



Investigation of Effect of Vegetation Cover on Soil Erodibility of River Banks

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ABSTRACT

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The effect of vegetation cover (VC), in addition to environmental changes, is one of the most critical aspects affecting the erosion of the soil of river banks. Therefore, this paper investigated the influence of vegetation cover (VC) on the erosion of Tigris River banks in Samarra City. The study was conducted with multiple monthly research periods (May, June, July, and August) during the summer of 2021 for testing the soil erosion in twelve sites on Tigris River banks. A mini jet erosion test (mini JET) device was used in this work to reduce testing times, save energy, and provide a low cost method. At each site two JETs were conducted, one on a soil covered with vegetation and other on a bare soil. The monthly average values of the soil erodibility coefficient (k_d), the critical shear stress (τ_c), and the percentage of VC (VC%) were computed for the soils with VC and the bare soils at each site. It was concluded that improvement of soil erodibility resistance could be achieved by the existence of VC due to an increase in soil organic matter (OM) content. It was noted that the k_d had more decreasing with the existence of VC compared to the bare soils at the twelve sites, while the τ_c showed more increasing. It was also discovered that the lowest value of k_d ($= 0.4 \text{ cm}^3/\text{N} \cdot \text{s}$) occurred at a VC% of 32.2% at site no. 12. The findings of this study supported the results obtained from previous researches which studied the effect of VC on bare soils. Finally, the study recommended that the VC% on the Tigris River banks within Samarra City be more than 32.2% to reduce the erosion of river banks as well as to preserve the morphology of the river.

1. INTRODUCTION

Establishment of vegetation is an effective biological strategy for erosion control. Bank erosion is a type of water erosion that has a number of negative consequences, including increased turbidity, degradation of river bank areas, and challenges created by silt deposited downstream. River bank erosion can be slowed down through the use of biological means in recognized sensitive portions.

Soil erosion is one of the most serious environmental issues in the world, incurring billions of dollars in damages each year and affecting long-term national economy. Mining processing, construction, smelting, road construction, and agricultural reclamation all have an impact on soil erosion because they decrease vegetation cover, increase runoff, and create erosion [1].

Bank erosion results in the destruction of fertile fields adjacent to rivers and the downstream transport of sediments by water flow [2]. Sediment transport from slopes to river systems is largely dependent on the presence/absence of vegetation in river beds, and this should be taken into consideration when assessing landscape degradation and/or recovery [3]. There has been a surge of interest recently in the influence of vegetation establishment on the soil's resilience to erosion. Elimination of vegetation diminishes the resilience of the river bank surface to erosion [4]. As a result, vegetation loss reduces soil resistance to erosion and augments runoff generation. The material eroded off banks enters rivers' water flows immediately, causing turbidity and a degradation of the water's quality [5, 6]. Bank erosion occurs when the shear

tension of flowing water exceeds the resistance of the soil. The application of biological approaches to control erosion is a priority for erosion control programmes due to their compliance with the environment and cost savings (by establishing a connection between vegetation and hydrologic processes) [7, 8]. Additionally, riverbanks are ideal locations for native plant establishment, which increases soil resistance to scouring by water [9, 10].

The application of vegetation techniques is an effective way to prevent soil erosion caused by water since vegetation is a key factor that impacts soil erosion [11]. The combined impacts of leaves, stems, roots, and litter allow plants to intercept rainfall, diminish erosion effects, and control surface runoff, thus completing the role of water management [12]. The activity of plant leaf tissue in intercepting rainwater reduces effective rainfall on a slope and the impact of erosion on the surfaces. Furthermore, plant leaves and stems may efficiently reduce the kinetic energy of raindrops and distribute a large raindrop into a small drop of water, resulting in less energy sprayed on the soil [13]. Physical characteristics of soil, such as soil strength, structural stability, and aggregate stability, all of which are related to soil erodibility, can be enhanced by vegetation root development. Furthermore, the roots can boost the capacity of soil infiltration, contributing in improvement of soil quality. Furthermore, vegetation has a significant impact on soil erosion due to its ability to alter hydraulic parameters as well as runoff and sediment yield conditions [14].

