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Geotechnical Properties and Slopes Stability for Banks Soils in South Part of Al-Hilla River at Meandering Areas, Babylon Governorate / Central of Iraq

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Abstract

The south part of the Babylon Governorate, located on the Hilla River, suffers from collapse and erosion of its banks, as well as the increase in sedimentation in the river, which reduces the river flow efficiency; due to the effect of the velocity river flow, which works on eroding one side of the river and sedimentation on the other side, forming meanders in the river. After the reconnaissance visit determine the meandering sites. A detailed study of the area was carried out by drilling (6) test boreholes representing three areas (Al-Wazeer, Al-Ibraheemia, and Al- Hashemia), two wells on both sides of the meander and at a depth of (10 m), for each borehole to observe the effect of the river flow velocity on the stability of slopes and to know the variation in soil properties, its bearing capacity and the consolidation on both sides of the river, and thus its effect on the engineering construction. Soil samples have been taken to carry out physical tests including: (moisture content test, specific gravity test, Atterberg limits tests, sieve analysis, and hydrometer tests), also engineering tests were done which included (permeability test, unconfined & triaxial compressive strength test, direct shear test, consolidation test, and bearing capacity), soil chemical tests that done (pH, total soluble salt, sulfate test, chloride test, gypsum test, and organic matter test). A study was also conducted for the stability of the bank slopes for the three stations, where the cross-section was monitored by the M9 device, as well as the height of the banks from both sides by the (level) device, Using Geo-Studio 2021 program with soil properties and by using (Bishop method) the safety factor was extracted for the two stations for erosion-prone areas. The highest result of the safety factor was in Al-Ibraheemia Station (2.85), then the banks of Al-Wazeer Station, with a value of (2.3), and the lowest value of Al-Hashemia Station, which amounted to (1.84). Under natural conditions, the average river flow level reaches it in a year is (27.15 m) above sea level. Where all the stations were (safe) unless the water level increased or decreased. Also, the research reached a determination of the allowable bearing capacity that soil of the banks reaches it before the landslide.

Keywords: River meandering, Al-Hilla River, Al-Wazeer Station, Boreholes, Geo-Studio 2021, slope stability.

الخصائص الجيوتكنيكية واستقرارية منحدرات ضفاف الجزء الجنوبي من نهر الحلة في المناطق الملتوية، محافظة بابل / وسط العراق

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الخلاصة

يعاني الجزء الجنوبي من نهر الحلة في محافظة بابل من مشاكل كانهيار وتآكل ضفافه، فضلاً عن زيادة الترسيب في النهر، مما يقلل من كفاءة تدفق المياه فيه؛ نتيجة لتأثير سرعة جريان النهر على ضفاف النهر، والتي تعمل على تآكل أحد جانبي النهر والترسبات على الجانب الآخر، مما يشكل تعرجات (التواءات) في النهر. بعد الزيارة الاستطلاعية لتحديد مواقع الالتواءات. تم إجراء دراسة تفصيلية للمنطقة من خلال حفر (6) آبار اختبارية

تمثل محطات (الوزير والإبراهيمية والهاشمية) وبواقع بئرين اختباريين على جانبي الالتواء النهري وبعمق يصل الى (10م)، لكل بئر لملاحظة تأثير سرعة جريان النهر على ثبات المنحدرات ومعرفة التباين في خواص التربة وقدرتها على التحمل والتماسك على جانبي النهر وبالتالي تأثيرها على البناء الهندسي. تم أخذ عينات من التربة لإجراء الاختبارات الفيزيائية والتي تضمنت (اختبار محتوى الرطوبة، اختبار الوزن النوعي، اختبارات حدود أتربيرج، والتحليل المنخلي، اختبارات الهيدرومتر) كما تم إجراء الاختبارات الهندسية والتي تضمنت (اختبار النفاذية، اختبار قوة الضغط غير المحصور وثلاثي المحاور، اختبار القص المباشر، اختبار التماسك وقدرة التحمل)، الاختبارات الكيميائية التي اجريت (الأس الهيدروجيني، الأملاح الذائبة الكلية، اختبار الكبريتات، اختبار الكلوريد، اختبار الجبس، اختبار المادة العضوية). كما تم إجراء دراسة استقرارية منحدرات الضفاف للمحطات الثلاث، حيث تم رصد المقطع العرضي بواسطة جهاز M9 ، وكذلك ارتفاع الضفاف من الجانبين بواسطة جهاز (LEVEL)، باستخدام برنامج Geo-Studio 2021 مع خواص التربة وبطريقة بي شوب تم استخراج عامل الأمان لمحطات السحب للمناطق المعرضة للتعرية. وباستخدام طريقة (الأسقف) تم استخلاص عامل الأمان لمحطات السحب للمناطق المعرضة للتعرية. أعلى نتيجة لعامل الأمان كانت في محطة الإبراهيمية (2.85)، ثم ضفاف محطة الوزير بقيمة (2.3)، وأدنى قيمة لمحطة الهاشمية البالغة (1.84). وفي الظروف الطبيعية يبلغ متوسط منسوب النهر سنوياً (27.15م) فوق مستوى سطح البحر. حيث كانت جميع المحطات (آمنة)، إلا إذا ارتفع منسوب المياه أو انخفض. كما توصل البحث إلى تحديد اقصى قدرة تحمل لترب الضفاف قبل حدوث الانهيار الأرضي.

1. Introduction

The research represents a case study of the stability of the banks of the south part of Hilla River and determining the effect of erosion of the banks, and the extent of their resistance to landslide by knowing the type of soil, and its relationship with the meandering of the river.

