersion ratio (DR, %) in soil solution decrease. From these figures, gravimetric DR values appeared to be slightly greater than those turbid metric ones. This may because the heating of soil suspension samples in an oven at 103 to 105° C may evaporate or burn some of the organic materials vulnerable in soil and stabilizers. However, the turbidity DR (%) appears to have a high correlation with both lime (R= -0.98) and bitumen (R= -0.96) amounts and in lesser extent with cement (R= -0.87). This is in fact not because cement is not a good stabilizer, but because a smaller amount (3%) of it has sharply reduced the DR of soil from (7.03 to 2.54%), compared with lime and bitumen (4.09 and 4.25%) respectively at the same percentage.

In the gravimetric methods; although it may be difficult to obtain a representative sample and it is time consuming and may take two or four hours or more to complete (Hach, 2009), and as far as that DR is well known to give a reliable estimation of soil erodibility (Grieve, 1979), and the micro-aggregation or dispersion technique developed by Middleton (1930) has since been used as index of aggregate stability, these results may suggest and recommend the use of that turbidity DR in assessing the stability of artificially stabilized soils.

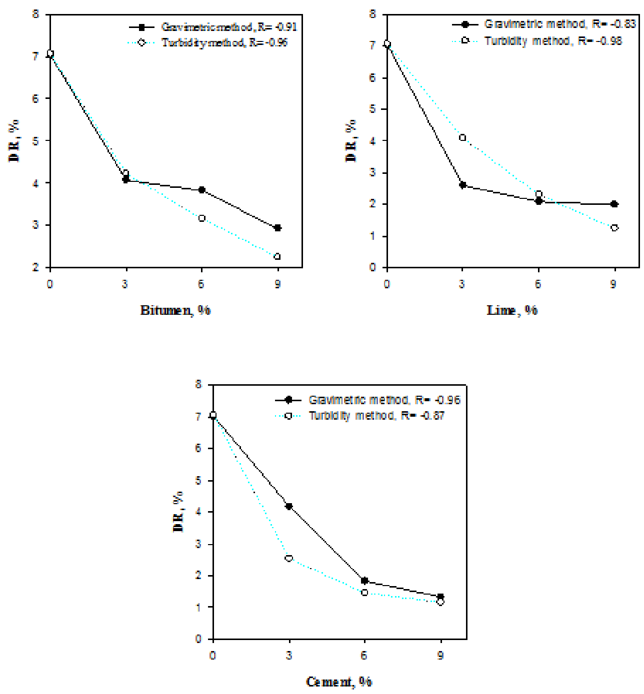

Figure 2. Relationships between DR (%) in (1:2 soil:water) soil suspension and stabilizers percentage

Figure 3 relates the Turbidity DR (%) of the three stabilizers with the erodibility coefficients (k_d). The turbidity DR of cement, bitumen and to some extent lime had significantly correlated with the k_d values of the stabilized soils (R= 0.99, 0.96 and 0.90) respectively. This can prove that the Turbidity DR (%) can be successfully used as a reliable index of the soil stabilization status. However, this fact is in agreement with Sadar and Engelhardt (1988) who found that turbidity measurements often can be correlated and used as a substitute for gravimetric solids measurement in the monitoring and controlling of industrial processes. A turbidity meter can be used as an alternative measure of suspended solids if sample and instrumental variables are properly controlled (Hach, 2013). Thus, he suggests:

1. The sample must be a true representative of the sample stream from which it came.
2. Consistent technique and environmental conditions must be used throughout the test to reduce variability in the instruments and samples.

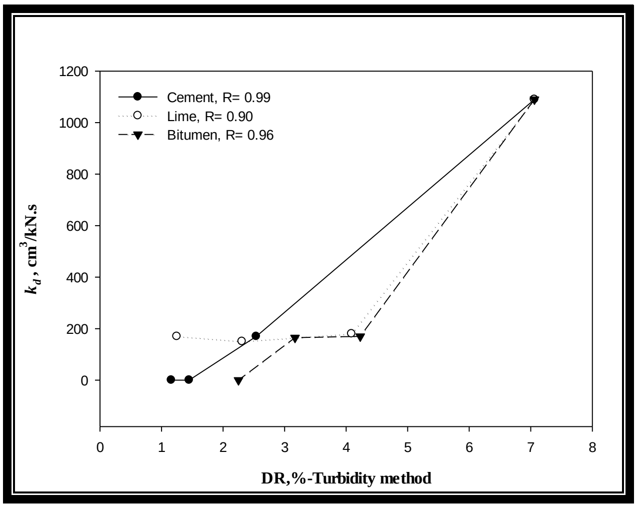

Figure 3. Relationships between DR (%), measured by the Turbidity method, in (1:2 soil: water) soil suspension and the erodibility coefficient (k_d)

Finally, the effects of the three stabilizers on the e turbidity dispersion ratio (as DR, %) are summarized in Table V. From this table and from the cement values in particular, an erodibility classification (Table VI) can be derived and suggested to evaluate the stability of artificially stabilized soils and other similar soil.

Table 5. Effect Of Stabilizers On The Turbidity Dispersion Ratio (Dr, %) In (1:2) Soil: Water Suspension

Stabilizer	Turbidity DR (%)			
	0%	3%	6%	9%
Cement	7.06	2.54	1.45	1.16
Lime	7.06	4.09	2.31	1.25
Bitumen	7.06	4.5	3.17	2.25
Mean	7.06	3.60	2.30	1.50

Table 6. Soil Stability (Or Erodibility) Classification, As Estimated By The Turbidity Dispersion Ratio (Dr, %), In (1:2) Soil: Water Suspension

Soil Stability/ or Erodibility Class	Turbidity DR, (%)
Very Stable/ Non-Erodible	< 2
Moderately Stable/ Moderately Erodible	2-7
Unstable/ Erodible	> 7

VI. CONCLUSION

This applied research is designed to examine the use portable turbidity meter devices in measuring the amount of suspended solids in soil solution and then to develop a simple and quick method to estimate soil stability and erodibility. It could be concluded from this work that:

1. All stabilizers (cement, lime and bitumen) have improved the stability of lead contaminated soils and cement was the best stabilizer.
2. There is a high and positive relationship between turbidity of soil solutions (as NTU or as DR, %) and suspended solids (as mg/l or as DR, %) and the stabilizer percentages.
3. There is a significant correlation between the turbidity DR (%) and other erodibility parameters measured in the laboratory by a "Mini" Jet Erosion Test; scouring depth (SD, mm), critical shear stress (τ_c, pa) and the erodibility coefficient (k_d, cm^3/kN.s).
4. The turbidity DR (%) has proved to be as a reliable index of stability in many artificially stabilized lead contaminated soils. Due to this fact and because this method is simple, quick and cost effective, so it can be suggested and recommended to be used as new method in estimating the stability of Iraqi soils.
5. From the finding of this study and according to the turbidity DR (%) values, a special soil stability/ or erodibility classification system is developed for this particular purpose.

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