According to Le Bissonnais & and Arrouays [15], increased vegetation cover results in an increase in organic matter. Soil

erodibility increases when organic carbon content declines, reducing infiltration and possibly causing erosion through increased runoff.

The significance of cryptogams (a form of vegetation cover) in runoff and erosion control was investigated by Gaskin and Gardner [16]. The stated advantage of cryptogams in minimizing soil erosion by water in semi-arid environments is particularly relevant for this study. As a result, cryptogams appear to provide a comparable level of protection against runoff and raindrop erosion to the soil surface as weed cover. The application of weed and cryptogam cover had been recommended to protect the soil surface from rainfall kinetic energy and surface water detention.

Langhans et al. [17] showed that the microorganisms such as algae form a vegetative cover have filamentous growth forms leading to bind soil particles together. These filaments secrete sticky polysaccharide sheaths surrounding their cells, which help to bind soil particles together.

Issa et al. [18] investigated the structural stability of soils and found that microorganisms like blue algae may have the potential to agglomerate soil particles. The protective role of algae cover is mostly due to soil aggregation, which is aided by polysaccharide exudates and algae filaments physical bonding. These have an impact on erodibility and give significant erosion resistance. Two types of vegetation cover were investigated by Hashim et al. [1] (blue algae and green algae). Throughout the observation period, dead algae attached to and bonded soil particles together, contributing to soil stability and increasing moisture and nutrient retention before decomposition.

Briaud et al. [19] pioneered the concept of classifying soil erosion according to soil type. They categorized the erosion of different types of soils depending on the relation between the shear stress of soil and the rate of erosion.

The goal of this research is to discover out how the soil erodibility parameters (erodibility coefficient, k_d , and critical shear stress, τ_c) of Tigris River banks in Samarra City, and the fact that recovery of vegetation cover is primarily target for reducing soil erodibility at that reach of Tigris River in Samarra City.

2. SOIL ERODIBILITY AND ROLE OF VEGETATION

The erosion rate of cohesive stream banks is frequently calculated employing the excess shear stress equation [20-22], which is stated as follows:

$$\epsilon_r = k_d(\tau - \tau_c)^a \quad (1)$$

where [23]:

ϵ_r : Erosion rate (cm/s),

k_d : Erodibility coefficient ($\text{cm}^3/(\text{N}\cdot\text{s})$),

a : Empirical exponent commonly assumed to be unity,

τ : Average boundary shear stress (N/m^2),

τ_c : Critical shear stress (N/m^2).

Also, the submerged jet erosion test (JET) was designed for both in situ and laboratory measurements of these parameters [24].

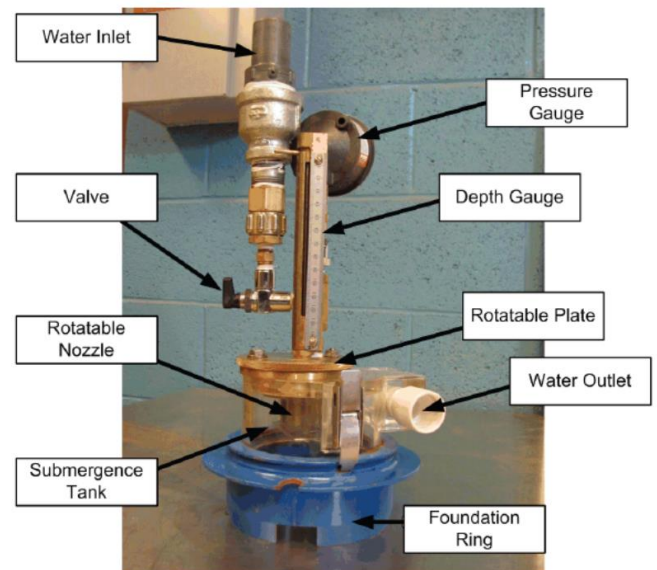
“Vegetation has a considerable influence on the surface and mass stability of slopes. Both the type of vegetation and the manner by which the slope degrades have an effect on the stabilizing or protective effects of vegetation. The protective