The Euphrates River in Babylon Governorate divided into two branches at the coordinates of (44º 27´ 11" E) (32º 1.272´63´´N), They are (AL- Hilla and AL-Hindeya) Rivers. The Hilla River is located within the sedimentary plain, and one of the most important features of The geomorphology of this region is characterized by its relatively gentle slope (at a rate of (1 m) per (7 km)), towards the south and southeast, and an oscillating system of water flow (active in spring and summer decreasing in winter) resulting in reduced ability to carry sediment downstream; Which makes the lateral activity superior to the vertical, and thus meanders are formed where sediment is transported by the shear stress resulting from the velocity of the water flow at the convex side, The Hilla River is exposed many problems such as the collapse and erosion of its banks, as well as the increase in sedimentation in the river, which reduces the river traffic efficiency; also the erosion of the banks causes damage to agricultural areas and agricultural production near the river. Al-Jawthari, studied the stability of the banks of a part of Shatt Al-Hilla in Al-Hashemia area in southern Babylon, the hazard map was made [1]. Where the research represents a detailed study to describe the stability of river banks and descriptive evaluation of the proportion of shoulder collapse. Al-Rubaiee and Al-Owaidi, study the geotechnical engineering about the effectiveness of Shatt Al-Hilla on the neighbouring area, as it was found that the study area suffers from many engineering problems such as cracks and fractures in the walls and floors of the building [2]. The determined study of the effects of fluctuation of the water level leaking from Shatt Al-Hilla on the soil properties and its bearing capacity. While Al-Jeafir and Al. Hussian, studied the bed sediments from Shatt Al-Hilla to Shatt Al-Arab at Basrah, where the study was (Sedimentology, mineralogical and environmental study of the Euphrates River from Babylon to Basrah, Iraq) [3].

The main aims of this study are identifying the relationship between the river meandering with river banks slopes stability at south part of governorate, and knowing the cause of the landslide (collapse) ; and determining the geotechnical properties of the soils of river banks.

2. Location of Study Area

The location of the study area was limited by the longitudes (44º 27´ 11" E) (44º 69´38" E), and latitudes (32 º 72´63" N) (32 º 38´ 33"N), where the study area was divided into three Stations (AL- Wazeer, Al-Ibrahamian, and Hashemia). These stations represented to most important meandering for the river as shown in the figure (1).

3. Geology and Tectonic of Study Area

From the geological side, Babylon Governorate (Study area) located within the Sedimentary basin in the unstable shelf according to the tectonic division of Iraq. According to the modern classification of Iraq [4], The stable shelf called Mesopotamian Zone, that it is located within the geosyncline basin between the Zagros Mountains in the north-east and the Stable Arabian plateau in the south [5]. From the geological point of view, recent deposits are from the Quaternary period of the Pleistocene and from Holocene in the study area, and these sediments are characterized by the Flood Plain Deposit of both the Euphrates River and its branches[6] , while alluvial deposits were formed during the Pleistocene period [7] , and there are deposits that fill the depressions, which collect as a result of floods, and generally consist of thin layers of fine sand and silty clay through which the river passes [8]. Lees and Falcon described tectonic of the region as by Mesopotamia is a large sedimentary basin (Syncline) which is active tectonically and passes through a subsidence with (Local Minor uplift) [9], this Geosyncline is linked to the mountain-building movement that occurs in the Zagros mountain range, which is still active so far. This basin receives the products of erosion as the downward movement continues. [10].

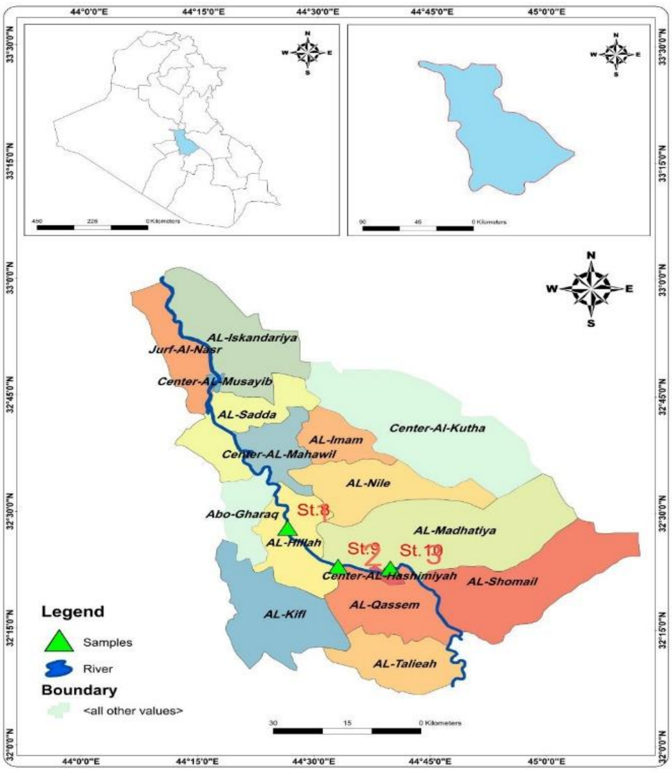


Figure -1 Study area locations

4. Materials and Methods

It means curvatures that occurring in the channel of the river and according to the stage or age the river passes through, it is on a large scale when the river be in the maturity stage, and this phenomenon is giving Indicator for end of the youth stage in the river (the river changed from youth to maturity), where a meanders are formed when the velocity of the river flow decrease to the point in which river activity moves from vertical (towards the river bed) to lateral erosion (towards the banks) [11] . River meander develop when the river erode in the concave side of the river's flow continuously, and in the opposite side (convex side) , sedimentation occurs , and at the same time a backflow of water will erode its direction to the bottom and it is slow working with it a quantity of sediments that have been carved and deposited on the convex side, Also riverine islands play a large role, especially in the straight parts of river in generating a water current towards the outer side of the meander, which leads to carving in it, There are three forms of the cross-section according to the erosion activity of the river, they are (A) convexity to the left of the flow, (B) there is no torsion due to the vertical activity of erosion, and (C) to the right convexity of the flow as in figure(2) [12].

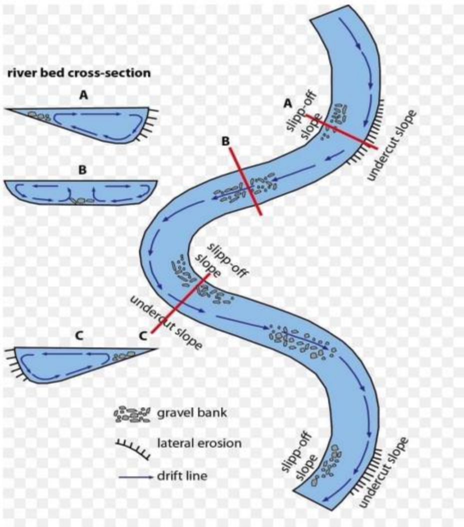


Figure -2 shapes of the river meandering.

4.1. Causes of the river torsion

The river meandering forms because of the vertical activity (deepening) of river flow be less than horizontal activity (widening), therefor meander occurs [11].

