THE STUDY OF INFILTRATION RATE AND ATTERBERG LIMITS OF SOILS IN KOI SANJAQ CITY, ERBIL GOVERNORATE, KURDISTAN REGION, NORTH IRAQ

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ABSTRACT

The present study aims to determine the infiltration capacity and some physical properties of soils from some selective locations in Koi Sanjaq city and near surrounding areas, within Erbil Governorate, north Iraq. The exposed geological formations (Pila Spi, Fatha and Injana) and Quaternary sediments have been studied, for this purpose. Pila Spi and Fatha formations are exposed in west, northwest, north, and northeastern parts of the study area, whereas, Injana Formation is exposed in the central, southern, southeastern, and southwestern parts of the study area. The Quaternary sediments cover some of the central parts of the study area, too.

Sixteen locations were selected in different parts of the study area, for sampling and infiltration test application. These locations were selected according to the type of the exposed rocks and existing of the Quaternary sediments. The depth of the infiltration capacity with time, grain size distribution, and Atterberg limits are determined for all the studied locations.

According to f (t) value, the infiltration capacity of the study area is between (Slow – Rapid). The infiltration capacity results indicated that the west and northwestern parts of the study area are characterized by Medium – Rapid rate of infiltration, the northern part is characterized by Medium rate of infiltration. Whereas, the central, east, southeast, southwest and northeastern parts are characterized by Slow – Medium rate of infiltration. However, the southern part is characterized by Slow rate of infiltration. Therefore, west, northwest and northern parts of the study area are considered as a good recharge areas for Koi Sanjaq city, as the Quaternary sediments are concerned, hence it is recommended not to use these areas for urbanization projects; to remain the area as a source of recharge for Koi Sanjaq city. The southern part of the study area is characterized by Slow rate of infiltration capacity, which indicates that it consists mainly of clay. The clay is characterized by high porosity, but low permeability, consequently the rate of infiltration is Low, therefore, this part is not recommended for deep water well drilling, consequently, the population of this part benefits the shallow water wells. The coefficient of permeability also is determined and the results indicated that the coefficient of permeability is High in the northern and northwestern parts of the study area, it decreases south wards.

The study of the grain size distribution of the soil samples indicated that the north, west and northwestern parts of the study area are characterized by increase of coarse grained sediments; whereas the central, south, southeast and southwestern parts are characterized by increase of fine grained sediments. The Atterberg limits (liquid limit and plastic limit) indicated that the soil is generally with low to medium plasticity index.

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دراسة سعة الترشيح وحدود أتربيرك للتُرب من بعض المواقع المختارة في مدينة كويسنجق محافظة أربيل، إقليم كوردستان، شمال العراق

گلاويز بكر بابير

المستخلص

الهدف من الدراسة الحالية هو تحديد سعة الترشيح وبعض الصفات الفيزيائية للترب في بعض المواقع المختارة من مركز مدينة كويسنجق، شمال العراق، وبعض المناطق المجاورة لها. إن التكوينات الجيولوجية المتكشفة في المنطقة هي بيلا سبي، الفتحة وإنجانة مع ترسبات العصر الرباعي. إن تكويني بيلا سبي والفتحة يتكشفان في الأجزاء الشمالية، الغربية، الشمالية الشرقية والشمالية الغربية من منطقة الدراسة، بينما يتكشف تكوين إنجانة في الأجزاء الوسطى، الجنوبية، الجنوبية الشرقية والجنوبية الغربية منها، وان ترسبات العصر الرباعي تغطي بعض الأجزاء الوسطى منها أيضاً. تم اختيار 16 موقع في منطقة الدراسة اعتماداً على نوع الصخور المتكشفة ونوع الرسوبيات التي تغطي منطقة الدراسة. وتم تحديد عمق الترشيح مع الوقت والتدرج الحجمي للرسوبيات مع معامل اللدونة لكل موقع.

اعتماداً على قيمة (ft) فان سعة الترشيح في منطقة الدراسة هي بين (بطيئ – سريع). كما تبين من نتائج سعة الترشيح، إن الأجزاء الشمالية الغربية والغربية تمتازان بمعدل ترشيح (متوسط – سريع)، أما الجزء الشمالي يمتاز بمعدل ترشيح متوسط. لكن الأجزاء الوسطى، الشرقية، الجنوبية الشرقية، الجنوبية الغربية والشمالية الشرقية تمتاز بمعدل ترشيح (واطئ – متوسط) والجزء الجنوبي يمتاز بمعدل ترشيح واطئ. ولذلك تعتبر الأجزاء الشمالية، الشمالية الغربية والغربية من منطقة الدراسة من مناطق التغذية الجيدة لمدينة كويسنجق وأطرافها، فيما يخص ترسبات العصر الرباعي، وعليه نقترح بعدم استخدام هذه المناطق لمشاريع البناء لتبقى مصدراً لتغذية المياه الجوفية في مدينة كويسنجق. إن الجزء الجنوبي من منطقة الدراسة يمتاز بسعة ترشيح واطئ والذي يدل على إن الجزء الجنوبي معظمه يتكون من الأطيان، حيث لها مسامية عالية ونفاذية قليلة، ولذلك فان معدل الترشيح يكون قليلاً، وعليه فان هذا الجزء من منطقة الدراسة غير صالح لحفر الآبار المائية العميقة. وان سكان المنطقة يستفادون من الآبار الضحلة لسد حاجاتهم اليومية من المياه.

كذلك تم تحديد معامل النفاذية لمنطقة الدراسة، وبينت النتائج بأن معامل النفاذية عالي في الأجزاء الشمالية والشمالية الغربية ويقل باتجاه الجنوب. دلت نتائج فحص التدرج الحجمي للرسوبيات بأن الأجزاء الشمالية، الغربية والشمالية الغربية من منطقة الدراسة تمتاز بزيادة الرسوبيات الخشنة، أما الأجزاء الوسطى، الجنوبية، الجنوبية الشرقية والجنوبية الغربية من المنطقة تمتاز بزيادة الترسبات الناعمة. وكذلك دلت نتائج فحوصات حد السيولة وحد اللدونة للنماذج، بشكل عام على إن معامل اللدونة في المنطقة قليل إلى متوسط.