effects of woody vegetation on mass stability range from mechanical reinforcement and restraint provided by the roots and stems to changes in the slope hydrology caused by soil moisture extraction via evapotranspiration. Slope vegetation loss or removal might result in increased erosion rates or more frequent slope failure. Numerous field and laboratory studies published in the technical literature can convincingly prove this cause and effect relationship.” [25].

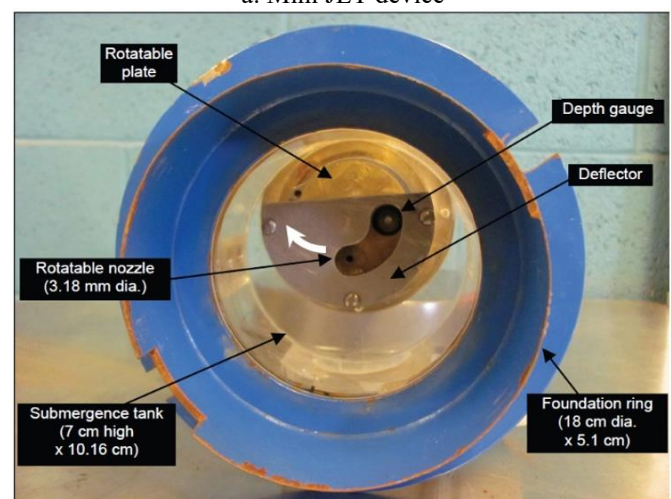
The banks of Tigris River characterize as productive places for agriculture in many Iraqi lands because of the fertility of soil and the vicinity of water [26, 27]. Referencing to the previous studies, the existence of vegetation cover on the river banks is considered beneficial from an economic point of view and in terms of preserving the morphology of the river. Therefore, it is necessity to preserve the natural vegetation, beneficial and environmentally harmless, found on Tigris River banks, and to aim for growing vegetation sending back beneficial economics and preserving the morphology of Tigris River.

3. METHODOLOGY AND MATERIALS

3.1 Mini JET device



a. Mini JET device



b. Rotatable of the device

Figure 1. Mini JET device

This investigation utilized the laboratory submerged micro JET apparatus depicted in Figure 1, which was recently designed by Hanson [28]. It is a new miniaturized version of Hanson and Hunt's original JET gadget [29]. The employed device is smaller and lighter than the original (975 cm³ and 4.2 kg) (28130 cm³ and 12.6 kg). As a result, it can be handled more simply in the field as well as in the laboratory. In comparison to the original JET device, the employed device requires less water and labour in the field to deliver the appropriate volume of water. Pressure gauge, exit and intake water, depth gauge, rotatable plate (depth gauge and nozzle), submergence tank, foundation ring, valve, and hoses comprise this equipment.

An Adjustable head tank is utilized to get the desired water pressure. Scour measurements are taken with the depth gauge. The nozzle on the rotating plate measures 3.18 mm in diameter. This rotatable plate is employed to keep water out of the soil sample at the start of the test and at multiple scour depth readings throughout the test run. The submergence tank measures 70 mm in height, 101.6 mm in diameter, and has a wall thickness of 6.4 mm. The submergence tank does not have a top opening, and the rotatable plate and depth gauge are mounted on the tank's top. When utilized in the field, the foundation ring is 180 mm in diameter and is driven 51 mm into the soil.