4.2. Classification of rivers meandering

That is, the river sinuosity index is the ratio of the real length to the ideal length as in equation (1)

$$S = \mathrm{Lt} / \mathrm{L}O \quad (1)$$

where: S = river sinuosity index , Lt = the distance between start and end point of the considered river reach computed along the channel centre line (real length) (m).

Lo=the valley length between the same start and end point (ideal length) (m).

According to Leopold and Wolman, meandering rivers have a sinuosity larger than 1.25[13]; according to (Leopold and Wolman) and (Rosgen) , the minimum ratio between the true length and the ideal length of the river sinuosity is (1.5) so that the sinuosity of the river is called meander [13], [14]. From these values, consider that the measurement of river level consists of a series of measurements of opposite bends in which the ratio ranges from (1 to 3.14).

1. If the ratio equal to 1, the course of the river is (straight).

2. It is considered (torsional), if the ratio ranges between (1-1.25) according to (Leopold and Wolman) and (Rosgen) [13], [14], and According to Leopold and Wolman the ratio is (1-1.5) [13].

3. If it exceeds (1.5), calculated (meander), the semicircle has equal to $\pi / 2 = 1.57$.

According to the above equation, the Hilla River is considered as meandering river, where the flow index of the Hilla River was (1.27) after measuring according to Brice, where the true length of the course (104 km), was measured and divided by the shortest distance between two points specified (The ideal length), which is 82 km [15].

4.3. The slopes stability

The slope stability is defined as the ratio between the force resisting collapse to the force causing the collapse and according to the conditions of the slope if it is soil or rocks; if the slope is from the soil, then the collapsed mass of soil slides on the landslide surface, the shear stress applied to the soil (the strength is resistance to collapse) and the safety factor is extracted ; safety factor (Fs) is important consideration in engineering construction design on a natural slope. Failure is often catastrophic and results human and material losses [16], classification of the slope soils according to the safety factor value (FS) as: FS < 1.0: unsafety Soil; FS = 1.0 - 1.2: Questionable safety Soil [17].

FS = 1.3-1.4 Satisfactory safety Soil; FS ≥ 1.4 stable (safety Soil)

$$Fs = \text{The } forces\ resisting\ movement \text{ /The forces promoting } movement \quad (2)$$

4.4. Field Investigations

Six Boreholes have been Drilled in March 2020 by using mechanical machine type (Flight Augers drill) ; the method of drilling was carried out according to the standard of the American society for testing and materials (ASTM D-1452 –D5783) which are used for taking the samples; the depth of boring were (10) m from the natural ground surface (N.G.S), three types of sample were taken ; the first samples type were disturbed samples (DS) , according to (ASTM D-1586) at intervals required to determine the classification of the soil layers . All disturbed samples were sent to the laboratory for further examination and testing. The second sample type were taken from standard penetration test (S.P.T), its symbol is (SS) take from split spoon of standard penetration test carried out in site, were also used as undisturbed samples type and the third samples were undisturbed, its symbol is (US), it were obtained according to (ASTM D-1587) after extraction , the Disturbed sample were trimmed , capped with polyethylene sacks or paraffin wax from top and bottom , and sealed properly at both ends , transported to laboratory for testing .

Figure -3 Images for study area represent field investigations stage where A- represent sampling of disturbed samples (DS), B- standard penetration test (S.P.T), and C&D are represented undisturbed samples (US)

.

4. 5. Laboratory Tests

The test program was decided by the soil special. The actual test proposed for a particular sample depends on the type of sample (DS ,US and SS) and the nature of its material . A full list of tests conducted for this project is:

A. Physical properties test consist number of tests are: (moisture content according to (ASTM D-2488) , Grain size analysis by (ASTM D-422) , Atterberg Limits by(ASTM D-4318) ,Specific gravity by (ASTM D-854) and Unit weight (wet and dry) by (ASTM D-4318).
B. Engineering tests: Consist number of tests as: (Consolidation tests, and swelling test according to (ASTM D2435-02); triaxial compression test (UU) according to (ASTM D- 2850) , Unconfined compression test, (ASTM D-2266) , and Direct shear (ASTM D-2850, D-4767)
C. Chemical tests on soil and water consist from number of analysis (Total Soluble salts test for soil (T.S.S) , pH test , Chloride content CL-, Gypsum content. , Carbonate Content $CaCo_3$. , Organic matter. And Sulphate content). according to (B.S. 1377-1990) all the tests were conducted according to the current standards of the American Society for Testing and Materials (ASTM) , and British Standard, mentioned for each test.

5. Results and Discussion

5.1 Stations results

The river meandering in Al Wazeer Station toward right side, Al-Ibraheemia Station toward right side, Al-Hashemia Station toward left side from water flow, which represents the erosion side (maximum velocity of the flow); and at another side is concavity of the river (the sedimentation area), to the left of the flow, the water level in this station ranges from (27.1 m) to (25.67) above sea level, as in Figure (4), (5),and (6). The flow velocity recorded highest rate from the right side. (0.9 m/sec) for Al Wazeer Station, (0.88 m/sec) for Al- Ibraheemia Station, and (0.8 m/sec) for (maximum discharge is (165 m3 /sec.) which effect on river bank with the impact angle (meander degree) is (55˚), (35˚), and (40˚), for the three stations respectively The natural vegetation on the two banks is high density; from willow, and reeds. Physical properties of soil: The results of basic properties tests explained in Table (1), (2) and (3).

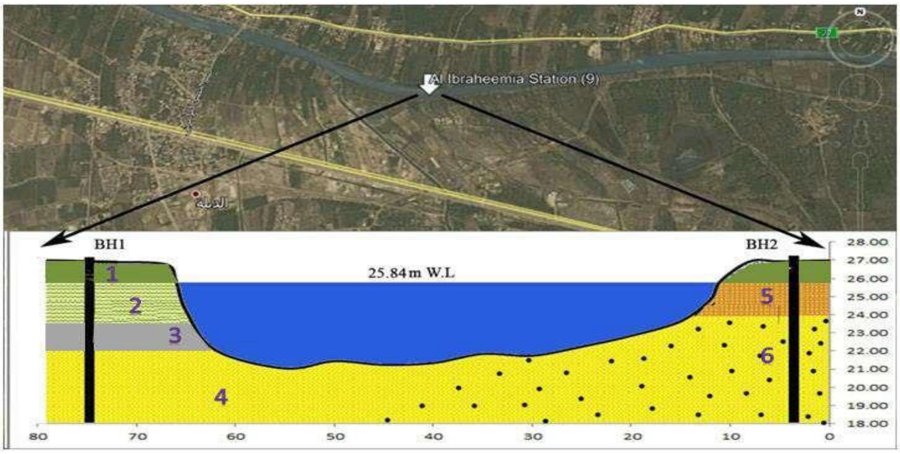


Figure -4 River cross section showing boreholes, and sequence of layers to Al- Wazeer station