INTRODUCTION

The study area lies about 70 Km east of Erbil city, central northern part of Iraq. It is bounded by UTM grid 3986000 and 3996300, in the north and 458000 and 474000, in the east (Fig.1). The area is surrounded by some mountains like Haibat Sultan, in the north, northeast and northwest, whereas in the west and southwest, it is surrounded by Bawaji Mountain (Fig.2).

The infiltration test method describes a procedure for field measurement of the rate of infiltration of water into soils, using double-ring infiltrometer. Many factors affect the infiltration rate, like the soil structure, soil layering and condition of the soil surface, degree of saturation of the soil, chemical and physical nature of the soil and of the applied liquid, head of the applied liquid, temperature of the liquid, and diameter and depth of embedment of rings. Thus, tests made at the same site are not likely to give identical results (ASTM D3385, 2010).

The grain size distribution curves can be used to understand certain grain size characteristics of soils, uniformly graded or nearly vertical lines represent poorly graded soils, such soils possess particles of almost the same diameter. A well-graded soil possesses a wide range of particle sizes ranging from gravel to clay size particles; a gap-graded soil has some of the sizes of particles missing (Murthy, 2002).

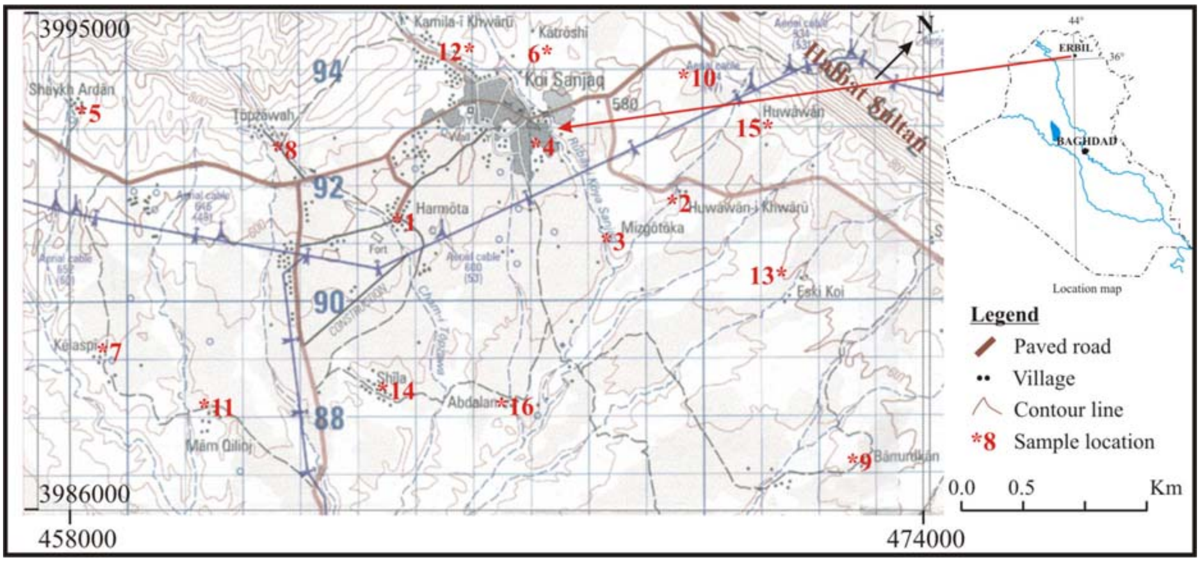

Fig.1: Location map of Koi Sanjaq city and some surrounding villages, showing the location of the collected samples