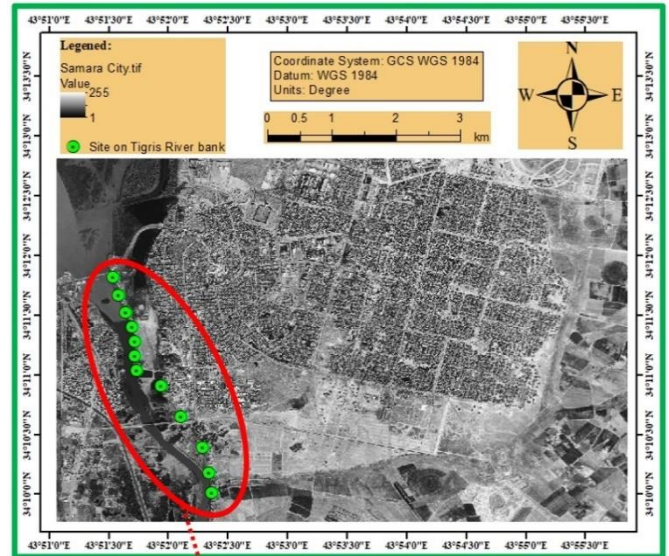
3.2 Study area and soil characteristics

Samarra is an Iraqi city. It is located on the east bank of the Tigris River (Figure 2 (a)), of about 125 km to the north of Baghdad City, in Salahuddin Governorate. Samarra City's principal supply of drinking water is the Tigris River. This city's climate is classified as arid to semiarid, with hot summers and freezing winters. In the current study, twelve sites on Tigris River banks within Samarra City were chosen, as shown in Figure 2 (a and b), to determine the effect of vegetation cover on soil erodibility parameters (k_d and τ_c) of Tigris River banks within this city. The coordinates of these sites and the distances between them were shown in Table 1.

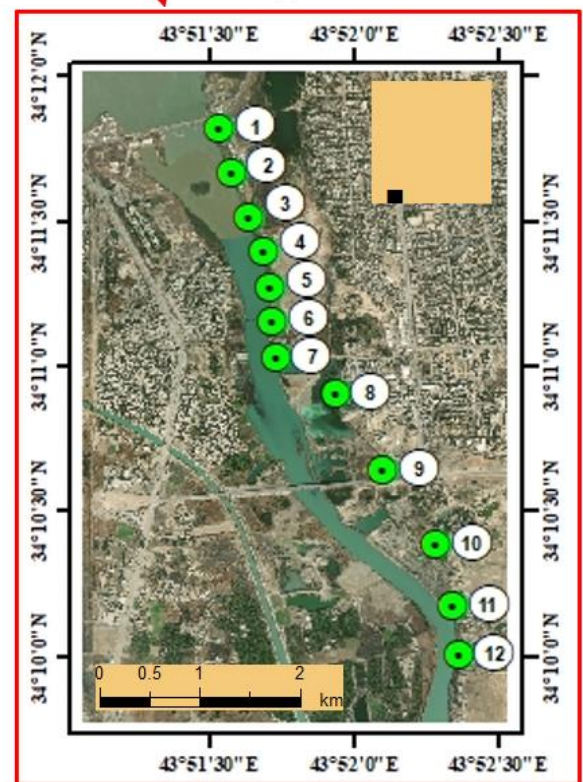
The vegetation cover in the twelve sites was found approximately in a blue-green colour as shown in Figure 3. It is also noted that this colour is approximately predominant one wherever VC founded on banks of Tigris River within Samarra City.

Table 1. Locations of twelve sites on Tigris River bank within Samarra City

Site no.	Coordinates		Distance (m)
	Longitude	Latitude	
1	34° 11' 50" N	43° 51' 33" E	
2	34° 11' 39" N	43° 51' 36" E	291.110
3	34° 11' 32" N	43° 51' 40" E	289.939
4	34° 11' 24" N	43° 51' 44" E	230.523
5	34° 11' 17" N	43° 51' 44" E	234.020
6	34° 11' 10" N	43° 51' 44" E	223.209
7	34° 11' 03" N	43° 51' 44" E	222.247
8	34° 10' 56" N	43° 51' 58" E	388.555
9	34° 10' 38" N	43° 52' 05" E	552938
10	34° 10' 23" N	43° 52' 16" E	545.651
11	34° 10' 12" N	43° 52' 20" E	407.980
12	34° 10' 02" N	43° 52' 23" E	312.703
			$\Sigma = 3698.875 \text{ m} = 3.7 \text{ km}$