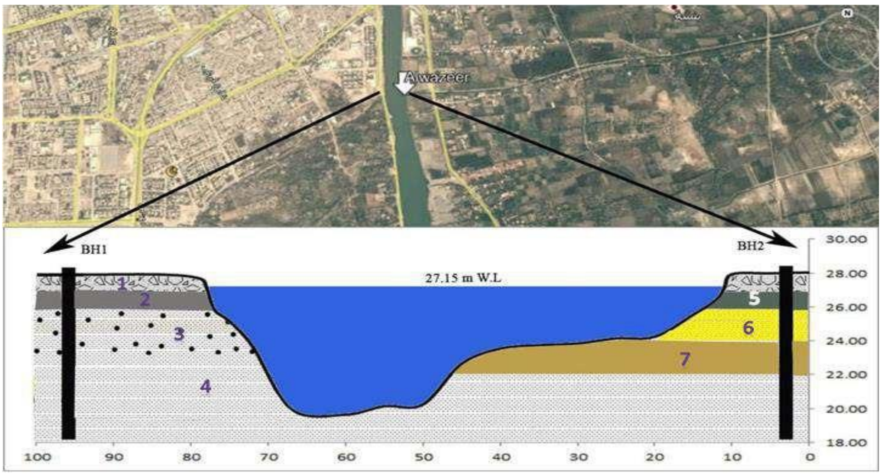


Figure -5 River cross section showing boreholes, and sequence of layers to Al- Ibraheemia station

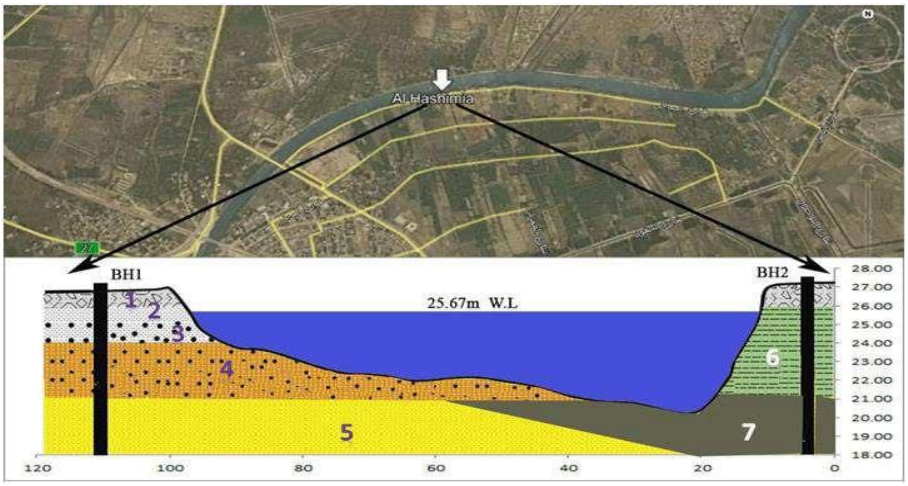
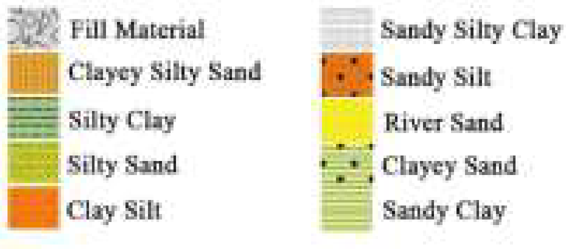


Figure -6 River cross section showing boreholes, and sequence of layers to Al- Hashemia station

The common legend of the three stations is:



5.2. Stations Results Discussion

A. Physical Results Discussion

The moisture content and the saturation rate of the soil are affected by two factors are subsurface water level, which changes with the fluctuation of the water levels of the river adjacent to the bank; The second influencing factor is the type of soil, either composed of coarse sediments such as sand with high permeability and low porosity, in which water retention is low, or vice versa in fine grains soils such as clay and silt; where it recorded the range moisture content(W%) was between (14-31) %, and the main moisture source is through capillary property.

As for the specific gravity (Gs), which is affected by the type of sediments and the extent of their compactness and convergence when forming the soil, as is the case in examining the weight of the dry and wet unit volume, where the highest specific weight was recorded values between (2.65-2.75) As for dry Unit weight was between (1.30-1.61) , while wet unit weight was between (1.70-1.99) g/cm^3. Another important characteristic that depends on the moisture content and soil type is the Atterberg limits, the range percentage of the liquid limit is (21-40) % , , because of the moisture content of soil is low, and fine grain size of soil .

While the range of the Plasticity Index is (8-24) %, and therefore it is classified according to (Al-Ashw, 1991) as (low plasticity soil. - highly plastic soil), while the range of the clay percentage was (2-72) %, While the range of silt percentage was (2-68) %, sand percentage was (3-73) %, and low percentage of gravel in the three stations.

Table 1- The results of the Basic properties tests for the soil in Al-Wazeer station.