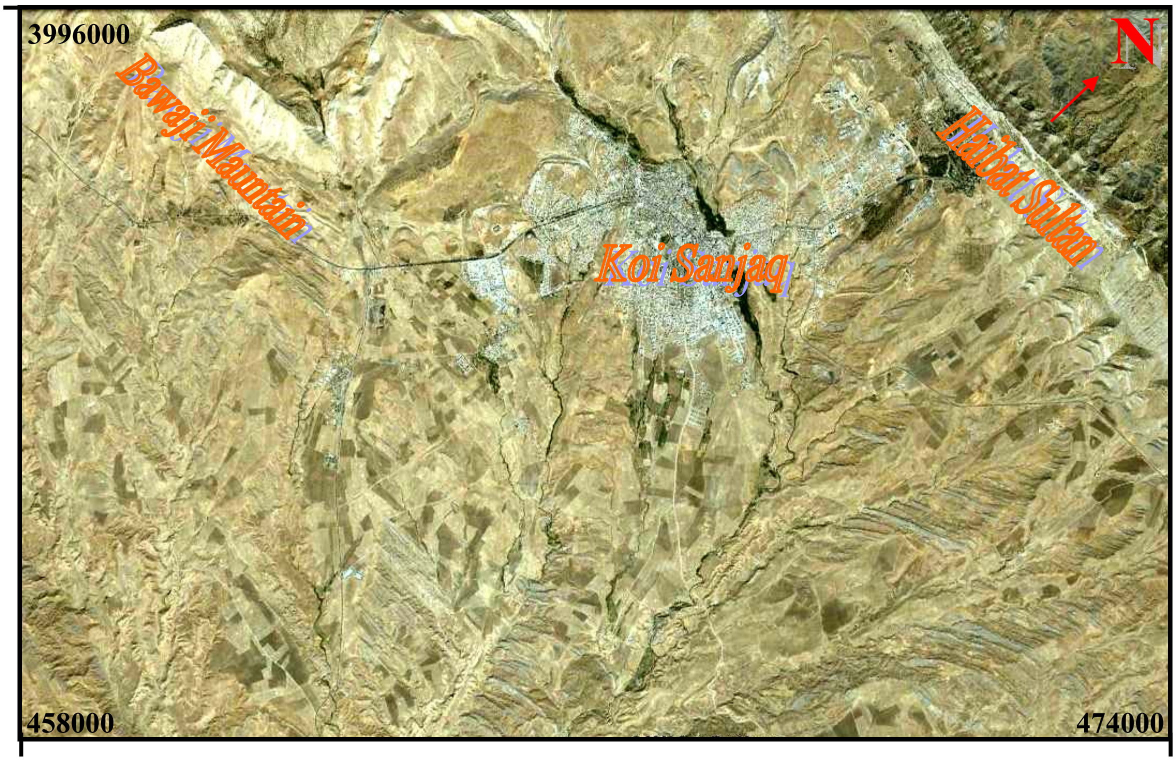

Fig.2: Satellite image of Koi Sanjaq city and near surroundings

PREVIOUS STUDIES

Many studies have been carried out in the study area.

- Sissakian and Youkhanna (1979) and Youkhanna and Sissakian (1986) dealt with the stratigraphy, structure geomorphology and hydrogeology of the study area and reported about the exposed formations and existing structures.
- Al-Qayim and Nisan (1989) dealt with the sedimentary facies analysis in the area.
- Al-Saadi and Al-Jassar (1993) studied the instability of rock slopes controlling part of the main road-cut slopes at the southwestern side of Haibat Sultan Mountain.
- Sissakian (1992 and 1997) complied the Geological Map of Kirkuk Quadrangle, and Erbil and Mahabad Quadrangles at scale of 1: 250 000, respectively and reported about the exposed formations, geological structures and hydrogeology.
- Saber (2006) studied the role of the natural geographical factors on the slope surface of Haibat Sultan Mountain area.

GEOLOGICAL SETTING

According to Buday and Jassim (1987) the study area is located within the boundary of the High Folded Zone and Foot Hill Zone of Cham Chamal – Butma Subzone. This zone occupies the central part of the Unstable Shelf. The Haibat Sultan Mountain is located to the north, northwest and northeastern parts of the study area, it represents the southwestern limb of Safeen anticline. The dip of the bedding ranges from (40 – 50)º to the southwest direction. In the study area, several formations are exposed; these are from the oldest to the youngest.

– **Pila Spi Formation**: This formation is Middle – Upper Eocene age (Bellen *et al*., 1959 and Buday, 1980). It forms continuous steep ridges at the crest and southwestern sides of Haibat Sultan Mountain. The formation consists mainly of light gray and yellowish white colour, well bedded and very hard limestone and dolostone, the rock at the lower part of the formation are interbedded with light yellowish white and very soft marl.

– **Fatha Formation**: This formation is Middle Miocene age (Bellen *et al*., 1959). It forms a continuous belt at the southwestern side of Haibat Sultan Mountain. The formation consists of cyclic deposits of mudstone and thin layers of limestone and gypsum. The mudstone is reddish brown in color, soft and represents the main constituent of the formation. The limestone is light grey and brown in color, well bedded and hard; some limestones are fossiliferous and include chert nodules, also gradual changes of marl and marly limestone occur at the middle part of the formation. The gypsum is white, hard, well bedded to massive.

– **Injana Formation**: The formation is of Upper Miocene age (Bellen *et al*., 1959). Consists of grey and brown calcareous sandstone interbedded with brown claystone and reddish brown siltstone in cyclic nature (Sissakian, 1992), the formation is underlain conformably by the Fatha Formation.

– **Quaternary sediments:** They cover several parts of the study area, especially the center of Koi Sanjaq city and some areas near the valleys.

METHOD OF WORK

The study includes both hydrogeological and engineering-geological analysis of the sediments in Koi Sanjaq city, and near surroundings.

▪ Hydrogeological Study

For hydrogeological study, the used method describes a procedure for field measurement of the infiltration rate of soils. Rates determined by pounding of large areas are most reliable method for determining the infiltration rate, but the infiltrometer-ring method is more feasible, economically. The double ring infiltrometer was used to prevent divergent flow in layered soils by providing an outer ring to encourage only vertical flow from the inner ring. Double ring infiltrometer consists of two iron rings (inner and outer rings) with 2 mm thicknesses, (30 and 60) cm diameters and 30 cm in height (Gregory *et al*., 2005) (Fig.3). It works by directing water to a known surface area due to the parameters of the inner ring. The rate of the infiltration is determined by the amount of the water that infiltrates into the soil per surface area, per unit of time. Infiltration can be measured by either a single or double ring infiltrometer, with preference usually lying with the double ring, because the outer ring helps in reducing the error that may result from lateral flow in the soil (McKenzie *et al*., 2002). The inner ring must be in the middle of the outer ring. An indicator is placed at the top of the two rings, and then water is added until it reaches the indicator. A ruler is placed in the inner ring to measure the depth of infiltration in millimeter. Before placing the double rings for measuring the infiltration in any location, the ground cover must be removed without disturbing the soil surface. Once this is done, the rings can be set in position and knocked into the ground about 10 cm, or until the rings are set firmly in the ground. Water can be supplied inside the rings either by a bottle assembly, to keep a constant head or manually. When filling up the rings, the outer ring is filled first so that the soil profile around the inner ring would be wet and only vertical flow would occur; then the inner ring is filled, later. The level of the water is recorded at this point as the start of infiltration.

Fig.3: Double ring infiltrometer of (30 – 60) mm diameter

The measurements, in the study area were recorded at different times (1, 2, 3, 4, 5, 8, 18………. and 300 min) (Table 1). Each test took about 5 hours. The infiltration rate can be calculated by the following equation:

$$\textbf{Infiltration rate} = \frac{\textbf{Cumulative depth of infiltration}}{\textbf{Time (hour)}} \quad \text{(Smith, 2002)}$$

The data are gained by a drop in the water height, giving infiltration of water over the time; the data are plotted on a graph for the infiltration versus time (Fig.4). Theoretically, once the soil becomes saturated, a steady state infiltration rate can be reached; the gradient of the line gives the steady state infiltration rate for that particular soil (Fig.5a, b, c).

