An effect of groundwater quality on wells design in South Khartoum

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Abstract:

This study has been carried out in the area located in the south of Khartoum city and some parts of Gezira state, which is situated between latitudes 15.251 N, 15.567 N, and 32.502 E, 32.922 E. The main objective of this research is to detect the effect of water quality on wells design, productivity, and sustainability. The groundwater in the study area occurs mainly in the Nubian sandstone and Gezira formations, in the porous parts, and can be separated into two aquifers: the upper aquifer zone and the lower aquifer zone, which are separated by thick layers of mudstone of different thicknesses, especially in the industry area (soba). For the purpose of this study, samples were collected from nine water wells and analyzed chemically and through a sieve analysis test. The testing results revealed that the south Khartoum basin has been polluted and has salinity in the upper zones with fit groundwater in the lower aquifer. As for the results of the sieve analysis, it was shown that the lower part of the aquifer has a very good gradient. The result of the study achieved the proper water well design for the basin and will be of good assistance to designers and decision-makers for future water projects. This study was conducted in the period between (12/05/2021 to 05.09.2022).

Keywords: New concept, Sieve Analysis, Poorly grade, Groundwater quality, Aquifer Materials, Saline zones.

تأثير جودة المياه الجوفية على تصميم الآبار بجنوب الخرطوم

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المستخلص: .

هدفت هذه الدراسه الي الربط بين جودة المياه الجوفيه والتحليل المنخليللطبقات الحامله للمياه للوصول الي تصميم أمثللابار المياه الجوفية لمنطقة جنوب الخرطوم والمناطق المجاوره لها من ولايه الجزيره علي أمتداد الحوض الجوفي علي خطي طول 32.922 و32.502 شرقا ودائرتي عرض 15.251و15.567شمالا .توجد المياه الجوفية في هذه المنطقة في ثلاثه خزانات جوفيه وهي رسوبيات الجزيره العلويه وتكوينات الجزيره السفلي والحوض النوبي والتي تفصل بطبقه طينيه سميكه خاصة في منطقة الصناعات سوبا. ولتحقيق هدف الدراسه تم حليل تسعه عينات كيمائيا كما تم تحليل منخلي لتكوينات الأحواض المائيه لبئرين . وخلصت الدراسه الي أن الخزان العلوي ملوث وبه ملوحه مع تأكيد جودة الخزان الأسفل وأيضا من خلال التحليل المنخلي توصلت الدراسه الي أفضليت تصميم البئر علي الخزان الأسفل من الحوض الحامل للمياه وستساعد الدراسه الباحثين والمصممين ومتخذي القرار في التصميم الأمثل للابار الجوفيه في جنوب ولاية الخرطوم .نفذت الدراسه في الفتره من 20121/05/12الي 2022/09/05.

1.ntroduction :

In the field of groundwater hydrology, major attention has been devoted to the development and application of aquifer hydraulics and well design but unfortunately, much less consideration was given to the quality and aquifer protection against pollutions. Although substantial effort may be expended on aquifer testing and computations to quantify the groundwater withdrawal, successful operation of the system may not be achieved if the well is not properly designed. This lack of attention to proper design can result in inefficient well and unfit drinking water and improper isolation of contaminated and saline zones.

The proper well design depends on type of aquifer formations is it loose, fine, course, gravelly or in cracks , the characteristics of the upper , lower zones of the targeted aquifer, aquifer type (confined or unconfined) ,grain size and water quality. Well design in basement complex rocks in which the formations is stable no need for casing used as an open whole design, only casing installed

on the surface as a conductor. If water is corrosive plastic casing can be used while steel casing is used for fresh water.
A quantitative description of soil particle size (PSD) is important for soil structure research (12). The proper selection of slot opening in relation to the sizes of aquifer materials (7).

The size of the screen openings in most type of geological formation varies depending mainly on the nature of the geological formation and the development of the aquifer or artificial gravel pack (fig2). When naturally developing water wells, the size of the screen opening (slot size)is chosen based on graduation of sizes of the grain samples representing the water producing layer that is obtained through the result of the sieve analysis (fig2) by maintaining and remaining. The aquifer materials retained about40% and allowing 60% to pass through the screen during the pumping and development process. But if the size of slot size of the screen is large oversized greeter than recommended, then the screen definitely enter the components of the fine aquifer materials are inside the well and thus it become very difficult to clean the well water from those sand .On the other hand, if the size of the screen opening is smaller than the size recommended, in these case, water flow is more decrease in the well, and, as a result, there is more decline in the water level, it is called more head loss, in addition to corrosion of well filters because of this resistance. The amount of slot size in the screen should not exceed 30 – 40%of the surface area of the screen in order to maintain a low speed for entering the water to the screen about(0.03 m/sec) or less, where the friction between water and slot size in the screen at this speed is negligible. It is important to take in consideration the upper and lower zones quality to make design which can achieve fit ground water quality.