B.H.	Samples type	Depth of sampling (m)		Particle size distribution and hydrometer analysis				Physical properties							SP.T. "N" Value	Symbol Unit Class	Distribution of soil
		from	to	Gravel%	Sand%	Silt%	Clay%	A	L.L%	P.I%	MC.%	G.S	Unite weight g/cm^3 γwet	γDry			
1	D.S.	0.5	1.0	7	16	30	47						1.75	1.33			Fill material
	U.S.	1.0	1.5	0	14	58	28	0.6	36	18	26	2.70	1.77	1.34		ML	Stiff brown sandy clayey silt with organic material
	S.S.	1.5	2.0	0	16	44	40				28		1.81	1.40	13		=
	D.S.	3.0	3.5	0	15	42	43					2.73					Stiff brown sandy silty clay with gypsum stiff
	U.S.	4.5	5.0	0	10	34	56	0.5	40	24	29	2.64	1.93	1.56		CL	Very stiff brown sandy silty clay
	S.S.	5.0	5.5	0	24	35	41					2.68	1.76	1.34	17		=
	D.S.	6.5	7.0	0	48	24	28				27		1.75	1.31		CM	Medium dense grey silty clayey sand
	U.S.	7.5	8.0	0	26	39	35	0.3	23	9	26	2.72				CL	Very stiff brown sandy clayey silt
	S.S.	9.0	9.5	0	28	37	35	0.4	28	13	29		1.85	1.43	18	CL	=
2	D.S.	0.5	1.0	7	20	34	39				16						Fill material with gypsum
	D.S.	1.5	2.0	6	23	33	38	0.4	39	14	19	2.71	1.86	1.47		ML	Very stiff brown sandy silty clay
	U.S.	2.0	2.5	0	55	34	11				23					SM	Medium dense grey clayey silty sand
	S.S.	2.5	3.0	0	51	37	12				24	2.69	1.77	1.41	11		=
	U.S.	4.0	4.5	0	13	32	55	0.5	40	23						CL	Stiff brown sandy silty clay
	S.S.	5.0	5.5	0	9	23	68		34	12	27	2.76	1.92	1.55	15	CL	=
	D.S.	7.0	7.5	0	3	58	39	0.3	39	11						ML	Very Stiff brown sandy clayey silt
	S.S.	8.5	9.0								25	2.73	1.941.93	1.55	15		=
	U.S.	9.5	10	0	37	44	19	0.2	21	9	26	2.75		1.54		CL	=

Table 2- The results of the Basic properties tests for the soil in Al-Ibraheemia station

B.H.	Samples type	Depth of sampling (m)		Particle size distribution and hydrometer analysis				Physical properties							SP.T. "N" Value	Symbol Unit Class	Distribution of soil
		from	to	Gravel%	Sand%	Silt%	Clay%	A	L.L%	P.I%	MC.%	G.S	Unite weight g/cm³ γwet	Unite weight g/cm³ γDry			
3	D.S.	0.5	1.0	7	23	38	32				14	2.66	1.71	1.30			Fill material
	S.S.	1.0	1.5	3	6	39	52	0.3	33	13					6	CL	Medium stiff brown sandy silty clay
	U.S.	2	2.5	0	5	37	58	0.3	34	16	28	2.71	1.95	1.57			=
	S.S.	2.5	3.0										1.93	1.55	9	CL	=
	U.S.	4.0	4.5	0	24	50	26				27	2.75					stiff brown sandy clayey silt
	S.S.	4.5	5.0	0	30	42	28	0.5	31	15	28		1.93	1.54	13	CL	stiff brown clayey silty sand
	U.S.	6.0	6.5	0	4	44	52	0.3	36	14	31	2.72	1.94	1.56			Very stiff brown sandy silty clay
	D.S.	7.0	7.5	0	7	42	51				30		1.92	1.45			=
	S.S.	8.0	8.5	0	6	48	46	0.4	34	17	29	2.73	1.99	1.61	23	OL	=
	D.S.	9.0	9.5	0	2	27	71				30	2.74	1.97	1.59			=
4	D.S.	0.5	1.0	8	41	29	22				16	1.67	1.70	1.31			Fill material
	S.S.	1.0	1.5	5	29	22	44	0.4	31	16		1.68	1.81	1.48	17	CL	Medium dense grey silty sandy clay
	U.S.	2.0	2.5	0	33	24	43				19	2.67					=
	S.S.	3.0	3.5	0	64	29	7						1.78	1.38	21	SM	Medium dense gray clayey silty sand
	D.S.	4.0	4.5	0	69	28	3				22	2.66					=
	S.S.	5.5	6.0	0	71	26	3						1.79	1.44	12	SM	=
	D.S.	6.5	7.0	0	73	24	3				21	2.65					=
	D.S.	7.5	8.0	0	70	25	5										=
	S.S.	8.5	9.0	0	67	31	2				24	2.65	1.82	1.45	34	SM	Hard gray clayey silty sand
	D.S.	9.5	10.0	0	68	28	4										=

Table 3 The results of the Basic properties tests for the soil in Al-Hashemia station

B.H.	Samples type	Depth of sampling (m)		Particle size distribution and hydrometer analysis				Physical properties							SP.T. "N" Value	Symbol Unit Class	Distribution of soil
		from	to	Gravel%	Sand%	Silt%	Clay%	A	L.L%	P.I%	MC.%	G.S	Unite weight g/cm^3 γwet	γDry			
5	D.S.	0.0	0.5	2	43	44	11				16	2.68	1.72	1.30			Fill material
	U.S.	1.0	1.5	0	6	44	50	0.4	31	19	20	2.74	1.83	1.47		CL	stiff brown sandy silty clay with organic material brown
	S.S.	2.0	2.5	0	34	31	35				26		1.88	1.50	14		stiff brown silty sandy clay
	U.S.	3.0	3.5	0	3	46	51	0.4	36	21	29	2.75	1.92	1.53		CH	stiff brown sandy silty clay
	S.S.	4.5	5.0	0	11	43	46				25	2.74	1.93	1.54	12		=
	U.S.	6.5	7.0	0	15	72	13	0.6	32	8	23	2.75	1.73	1.31		ML	Medium stiff brown clayey sandy silt
	S.S.	8.0	8.5		51	26	23				26				10		Loose gray clayey silty sand
	D.S.	9.0	9.5	0	66	20	14				22	2.68	1.79	1.38		SM	=
	U.S.	9.5	10.0	0	31	29	40	0.3	24	11	27	2.73	1.88	1.51		CL	Medium stiff brown silty sandy clay
6	D.S.	0.0	0.5	11	26	36	27				15						Fill material
	U.S.	1.0	1.5	0	45	34	21	0.5	36	12	17	2.69	1.90	1.51		ML	Very stiff brown clayey silty sand with organic materials
	S.S.	2.0	2.5	0	23	19	58	0.4	31	23	26	2.72	1.93	1.53	17		Very stiff brown silty sandy clay
	U.S.	3.0	3.5	0	27	25	48	0.5	32	12	25		1.82	1.43		CL	=
	S.S.	4.5	5.0	0							24	2.71	1.83	1.44	15		=
	U.S.	6.5	7.0	0	69	23	8				25		1.72	1.31		SM	Medium dense gray clayey silty sand
	S.S.	8.0	8.5	0	61	24	15				26	2.69	1.74	1.33	14		=
	D.S.	9.0	9.5	0	51	28	21				26	2.68	1.80	1.41			=

B. Engineering Results and Discussion

Engineering properties of soils consist (permeability, uniaxial compressive strength, direct shear test, unconsolidated undrained (UU), and consolidation test) as below: Permeability it depends on the size and shape of the soil granules, where the increase of sorting and the grain size, leads to increase of the permeability. As for the bearing capacity of the soil, it is depending on the type of soil as its percentage ranged in (Al-Wazeer, AL-Ibraheemia ,and Al-Hashemia) Stations, where the value of permeability (K) for the layers changes between ($4*10^{-5}$ to $5*10^{-2}$) mm/Sec. As for the highest bearing capacity (q all) recorded (q all = 10 Tons/m^2, (100 kN/m2)), at a depth of 6 m. As for the right side of flow (sedimentation area). The results of the uniaxial compressive strength (qu) showed the range of the uniaxial compressive strength of (78-35 kN/m2), cause of rise in values because the soil it consists of a high percentage of clay, characterized by its high resistance to loads because of its high cohesion, and the minimum value because the layer is made of sand with little cohesive strength.