(a)



(b)

Figure 2. Distribution of twelve sites plotting on satellite image of Samarra City (0.0011 cm error)

3.3 Field procedure and sampling

In the current work, twelve pairs of JETs (24 tests) were conducted in twelve sites (Figure 2 and Table 1) on Tigris River banks in Samarra City to compare the soil erodibility parameters between the soils with VC and the bare soils. At each site, the mini JET device was used to conduct two JETs side by side on the soil with VC and the bare soil (Figure 4). Then, a cylinder of 5 cm diameter and 5 cm depth was used to collect two soil samples from the covered and the bare soils at each site (24 soil samples). The JETs sets and the soil samples sets were conducted monthly (May, June, July, and August) during the summer of 2021.

A constant water pressure head of 90 cm for all tests was desirably set. Hence, a constant head tank with a surface approximately 60 cm above the employed device's outflow was used to maintain the water pressure head of 90 cm during the tests. To conduct the test on vegetation-covered soil, the foundation ring of the mini JET device was positioned slightly off centre of the plant stems to guarantee the impinging jet made contact with the soil and roots rather than the stem. Before the test, vegetation stems were trimmed to roughly 1 cm above the soil surface. After detaching the device from the foundation ring, any remaining water was allowed to drain and infiltrate until the scour hole was entirely dry and the foundation ring was removed. Using an Excell spreadsheet tool provided by Daly et al. [30] and the Blaisdell et al. [31] solution, the data from the employed device were utilized to derive k_d and τ_c . If the scour depth was greater than 15 mm in the first two 15 second time intervals, the data were removed from the analysis assuming that the scour depth measurements were for loosened soil created during the insertion of the foundation ring for these in situ soils [32].



Figure 3. In situ vegetation cover at Tigris River banks within Samarra City



Figure 4. Site of field JET (using mini-JET device) with side-by-side soil covered with vegetation and bare soil

The soil samples were collected from the ground around the scour hole for the test on the soil with VC and the bare soil. The soil samples (24 samples) were taken to determine the physical and the chemical characteristics of soil according to

the ASTM standards. For all monthly tests in all sites, the physical and chemical characteristics of the soils with VC were found with very close convergent values and also the same very close convergence was found for the bare soil. Therefore, the monthly (4 months) and spatial (12 sites) average tests values for the soils with VC and also for the bare soils were considered to be extended along Tigris River banks within Samarra City as shown in Table 2. Hence, the overall classification of the soil of Tigris River banks in the study area was to be as *sandy clay loam* according to the United States Department of Agriculture (USDA).

Table 2. Monthly and spatially average values of some physical and chemical characteristics of soil of Tigris River banks in Samarra City

Soil characteristics*Units	Soil with VC	Bare soil
OM	% 2.6	1.8
Sand	% 53.2	53.2
Silt	% 10	10
Clay	% 36.8	36.8
Soil texture	Sandy clayey loam	

3.4 Analytical methods of JET

Hanson and Cook [23] calculated the maximum average shear stress along the jet impingement zone boundary (τ_j) as follows (Figure 5):

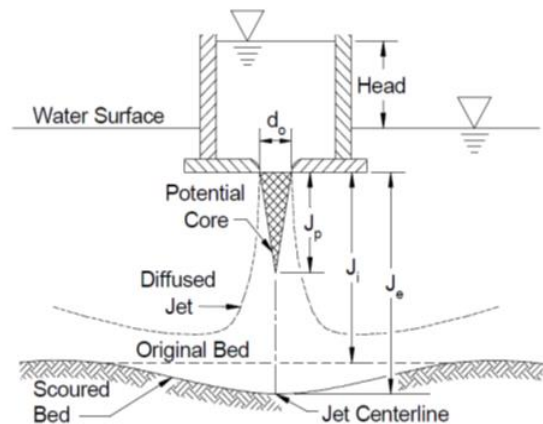


Figure 5. Schematic presentation of JET device [23]

$$\tau_j = \tau_o \left(\frac{J_p}{J} \right)^2 \quad (2)$$

where:

$$\tau_o = C_f \rho_w U_o^2 \quad (3)$$

and:

$$U_o = C \sqrt{2gh} \quad (4)$$

also,

$$J_p = C_a d_o \quad (5)$$

$$\begin{cases} C_f = 0.00416 \\ C_a = 6.3 \end{cases} \quad (6)$$

where:

- τ_o : Maximum shear stress due to the jet velocity at the nozzle (N/m²);
- C_f : Coefficient of friction;
- U_o : Jet velocity (m/s);
- C : discharge coefficient; Al-Madhhachi et al. [28] indicated C values ranging from 0.70 to 0.75 for the mini JET;
- h : Pressure head (m);
- d_o : Nozzle diameter (cm);
- J : Scour depth (cm);
- J_p : Potential core length from jet origin (cm);
- J_i : Jet nozzle height (initial jet orifice height);
- J_e : Equilibrium scour depth.

Also, should be note:

Notes

- i. The schematic presentation of the original JET device is the same for the mini-JET device.
- ii. J_p denotes the distance between the jet orifice and the jet centre at which the jet velocity remains equivalent to the velocity at the orifice. Typically, this distance is six orifice diameters from the jet orifice. Consequently, Eq. (6) can be expressed as follows:

$$J_p = 6d_o \quad (7)$$

Hence, according to Eq. (2):

1. The maximum initial shear stress along the boundary (τ_i) could be determined when J is equal to J_i , i.e. $\tau_j = \tau_i$.
2. The critical shear stress was assumed to occur when J is equal to J_e , i.e., $\tau_j = \tau_c$.

As mentioned in the field procedure (Section 3.3), the Excel spreadsheet tool provided by Daly et al. [30] using the J_p developed by the Blaisdell et al. [31] and Eq. (2) were used to determine τ_c and k_d .

4. RESULTS AND DISCUSSION

Any physical, chemical, or biological cover can improve the soil erosion resistance if the k_d is reduced and the τ_c is increased [33, 34]. The final results of the current study showed that the presence of VC on the soils of the Tigris River banks within Samarra City reduced soil erosion compared to soils that were bare. The major reason was attributed to the increase in OM content in the soils with VC compared to the bare soils as shown in Figure 6. It was noted that the monthly average values of k_d and OM for the soils of Tigris River banks with VC at the twelve sites showed a more significant decrease in k_d with an increase in OM content compared to the bare soils

at those sites, as shown in Figure 7. On the other hand, the monthly average values of τ_c and OM for the soils with VC in the twelve sites on the Tigris River banks showed a greater increase in τ_c with an increase in OM content compared to the bare soils at those sites, as shown in Figure 8.

Then, referring to Figures 6 through 8, it was clearly showed that the two significant sites were 8 and 10. These two sites had the extreme values as shown in Table 3. Commonly, the detection data were referred to that the increase in OM content led to improve soil erodibility parameters of Tigris River banks taking into the physical and chemical characteristics of soil at the sites.

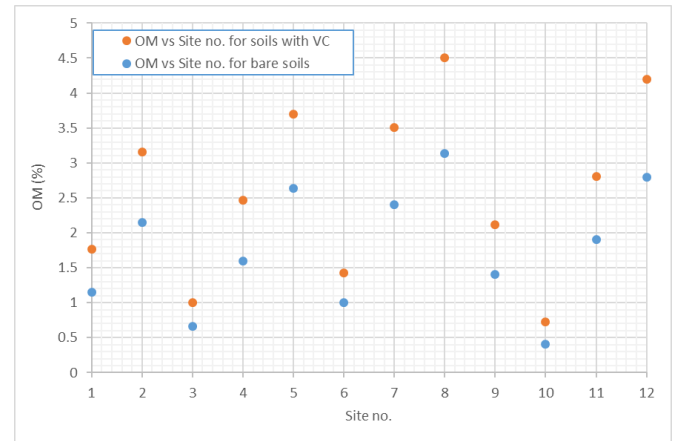


Figure 6. Monthly average values of OM content for the soils with VC and the bare soils at twelve sites on Tigris River banks in Samarra City