2- Objective of the study:

This study aimed to detect whether design need for isolation of the polluted and saline zones to protect the aquifer against contamination and salinity, selection of appropriate construction materials (casings), performance and cost effectiveness, and proper size of screen slot openings

- The main purpose is to detect the proper well design with good ground water quality.
- From the laboratory, the samples were collected and tested for chemical test, was determined using the WHO and Sudanese standards.

3 –MaterialsandMethods:

3.1- study area

The area is located in south Khartoum city and some part of North Gezira state, which is situated between latitude 15.251 N, 15.567 N and 32.502 E, 32.922 E (Fig 1), the area located between the two Niles White Nile at the western boundary and the Blue Nile at the eastern part occupying a surface area of about 788.33km². The water resources availability is highly increased and increasing water demand make the water resources management extremely important for sustainable development. The geological characteristics of the study area is mainly consists of three zones upper and lower Gezira formations and Nubian sandstone (9).

Table 1: Geologic Sequences in the Study Area.(5)

Age	Formation	Lithology	Average thick. (m)
Quaternary to Recent	Upper Gezira formations	Gravels, sands, sandy clay, clays and limes. Pedi plains, alluvial fans.	0 - 65
Early to middle Tertiary	Lower Gezira formations	Gravels, sands, sandy clay, clays and limes. Medium to course sand, course sand	120-400

Age	Formation	Lithology	Average thick. (m)
Mesozoic-Cretaceous	Nubian Fm.	Sandstone, siltstone, Clay stone and conglomerates. Fans and Playas	400 - 900

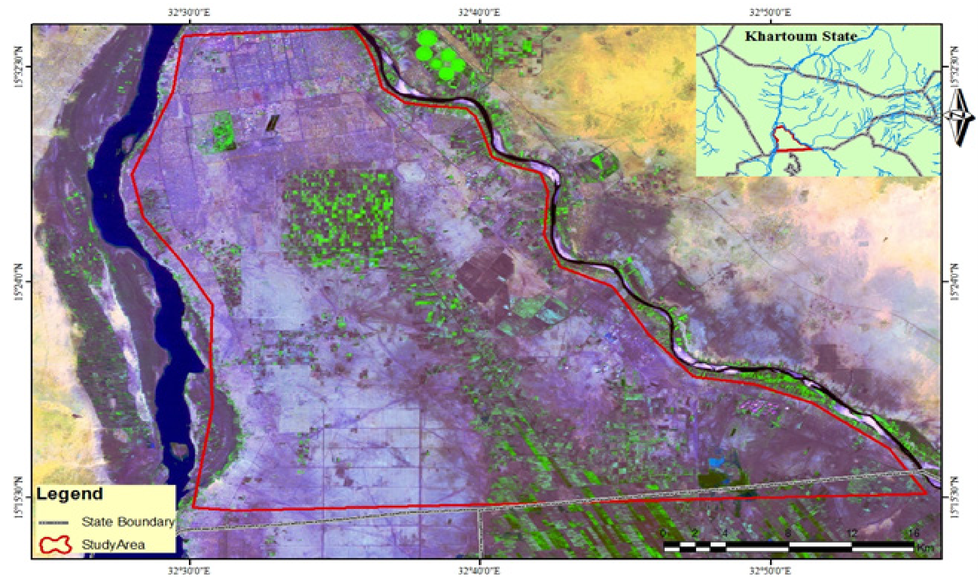


Figure (1): Location Map of the Study Area.
Source: Water resources Assessment and Development project in Sudan (WADS).April 1989.

4-Data Collection:

- Collection of water samples:

Nine samples for this study were collected from different boreholes in the study area and analyzed for physical and chemical analysis (Table 1).

The samples for this study were collected in poly ethylene bottles for chemical analysis in 250ml sterile-glass bottle. They were taken to the laboratory (at ambient 25C°). Then the samples were immediately analyzed.

4.1-Sampling methods for physical and chemical analysis:

All precautions were considered to collect samples which are representative as far as possible of the water to be examined in accordance with methods of laboratory test of water.

The water samples collected for chemical and physical analysis were used to determine PH, color, temperature, turbidity, odor, total hardness, total alkalinity, nitrates and TDS as the followings:

The containers (new, clean, plastic bottles with screw cap, 2.5 liter) were used.

The container was gently washed by distilled water firstly, and then filled with water samples.