Table 1: Infiltration rate of soils with time in selected locations within the study area

Locations / Time (min)	Harmota	Huwawan Khuaru	Shila	Bamurtkan	Shekh Ardan	Haji Kalla	Kela Spi	Top Zawa	Koi Sanjaq center	Hibat Sultan	Mam Qilinj	Kamila	Eski Koya	Mizgotoka	Huwawan	Abdalan
1	81.43	75.45	162.27	152.21	382.00	432.07	382.5	110.35	69.04	120.32	182.24	203.2	335.24	225.4	75.53	130.45
2	79.12	73.61	154.53	141.23	334.03	401.00	357.88	110.02	68.12	111.02	170.72	182.5	302.54	210.43	68.22	116.23
3	73.53	71.87	145.45	130.34	290.09	376.86	334.21	107.52	66.05	109.52	158.35	171.2	270.21	187.56	60.14	109.32
4	66.45	70.25	131.09	122.44	249.42	332.34	312.34	104.31	65.02	107.35	145.00	162.4	245.00	166.54	53.54	102.56
5	63.12	67.21	110.09	111.56	217.35	293.21	291.33	103.11	64.33	105.25	133.44	154.2	221.67	154.95	48.07	97.55
8	51.60	55.24	105.34	82.04	166.25	210.34	233.55	99.23	53.22	101.75	122.25	136.35	164.06	132.00	41.45	86.23
10	47.15	53.67	96.42	77.21	143.77	175.22	202.05	97.35	50.03	100.50	113.00	130.20	141.76	124.33	37.00	80.45
12	43.05	51.25	85.53	74.72	119.22	153.02	182.5	97.52	47.25	99.04	104.80	124.00	127.86	116.87	33.56	78.15
15	39.15	49.72	80.35	69.00	106.43	125.76	151.87	94.23	44.34	96.25	95.54	117.02	106.33	108.25	29.90	74.67
20	33.26	44.32	76.32	66.86	95.22	94.77	119.32	96.31	40.75	94.02	90.05	104.21	87.44	102.45	26.86	70.35
25	28.35	41.44	70.25	60.22	95.22	71.88	85.21	93.02	37.04	94.07	85.00	98.00	73.45	97.44	23.55	65.00
30	25.26	38.22	64.06	54.21	90.32	65.22	80.23	92.45	34.55	93.78	80.00	92.34	63.33	88.23	21.67	61.58
35	24.44	35.72	60.44	50.22	85.45	61.85	76.34	91.05	32.43	92.05	76.23	85.08	56.89	79.23	20.54	57.34
40	23.52	32.44	57.35	46.90	70.75	54.83	71,54	90.02	31.02	92.05	71.00	80.31	53.22	75.55	19.50	54.76
45	22.32	30.67	54.72	40.67	67.45	48.21	67.33	89.01	30.52	91.50	66.34	75.45	49.54	69.42	19.00	51.88
50	21.12	27.88	49.59	36.78	63.00	43.53	62.02	88.20	29.23	91.02	62.45	69.22	46.95	63.25	18.42	45.22
55	20.03	25.66	41.31	30.54	58.78	38.25	54.88	88.01	28.04	90.78	57.24	65.24	43.25	52.90	18.07	40.75
60	20.62	24.67	35.44	26.00	57.54	33.55	52.04	87.03	27.53	90.00	52.45	60.22	40.50	47.42	17.61	36.16
70	19.40	23.66	31.05	18.58	48.66	22.25	44.70	84.23	25.41	87.52	44.50	56.21	35.23	42.56	16.07	27.83
80	18.35	22.78	26.32	17.03	46.87	25.76	37.74	82.50	24.22	86.22	36.21	54.98	33.53	40.23	15.21	21.65
90	18.12	21.00	15.52	15.34	40.21	24,60	28.23	81.02	23.03	85.03	32.33	51.76	29.03	37.82	15.00	15.33
105	17.50	20.45	15.01	13.22	36.08	24.22	15.43	78.42	22.12	82.22	21.25	47.87	26.55	35.65	14.82	10.00
120	17.21	19.50	14.70	12.06	33.86	24.14	13.82	77.50	22.45	81.52	15.22	43.50	23.05	30.66	13.95	8.50
135	17.15	19.02	12.75	11.50	30.24	23.73	12.35	75.23	21.00	79.04	10.76	40.34	22.34	28.21	13.55	8.00
150	16.75	18.63	10.62	11.02	28.22	23.34	10.95	72.51	20.54	76.52	8.50	35.56	21.87	26.87	13.15	7.65
180	16.50	18.03	9.45	9.44	24.22	23.05	9.1	69.04	20.25	72.58	8.15	32.343	17.56	22.65	12.66	7.00
210	16.25	18.00	8.05	8.35	23.31	22.84	8.21	67.01	19.55	70.24	7.45	30.21	15.50	19.00	12.45	6.52
240	16.09	17.55	8.00	7.99	22.51	22.57	7.30	65.54	19.43	69.52	7.55	27.43	14.55	17.00	12.00	6.20
300	16.09	17.65	8.00	6.85	22.0	22.22	7.00	65.00	19.13	69.11	7.54	27.05	14.2	14.00	12.00	6.20