The results of the cohesion force (C) and the internal friction angle have the range value of the cohesion force of (5-45.6) ton/m^2 cause of rise in values, because the soil contains a high percentage of clay, which has a high cohesion force that resists the shear force, while the minimum value of the cohesion strength because the soil contains a law percentage of clay. the range value of the angle of internal friction is (3°- 24°), because the soil contains a high percentage of sand, which has a high angle of friction, and the lowest value of the angle of internal friction because the soil contains a low percentage of sand. (Consolidation) and the results were (Cc) Compression index that the range value of the index was (0.15-0.25), because the soil has a high percentage of clay, which is characterized by its ability to compress, and the lowest value of the compressive Index, because the soil has a low percentage of clay, which is characterized by being highly compressible. (Cr) The range value of the Swelling index (Cr) was (0.25-0.47), this may be due to the soil containing some clay minerals that have the ability to swell, also the highest ratio of the primary void ratio (eo) was (0.63-1.01), because the soil contains a high percentage of clay as it is characterized by not connected voids, because of its high porosity, and the lowest initial void ratio because the soil contains a relatively small proportion of clay, as clay is characterized by containing gaps, because its porosity is high .

The range value of Pre- consolidation pressure (Pc), was (120-200 kN / m2), this means that the soil contains a high percentage of clay or has been affected by previous loads that caused the consolidation, and the lowest value of Pre- consolidation pressure (Pc) , because the soil contains a low percentage of clay or the soil may not have been previous loads that caused its consolidation; the initial consolidation pressure (Po) is the primary consolidation pressure , the values of (Po) ranged between (130-303 kN/m2), due to the increasing in the density of the soil layers above the sample, due to the increase in depth effect of lithostatic pressure above the sample , and the lowest value of (Po) due to the low density of the soil layers above the sample. The over consolidation ratio (OCR), has the highest value less than (1) where the soil classified according to Holtz, Kovacs, and Sheahan [18].

Table 4- Results of the engineering properties of soil in Al- Wazeer station

B.H. NO.	Depth (m) From-To	q_u kN/m^2	C kN/m^2	∅o	Consolidation				
					e_o	C_c	C_r	P_o (kN/m^2)	P_c (kN/m^2)
1	0.5-1.0	34	7.2	21					
	1.5-2.0	41	15.8	7	0.77	0.183	0.047	236	**180**
	4.5-5.0	54	22.7	6	0.63	0.176	0.042	208	**160**
	7.5-8.0	62	45.6	3	0.71	0.181	0.045	220	**175**
2	0.5-1	36	8.4	19					
	1-1.5	44	37	4	0.81	0.174	0.039	180	170
		53	9	18					
	5-5.5	58	23	8	0.69	0.171	0.38	184	**150**
	7.5-8	62	27.8	7					
	8.5-9	64	8	31					

Table 5- Results of the engineering properties of soil in Al-Ibraheemia station

B.H. NO.	Depth (m) From-To	q_u kN/m^2	C kN/m^2	∅o	Consolidation				
					e_o	C_c	C_r	P_o (kN/m^2)	P_c (kN/m^2)
3	1.5-2.0	31	20	6					
	3-3.5	46	8	22	0.91	0.17	0.038	300	**190**
	6-6.5	58	6	24					
	9.0-9.5	63	43.1	3	0.680	0.147	0.032	184	170
4	1-1.5	38	9	20					
	2-2.5	41	17.7	12	0.952	0.173	0.040	303	200
	7.5-8	52	7	19					
	8.5-9	65	5	21					

Table 6- Results of the engineering properties of soil in Al-Hashemia station

B.H. NO.	Depth (m) From-To	q_u kN/m^2	C kN/m^2	∅o	Consolidation				
					e_o	C_c	C_r	P_o (kN/m^2)	P_c (kN/m^2)
5	1-1.5	**35**	**8.1**	**21**	**0.9**	**0.25**	**0.037**	**30**	120
	3-3.5	**41**	**33.8**	**6**	**1.01**	**0.21**	**0.034**	**68**	130
	6-6.5	**49**	**9.5**	**17**	**0.79**	**0.19**	**0.025**	**88**	190
	8.5-9.0	**56**	**23.4**	**9**					
6	1-1.5	**38**	**21.7**	**7**					
	3-3.5	**46**	**24.5**	**10**	0.93	0.15	0.04	211	**175**
	7.5-8	**54**	**11**	**16**					
	8.5-9	**63**	**45**	**3**					

C. Chemical Results Discussion

The Chemical tests for soil and water samples results in (Al-Wazeer, AL-Ibraheemia, and Al-Hashemia) stations for two wells (1and 2), were as follows: The percentage of (SO^3) ranged between (4.78 to 0.07) %, within the normal range of its concentration in soil. The same applies to the total salts in soil and water (T.S.S), which were within the normal range, as they ranged in the two wells from (0.25-10.56) %. For the organic matter content of the three stations soil, it was little, reduced to relatively high percentages in the upper layers The highest value was recorded (0.33)%, and this percentage begins to decrease with depth until reached less than (0.04)%, since the density of organic matter is low in relation to the components of soil.