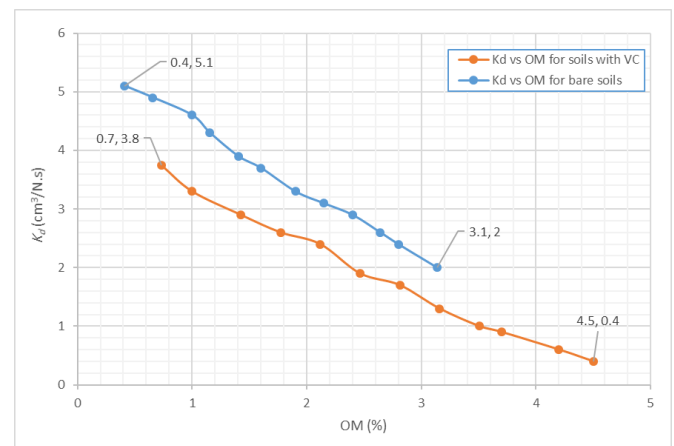


Figure 7. Relation between the monthly average values of k_d and OM content for the soils with VC and the bare soils at twelve sites on Tigris River banks in Samarra City

Table 3. Monthly average values of OM, k_d and τ_c at site no. 8 and site no. 10 (significant sites)

Site no.	Soil surface	OM (%)	Increase in OM	k_d (cm ³ /N.s)	Decrease in k_d	τ_c (N/m ²)	Increase in τ_c
8	with VC	4.5	$= \left(1 - \frac{3.1}{4.5}\right) \times 100 \cong 31\%$	0.4	$= \left(1 - \frac{0.4}{2}\right) \times 100 = 80\%$	4.2	$= \left(1 - \frac{2.7}{4.2}\right) \times 100 \cong 36$
	Bare	3.1		2		2.7	
10	with VC	0.7	$= \left(1 - \frac{0.4}{0.7}\right) \times 100 \cong 43$	3.8	$= \left(1 - \frac{3.8}{5.1}\right) \times 100 \cong 26\%$	0.8	$= \left(1 - \frac{0.2}{0.8}\right) \times 100 = 75$
	Bare	0.4		5.1		0.2	

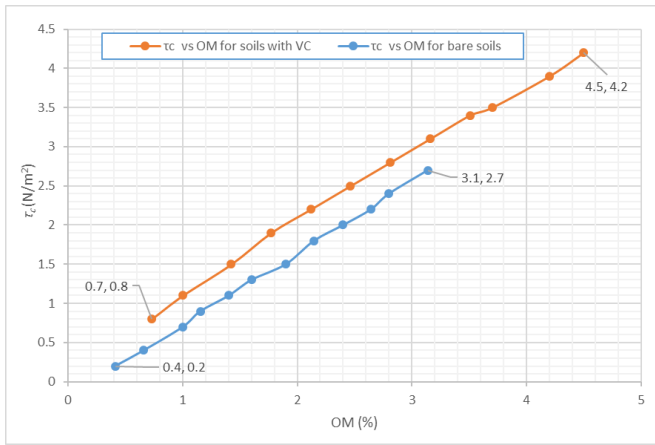


Figure 8. Relation between the monthly average values of τ_c and OM content for the soils with VC and the bare soils at twelve sites on Tigris River banks in Samarra City