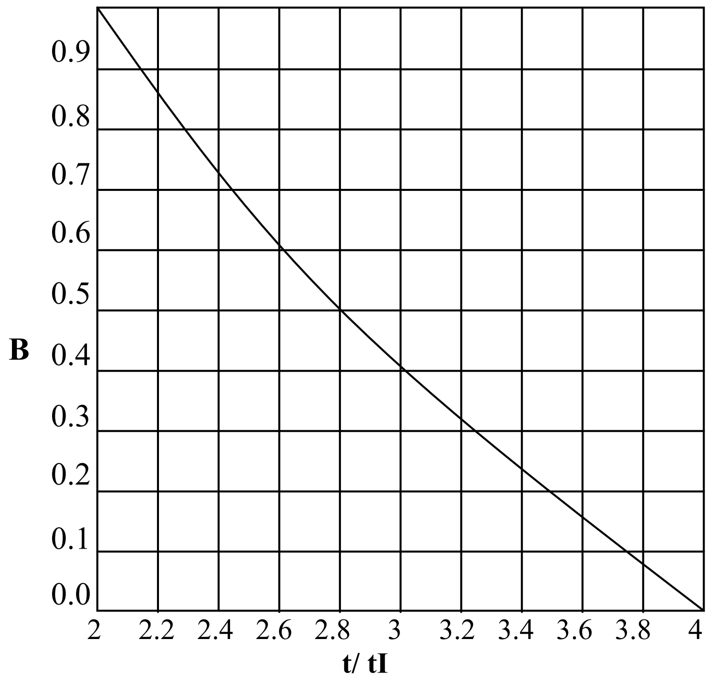

Fig.4: (B) Determination curve from (t/ tI) for calculating the coefficient of permeability (Chnaray, 2003)

▪ **Engineering Geological Study**

For studying the soil consistency and grain size distribution, samples were collected from the same locations where infiltration tests were applied. For grain size distribution, sieve analysis and wet analysis were applied. The textural composition of the soil is determined by screening of the soil through a series of sieves of various sizes and weighing the materials retained by each sieve. The following calculation was applied.

$$\textbf{Percentage of retained on any sieve} = \frac{\textbf{Mass of soil retained}}{\textbf{Total soil mass}} \times 100$$

Cumulative percentage retained on any sieve = Sum of percentage retained on all coarser sieves

Percentage finer than any sieve = 100 – cumulative percentage retained

The results are represented on semi-log graph paper. The percentage of fines is presented on normal scale, whereas the particles diameter on the log scale (Fig.6) (Murthy, 2002).

Soils consisting of materials smaller than 0.002 mm are demoted as clay, if more than half of the materials are larger than sieve No. 200, and then the soil is considered as coarse grained soil. For soil consistency, Casagrande method was used. For this test, about 250 gm of soil passing through sieve number 40 (0.425 mm diameter) was taken. A quantity of distilled water was added and mixed to form a uniform soil paste. A portion of the soil paste was placed in the cup of liquid limit device and leveled by spatula, using groove tools to cut the soil in the cup. The cup is given blows, the number of blows required to close the groove for distance of 13 mm is noted down. Some of the paste, at the place where the groove has closed is taken for water content determination. About three sets of blow numbers and water content were measured. After that, a flow curve was drawn, by plotting the water content value; on natural scale against the number of blows; on log scale to obtain a straight line. The liquid limit is obtained as water content corresponding to 25 blows (Fig.7).

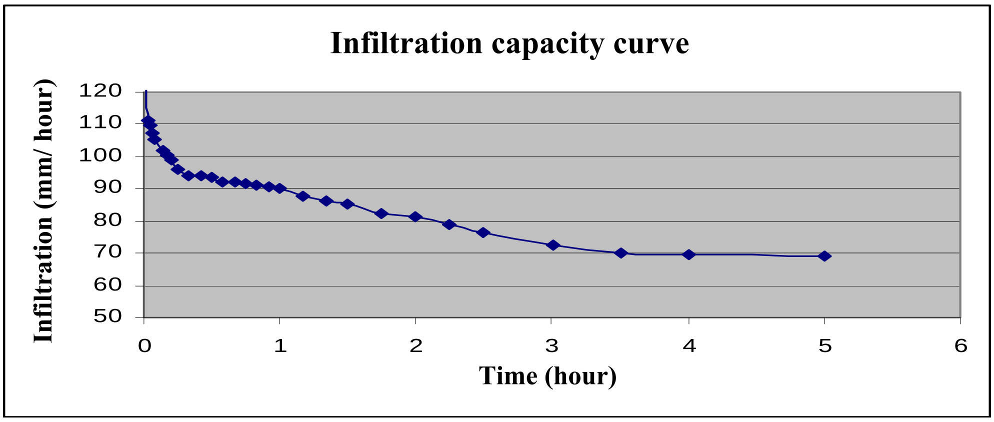

Fig.5a: Infiltration capacity curve (Sample No.8)

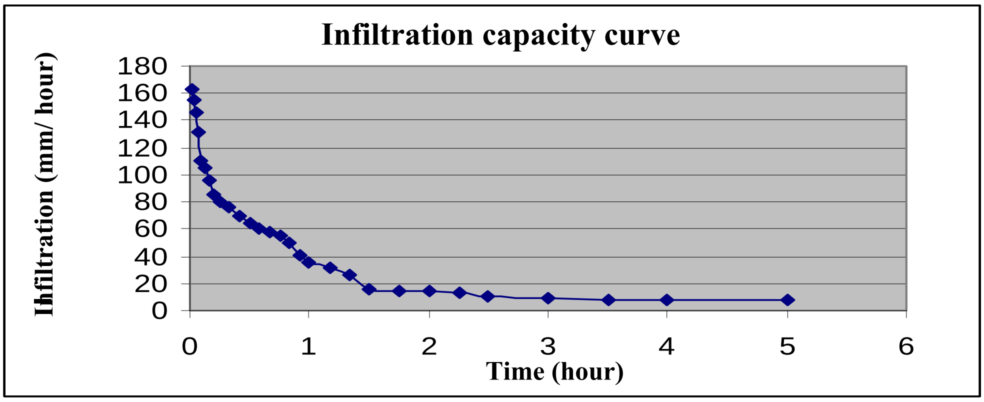

Fig.5b: Infiltration capacity (Sample No.14)