Table 7- The results of the chemical tests of Al-Wazeer station soil

B.H. NO.	Depth		SO_3	T.S.S.%	Org.%	Gypsum%	Ca CO_3%	PH	Cl%
	from	to							
1	1.0	1.5	0.35	1.11	0.33	0.75	23.3	8.4	0.017
	2.5	3.0	0.20	0.72	0.24	0.43	24.1		0.017
	6.0	6.5	0.40	1.89	0.11	0.86	36.7	8.3	0.016
	9.0	9.5	0.32	1.00	0.08	0.68	24.9		0.16
2	1.0	1.5	4.78	10.56	0.36	10.2	15.2	8.6	0.019
	4.5	5.0	3.87	8.85	0.30	8.32	26.9		0.19
	6.5	7.0	0.53	1.42	0.09	1.14	28.7	8.2	0.018
	9.0	9.5	0.47	1.19	0.04	1.01	30.1		0.017

Table 8- The results of the chemical tests of Al-Ibraheemia station soil

B.H. NO.	Depth		SO_3	T.S.S.%	Org.%	Gypsum%	Ca CO_3%	PH	Cl%
	from	to							
3	1.0	1.5	0.30	1.11	0.19	0.66	46	8.1	0.017
	2.5	3.0	0.42	0.78	0.11	0.90	44		0.015
	6.0	6.5	0.29	0.81	0.09	0.63	45	8.3	0.017
	9.0	9.5	0.08	0.25	0.07	0.17	48		0.015
4	1.0	1.5	0.15	0.82	0.15	032	41	8.2	0.018
	4.5	5.0	0.10	0.90	0.11	0.21	42		0.016
	6.5	7.0	0.09	0.80	0.07	0.19	45	8.5	0.014
	9.0	9.5	0.07	0.25	0.03	0.15	47		0.012

Table 9- The results of the chemical tests of Al-Hashemia station soil

B.H. NO.	Depth		SO_3	T.S.S.%	Org.%	Gypsum%	Ca CO_3%	PH	Cl%
	from	to							
5	1.0	1.5	0.36	1.31	0.08	0.78	15	8	0.016
	2.5	3	0.14	0.87		0.31	15.1	8.1	0.015
	6.0	6.5	0.13	0.71	0.05	0.24	15.3	8	0.015
	9.0	9.5	0.12	0.6		0.15	14.9	**8.2**	0.016
6	1.0	1.5	0.52	0.90	0.09	1.07	42	7.9	0.018
	4.5	5.0	0.41	0.82		0.88	45	8.1	0.017
	6.5	7.0	0.09	0.43	0.07	0.19	23	8.0	0.017
	9.0	9.5	0.12	0.45		0.26	39	8.0	0.016

D. Slope stability

D.1. Al-Wazeer Station

Al- Wazeer station has a safety factor of 2.3 in normal conditions as in figure (5-7), when the flow water level is 27.15m, Therefore, the slope is considered safe. The increase and decrease of the river's flow level , and effect of loads , where reaches the safety factor to 0.48 when it rise to +2m, above the natural water level and be 0.46 when dropped to depth (-2 m),under water level, so in the two cases the slope is (unsafe), also when the loads rise even 300 kN, as in table safety factor decrease to (1) where the landslide occur (soil failure), depend on (Bishop and Taylor methods), for extracting the safety factor for the right bank of the flow, by GeoStudio 2021 program.

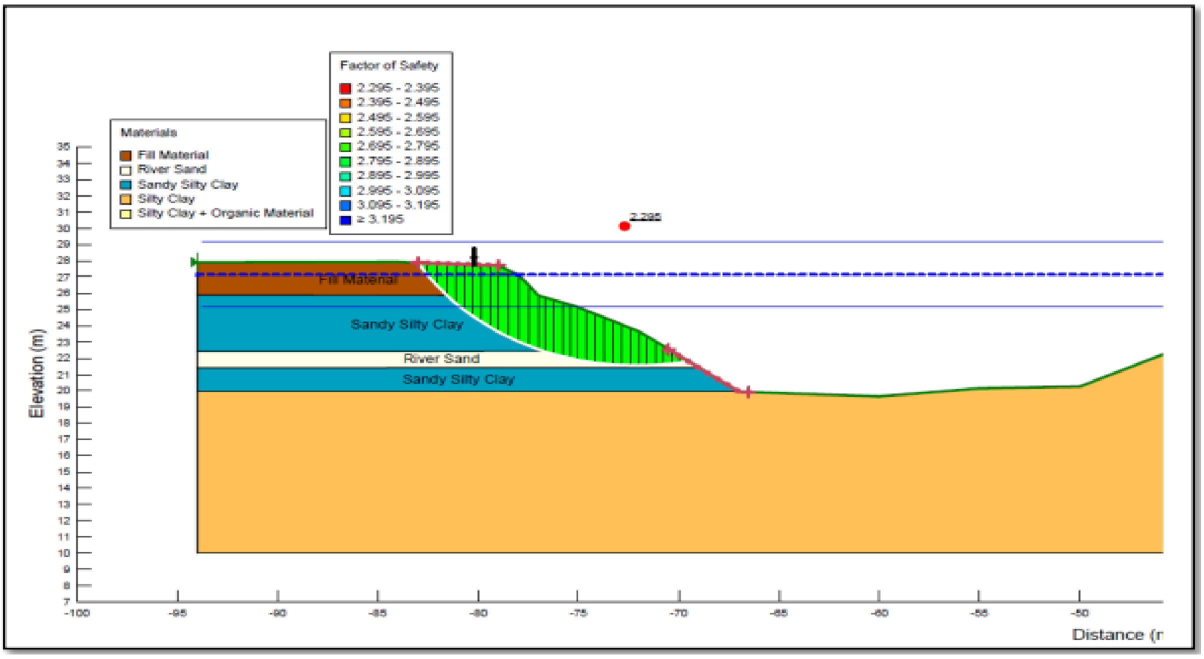


Figure -7 Safety factor extracting for the right bank of the flow at Al-Wazeer Station, by GeoStudio 2021 program

D.2. AL-Ibraheemia Station

The safety factor in AL- Ibraheemia station was recorded with a value of 2.85 under natural conditions as in figure (5-8) when the Water level is (25.84m), and therefore the slope of the bank is considered safe, but when the water level rise to (+2m) , it gradually decreases until it reaches (0.21) then safety factor will equal to 0.20 at (-2m) , in the two cases the slope will be (unsafe) , it bears loads more than(100) kN , after this loads the bank soil start collapsing.