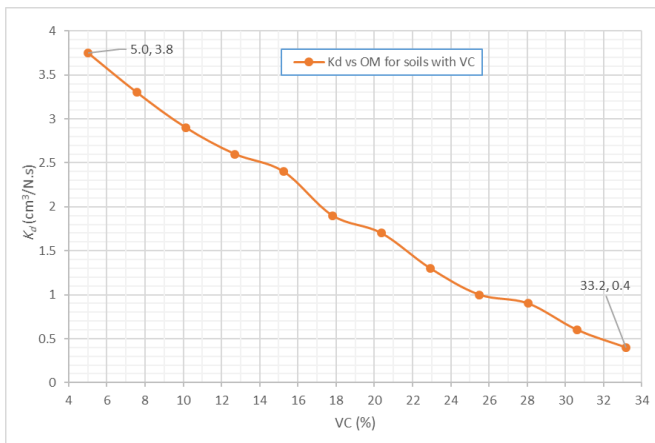


Figure 9. Relation between the monthly average values of k_d and VC% for the soils with VC at twelve sites on Tigris River banks in Samarra City

Hence, it is concluded that the findings of the current study agree with those obtained by Hashim et al. [1], which showed an increase in OM content led to soil protection from water erosion. Finally, this study assessed the soil erosion at the twelve sites on the Tigris River banks within Samarra City with respect to the percentage of cover of vegetation (VC%) at those sites. The VC% was approximately evaluated with respect to the bare soil at each site. Figure 9 illustrates the relationship between the monthly average values of k_d and VC% at the twelve sites on the Tigris River banks in Samarra City. It was noted that the minimum value of k_d was equal to $0.4 \text{ cm}^3/\text{N} \cdot \text{s}$, corresponding to a VC% of 32.2%. Therefore, it was recommended to have vegetation cover of more than 32.2% on the Tigris River banks within Samarra City to reduce soil erosion at the banks of the river as well as preserve the morphology of the river.

5. CONCLUSIONS

The purpose of the current study was to determine the influence of vegetation cover (VC) on the erosion of the banks of the Tigris River in Samarra City. Throughout the summer of 2021, the study tested soil erosion in twelve places along the Tigris River banks using multiple monthly research periods (May, June, July, and August). This work utilized a

micro jet erosion test (mini JET) apparatus to shorten testing periods, conserve energy, and give a low-cost technique. Two JETs were done at each site, one on vegetation-covered soil and one on bare soil. Accordingly, it can conclude the below points:

1. For each site, the monthly average values of a soil erodibility coefficient (k_d), a critical shear stress (τ_c), and the percentage of VC (VC%) were calculated for soils with VC and bare soils.
2. The results indicated that the presence of VC could improve soil erodibility resistance by increasing the soil organic matter (OM) content.
3. It was shown that the k_d decreased more rapidly with the presence of VC than with bare soils at the twelve sites, although the τ_c increased more rapidly.
4. The findings also uncover that the lowest value of k_d ($= 0.4 \text{ cm}^3/\text{N} \cdot \text{s}$) was found at site 12 with a VC% of 32.2%.
5. Finally, the outcomes of this study corroborated prior researches on the effect of VC on bare soils. Therefore, the study advised that the VC% on the banks of the Tigris River inside Samarra City be greater than 32.2% to prevent river bank erosion and to retain the river's morphology.

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NOMENCLATURE

a	empirical exponent commonly assumed to be unity
C	discharge coefficient; Al-Madhhachi et al. [28] indicated C values ranging from 0.70 to 0.75 for the mini JET
C_f	Coefficient of friction
d_o	nozzle diameter (cm)
h	pressure head (m)
JET	jet erosion test
J	scour depth (cm)
J_e	equilibrium scour depth
J_i	Jet nozzle height (initial jet orifice height)

J_p	potential core length from jet origin (cm)
k_d	erodibility coefficient ($\text{cm}^3/(\text{N}\cdot\text{s})$)
OM	organic matter content (%)
U_o	jet velocity (m/s)

Greek symbols

ε_r	erosion rate (cm/s)
τ	average boundary shear stress (N/m^2)
τ_c	critical shear stress (N/m^2)
τ_o	maximum shear stress due to the jet velocity at the nozzle (N/m^2)