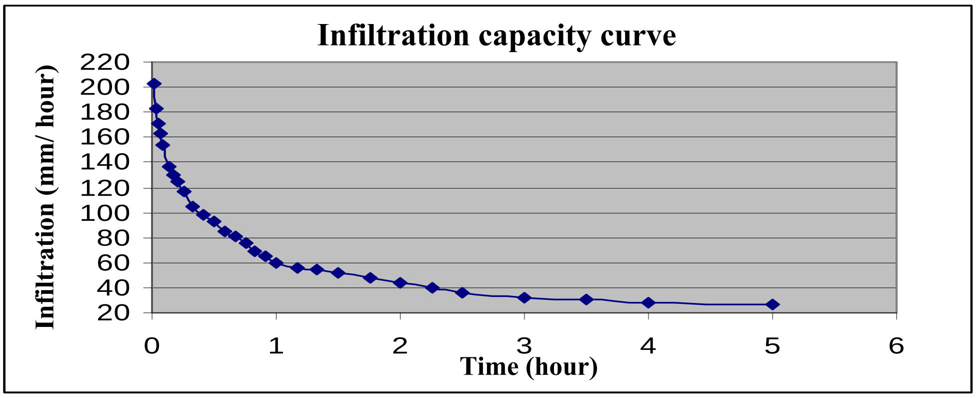

Fig.5c: Infiltration capacity curve (Sample No.12)

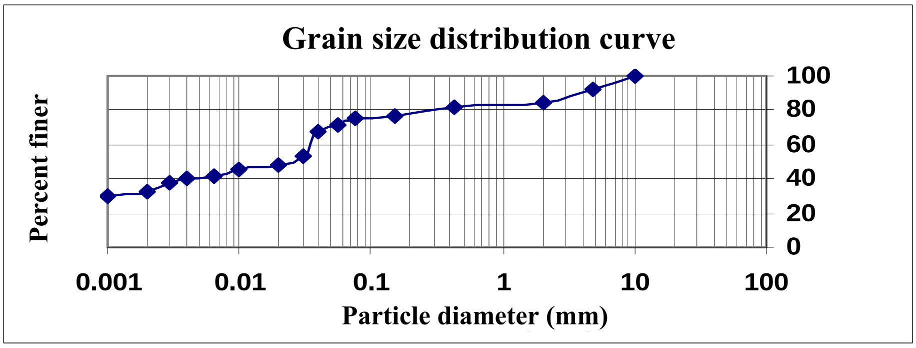

Fig.6a: Grain size distribution (Sample No.2)

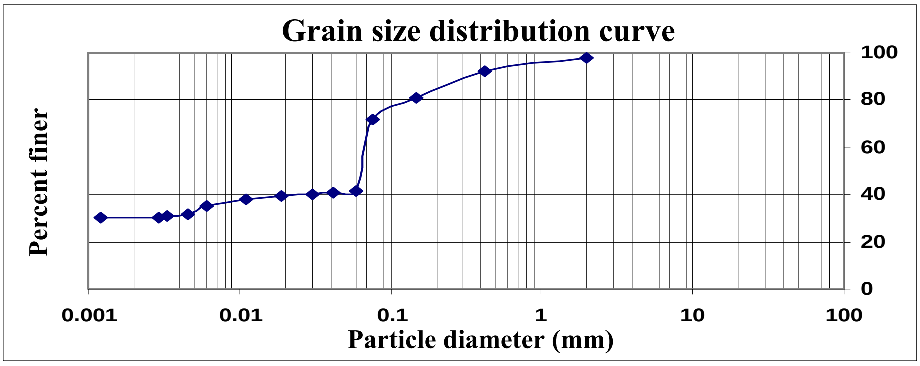

Fig.6b: Grain size distribution (Sample No.9)

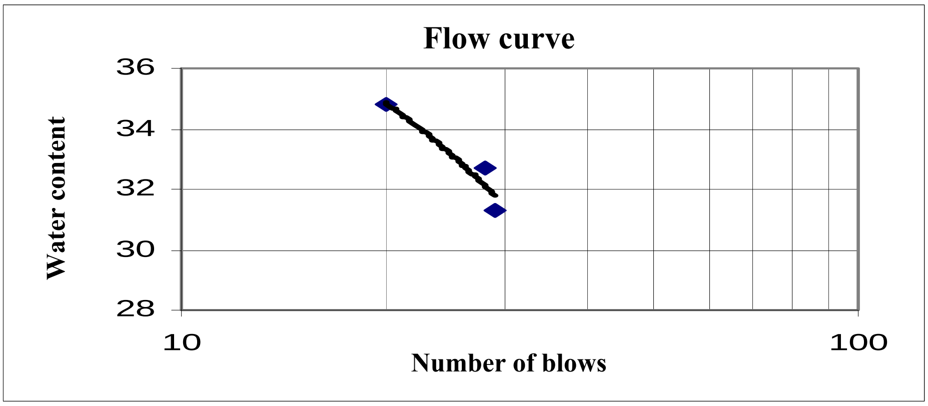

Fig.7a: Liquid limit test by Casagrande (Sample No.1)

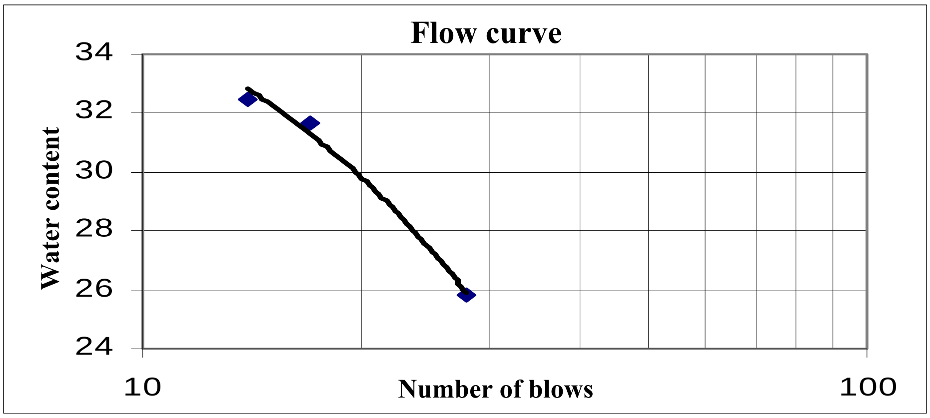

Fig.7b: Liquid limit test by Casagrande (Sample No.2)