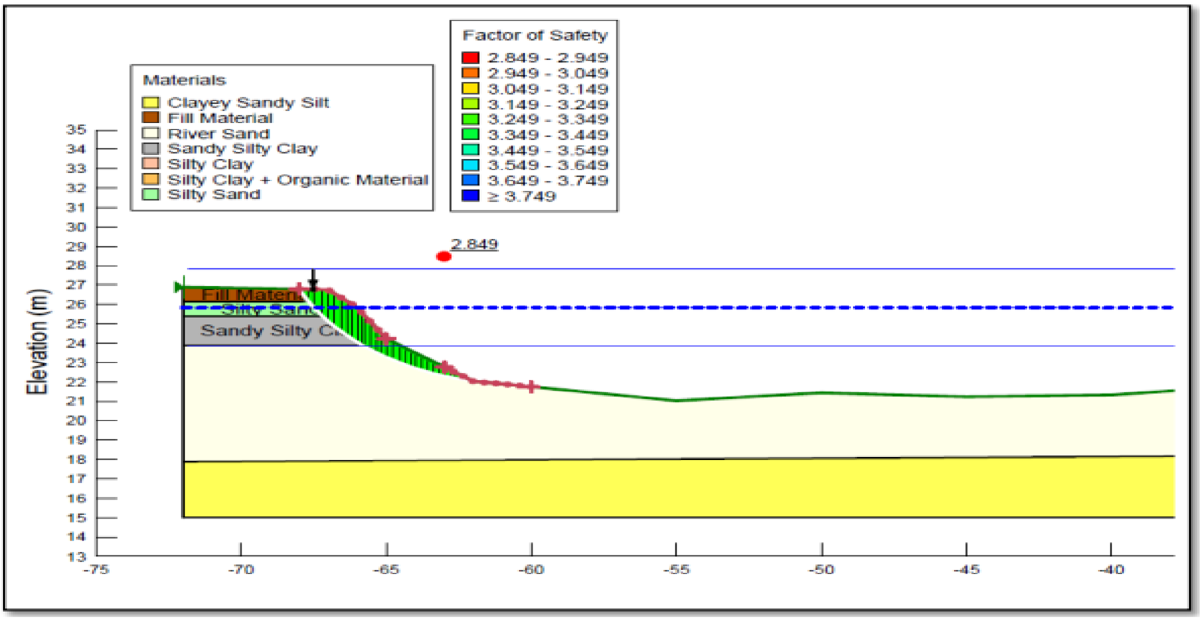


Figure -8 Safety factor extracting for the right bank of the river at Al-Ibraheemia Station, by GeoStudio 2021 program

D.3. Al-Hashemia Station

The safety factor in the Hashemite station is 1.84 in natural conditions as in the figure (5-9), when the flow water level is 25.67m, a rise and fall of the river's flow level and loads, effect on safety factor. It reaches to (0.43) when it rises (+2m), above the natural water level and be (0.42) when dropped (-2 m), under water level, so that in the two cases the slope is (unsafe), also when the loads rise even (200 kN), safety factor decrease to (1) where the landslide occurs (soil failure) according to (Bishop and Taylor methods), for extracting the safety factor for the left bank of the river, by GeoStudio 2021 program.

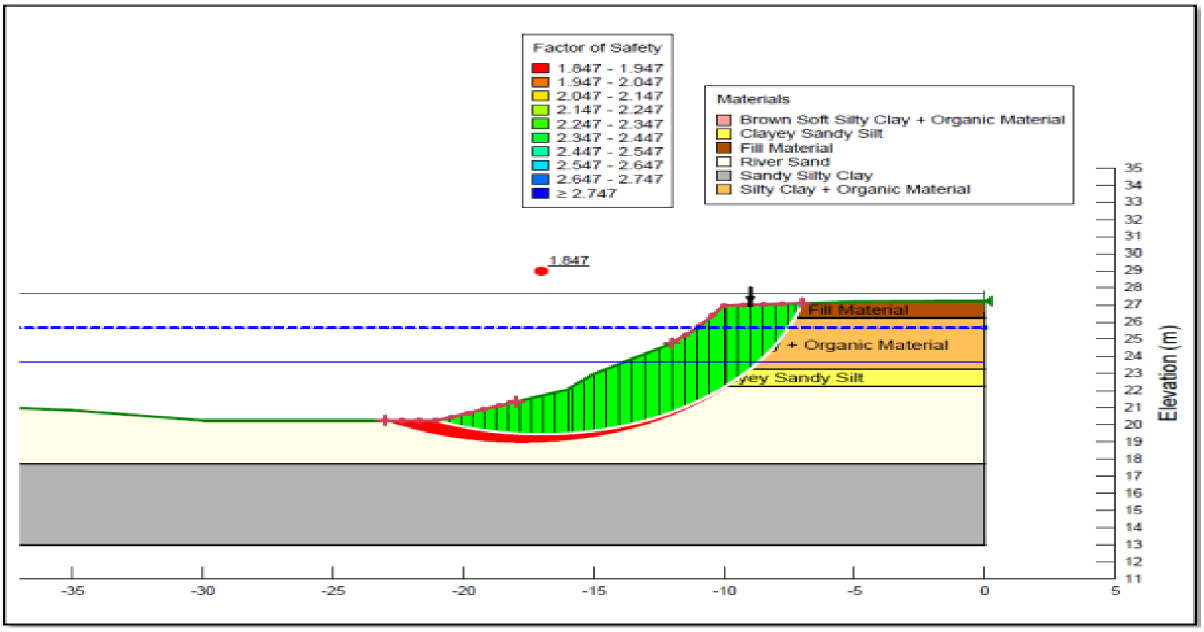


Figure -9 Safety factor extracting for the left bank of the river at Al-Hashemia Station, by GeoStudio 2021 program

6.Conclusions

The geotechnical results in all study stations showed that the convex side (erosion), is consisting from layers of clay, silt and sand, often be regular, while the concave side (sedimentation) mostly consists of river sand low (density, specific gravity and, cohesion)

Hilla River affected by the energy of the flow velocity and according to type of banks soils, therefor the meander is forming.
The rise and fall of the river water level affects the safety of the slopes, as in both cases the safety factor decreases, but when it decreases (dry season), its effect is often greater.
The bearing capacity of the banks on both sides of the river is low for all study stations, reaching at its best to 7 t/m^2.

7.Recommendations

1. Develop a comprehensive study along Hilla River about the effect of the river flow on the slope stability of the banks.

2.Slope grading (flattening) the steep bank slopes of by reducing their slope angle, this will increase slope stability.

3. According the determined safety factors in the studied locations, construct buildings that require high bearing capacity on or near these locations are unsafe.

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