RESULTS AND DISCUSSION

Horton (1940) in Chin (2006) proposed the following equation for describing the infiltration capacity [f (t)].

$$\mathbf{f(t) = f(c) + (fo - fc)\, e^{-kt}}$$

were:

f (t) = infiltration capacity (mm/ hour)

f (c) = equilibrium infiltration capacity (mm/ hour)

fo = initial infiltration capacity (mm/ hour)

k = constant (1/ hour)

t = total time during infiltration time (hour)

The values of **fo**, **f(c)** and **k**, in the study area, were measured from Statistical Package for Social Science (SPSS) programs, and depending on the value of infiltration rate (mm/ hour) and time (hour) (Table 2).

For example, the infiltration capacity [**f (t)**] of Harmota location is calculated as follows:

$$f(t) = 18 + (86 - 18)e^{-4.7\times 5}$$

$$f(t) = 18 \text{ mm/ hour}$$

Table 2: Infiltration results for different location in the study area

Sample No.	Location	X (UTM)	Y (UTM)	f (t) (mm/ h)	fc (mm/ h)	fo (mm/ h)	k (1/ h)	R^2	Classification of infiltration capacity
1	Harmuta	464975	3991802	18	18	86	4.7	0.99	S – M
2	Huwawan Khuaru	469500	3991800	20	20	76.07	2.35	0.99	M
3	Mizgotoka	468290	3991159	19.47	19.47	201.55	2.44	0.95	S – M
4	Center Koi Sanjak	466710	3993033	21.54	21.54	71.06	2.6	0.98	M
5	Shekh Ardan	459000	3993498	48.81	48.81	408.11	7.7	0.96	M
6	Haji Kalla	466322	3993020	31.04	31.04	482.42	6.2	0.99	M
7	Kela Spi	459510	3989090	19.9	19.9	397.18	3.93	0.98	S – M
8	Top Zawa	462335	3993100	64.16	63.79	105.39	0.94	0.96	M – R
9	Bamurtkan	472925	3987150	12.7	12.7	139.9	2.55	0.96	S – M
10	Haibat Sultan	469142	3994445	70	68.85	108.07	0.7	0.92	M – R
11	Mam Qilinj	461188	3988120	9.7	9.6	159.85	1.46	0.96	S – M
12	Kamila	465120	3994656	37.2	37.2	183.11	2	0.97	M
13	Eski Koya	471535	3990125	19.4	19.14	200	2.58	0.98	S – M
14	Shila	464220	3988620	12	12	146.6	1.9	0.96	S – M
15	Huawawn	470950	3993369	20.36	20.36	77.06	5.99	0.98	M
16	Abdalan	466627	3988305	4.94	4.82	113.72	1.36	0.97	S

S = Slow

M = Medium

R = Rapid

Depending on f (t) values, Nikolov (1983) classified the infiltration capacity into six types (Table 3).

Table 3: Classification of infiltration capacity
(Nikolov, 1983)

Infiltration capacity [f(t)]	Type
>160 mm/ hour	Rapid (R)
60 –160 mm/ hour	Moderate – Rapid (M – R)
20 – 60 mm/ hour	Moderate (M)
5 – 20 mm/ hour	Slow – Moderate (S – M)
1.2 – 5 mm/ hour	Slow (S)
<1.2	Very slow

Some problems of using the double ring method are that it is very time consuming, requiring frequent attention, either by recording measurements or by maintaining equilibrium in the height between the rings. The practicality of the instrument is reduced by the fact that the rings are extremely heavy to move. It also requires a flat undisturbed surface. The infiltration rate varies within different soil types, which can affect the accuracy of the results (McKenzie *et al*., 2002).

The coefficient of determination (R^2) is calculated to determine the accuracy of Horton model (Chnaray, 2003), which is about 0.92 – 0.99. It means that this model is most accurate. However, the infiltration is important for determination type of texture in the study area; also, it is important for determination coefficient of permeability (C).

The coefficient of permeability for the study area is determined as follows:

C = B × V/A× t (Stevanoic, 2002).

where:

C = Coefficient of permeability
B = factor calculated from the value of (t/ tI) (according to Fig.4)
t = total time during the infiltration (min)
tI = time during using half of the water for infiltration
V = the total amount of water used in infiltration test (m^3)
A = the area of the inner ring used in the test (m^2)

For Harmota location, the above equation functions as follows:

V = volume of the cylinder × height of the water column
Volume of the cylinder = $r^2 \times \pi = (0.15)^2 \times 3.14 = 0.07065$ (m^3)
r = radius of the inner ring = 15 cm = 0.15 m
Height of the water column = 83.5 mm = 0.0835 m (Table 1)
B = 1.0 (Fig.5)
A = 0.07065
t = 300 min
C = $1.0 \times 5.89 \times 10^{-3} / 0.07065 \times 300 = 2.783 \times 10^{-4}$ (Table 4)

Table 4: Coefficient of permeability in Koi Sanjaq city and surrounding villages

Location	t	tI	t/ tI	B	Coefficient of permeability C (m/ sec)
Harmuta	300	150	2	1.0	2.783×10^{-4}
Huwawan Khuaru	300	140	2.14	0.9	2.645×10^{-4}
Mizgotoka	300	20	15	–	Equation not implicated
Center koi Sanjak	300	140	2.14	0.9	2.869×10^{-4}
Shekhardan	300	78.5	3.82	0.07	0.641×10^{-4}
Haji Kalla	300	140	2.14	0.9	3.333×10^{-4}
Kelaspi	300	30	10	–	Equation not implicated
Topzawa	300	145	2	1.0	1.083×10^{-4}
Bamurtkan	300	15	20	–	Equation not implicated
Haibat Sultan	300	135	2.22	0.87	9.859×10^{-4}
Mamqilinj	300	10	30	–	Equation not implicated
Kamila	300	80	3.75	0.12	1.352×10^{-4}
Eski koya	300	40	7.5	–	Equation not implicated
Shila	300	15	20	–	Equation not implicated
Huwawan	300	135	2.22	0.87	1.736×10^{-4}
Abdalan	300	12	25	–	Equation not implicated

Coefficient of permeability (C) is determined for different parts of the study area (Table 4), which indicated that the west and northwestern parts are characterized by high rate of coefficient of permeability that decreases southwards.

In some locations, the equation of coefficient of permeability was not applicable (Table 4). This means that those locations are with low permeability and their lithology mainly consist of clay, which is characterized by high porosity, but very low permeability. The results indicate that the coefficient of permeability is high in the west, north, and northwestern parts of the study area and decreases southwards.

The grain size analysis results are represented in Fig. (6) and Table (5). The results indicate that the north, west, and northwestern parts of the study area are characterized by presence of coarse grained sediments, as in samples no. 1, 2, 4, 6, 8 and 10, which coincide with the results of the infiltration test results. The central, southwest, southeast and southern parts are characterized by increase of fine grained sediments.

The plasticity index classification is based on plasticity index chart (Das, 2004) (Table 6). Plasticity index indicates that the range of moisture in the soil, when the soil is with high moisture content, then the plasticity index increases, which have great affect on the engineering projects, because the soil will be of swelling type. The liquid limit and plastic limit in the studied samples, according to Casagrande test method (Table 7 and Fig.7) show that samples are with low to medium plasticity.

Table 5: Percentage of gravel, sand, silt, and clay size particles of the studied samples

Sample No.	Location	Clay (%)	Silt (%)	Sand (%)	Gravel (%)
1	Harmuta	30.3	40.7	29	0
2	Huwawan Khuaru	32.5	42.0	19.5	6
3	Mizgotoka	40.0	45	15.0	0
4	Center koya	30.33	39.22	26.45	4
5	Shekh Ardan	39.22	38.30	14.48	8
6	Haji Kalla	31.70	42.23	21.07	5
7	Kela Spi	37.85	46.42	15.73	0
8	Top Zawa	20.45	42.33	26.78	10.44
9	Bamurtkan	30.42	42.58	27.0	0
10	Haibat Sultan	21.44	44.75	24.59	8.22
11	Mam Qilinj	37.22	42.26	20.52	0
12	Kamila	35.53	38.90	21.57	4
13	Eski Koya	30.62	42.0	22.38	5
14	Shila	31.25	48.0	20.75	0
15	Huawawn	35	45	13	7
16	Abdalan	35.5	48.0	17	0

Table 6: Plasticity index chart (Das, 2004)

Plasticity index (PI)	Description
0	Non plastic
1 – 5	Slightly plastic
5 – 10	Low plasticity
10 – 20	Medium plasticity
20 – 40	High plasticity
> 40	Very high plasticity

Table 7: Liquid limit and plastic limit test results of the studied samples by Casagrande method (Ramamurthy, 2005)

Sample No.	Location	Depth (m)	Casagrande method		
			LL (%)	PL (%)	PI
1	Harmuta	0.0 – 1.0	33	24.5	8
2	Huwawan Khuaru	0.0 – 1.0	27.3	17.2	10.1
3	Mizgotoka	0.0 – 1.0	25.5	17.5	8
4	Center koya	0.0 – 1.0	29.5	21.6	7.9
5	Shekh Ardan	0.0 – 1.0	27.0	18	9
6	Haji Kalla	0.0 – 1.0	28	18.2	9.8
7	Kela Spi	0.0 – 1.0	25.6	16.8	8.8
8	Top Zawa	0.0 – 1.0	32.5	26.5	6
9	Bamurtkan	0.0 – 1.0	29	18	11
10	Haibat Sultan	0.0 – 1.0	27.5	21	6.5
11	Mam Qilinj	0.0 – 1.0	32	20.2	11.8
12	Kamila	0.0 –1.0	31.2	21.2	10
13	Eski Koya	0.0 – 1.0	26	16.3	9.7
14	Shila	0.0 – 1.0	29.5	17.5	12
15	Huawawn	0.0 – 1.0	31.5	21.5	10
16	Abdalan	0.0 – 1.0	32.5	20.5	12

CONCLUSIONS

- The application of infiltration method in the study area indicated that the west and northwestern parts are characterized by Medium – Rapid rate of infiltration. The northern part is characterized by Medium rate of infiltration. The central, east, southeast, southwest and northeastern parts are characterized by Slow – Medium rate of infiltration, whereas the southern part is characterized by Slow rate of infiltration.
- The southern part of the study area is covered mainly by rocks of the Injana Formation, which is characterized by abundant claystone beds, which are characterized by high porosity but very low permeability, so the rate of infiltration is Low.
- In some locations, the equation of the coefficient of permeability was not applicable (Table 4), it means that those locations are with low permeability and their lithology mainly consist of claystone, which is characterized by high porosity, but very low permeability. The results indicated that the coefficient of permeability is High in the northern, northwestern and western parts of the study area and decreases south ward.
- The study of grain size distribution indicated that the north, west and northwestern parts of the study area are characterized by increase of fine grained sediments whereas; the central, south, southeast and southwestern parts are characterized by increase of fine grained sediments. The Atterberg limits (liquid limit and plastic limit) indicated that generally the sediments are with low to medium plasticity index.
- The infiltration capacity results coincide with the acquired Liquid limit and Plastic limit, indicating that the grain size highly affects on the infiltration capacity. This also confirms that the infiltration test was successfully applied in the study area.

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