The water samples of groundwater were taken from the source directly via nozzle or tap near the source, before it flows through the network distribution system.

4.2- Methods of analysis:

PH was measured by PH meter, electrical conductivity (EC) was measured at temperature 25C° by conductivity meter. Potassium K^+K^+) were obtained by 543 nm flame photometer.Bicarbonate (HCO_3) was determined by titration against HXL (0.012 N) to PH 4.5 using methyl orange as an indicator.Total hardness (TH) was obtained by calculation from 〚Ca〛 ^ (2+) and 〚Mg〛 ^(2+) determined concentrations.Nitrate (NO_3) was determined by Cadmium reduction method. NO_3 is reduced almost quantitatively to nitrite (NO_2) in the presence of Cadmium(10).

5- Steps of Designing a Well:

The following steps should be followed so as to design a well:

Determine depth, minimum well diameter of borehole, screen and filter characteristics

3.1- Length and types of Casing:

The length of the upper casing is controlled by the requirements of the pump and aquifer depth beside water quality and type of formations to be drilled. If the formation is stable, casing can be inserted only on the depth of the upper lose formations as open hole design. If water is corrosive plastic casing is preferred. The specifications for the steel casings are designated by letters and numbers. There are several such specifications, but the ones most likely to be used for water well casing are ASTM A-120 and A-53 (6).

5.2-Selection of Gravel Grading

- ✓ The aim is to identify the material which will stop significant quantities of material moving into the well while minimizing energy losses. Artificial gravel packs are used where the aquifer material is fine, well-sorted or laminated and heterogeneous. The size of gravel pack is chosen by sieve analysis .In practice, the size of gravel pack reaches about five times than slot size, and according to (2) gravel pack is chosen by properties available.

The normal approach is to use a filter pack when:

- The uniformity coefficient < 3;
- The aquifer is fine, with D10 of the formation < 0.25 mm.
- Effective size≥ 0 .01

5.3- Natural Gravel Packs

These are produced by the development of the formation itself. Development techniques are used to draw the finer fraction of the unconsolidated aquifer through the screen leaving behind a stable envelope of coarser and therefore more permeable material (fig.2).

6- Standard grain size:

Particular grain size characteristics of the aquifer:

Dx: The sizes of particles such that x percent is smaller, i.e. (100 – x) percent is retained.

Uniformity coefficient**:** Ratio of the D40 size to D90 size of the material (low coefficient indicates uniform material).

Uniformity coefficient = D40/ D90.

Suitable aquifers are coarse grained and ill sorted, generally with a uniformity coefficient greater than 3.

Slot size recommended for the screen is between D10 and D60 (often D40). Choice of slot size is then dependent upon the reliability of the sample and nature of aquifer.

6.1-Diameter

The diameter casing and screen must be large enough for the pump to be a comfortable fit, making. In general, the vertical velocity within the well casing needs to be less than 1.5-2 m/sec to minimize well losses.

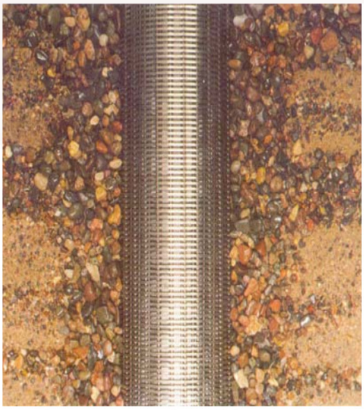


Figure (2) Natural development removes most particles near the well screen that are smaller than the slot openings, (4).

6.2- Well screen slot openings:

The selection of the screen slot sizes is based upon the aquifer or filer pack material grain size distribution (1) . The slotted sizes have been used to provide sand control in much water well, sometimes fine slots clogged by small sand and silt particles. Theoretically, the slot size should be as wide as possible. The width of these slots is normally made as small as mechanically practical so that they will retain a large fraction of the formation and as much as possible (2). In practice, the values of slot opening vary from low as 0.2mm to large as 5mm.

The shape of slot openings is different shaped wire, which is carefully slot (wound) so that there is a continuous gap between wires. The shape of slot size in horizontal and vertical formers placed around the internal diameter of the screen. Wire wrapped screens have the advantage over a slotted liner that the gap between the wires can be made smaller and be held to the target value with a much greater accuracy; allowing the screen to retain finer-grained formations than the slotted liner (8).

Screen slot openings are determined based on the nature of aquifer and the sizes of formation granules that are mechanically analyzed in the laboratory (Fig 3) . After drawing the sample curve from plotting the values of the sieve opening on the bases of granular size on the horizontal axis and the corresponding percentage of the cumulative retained weights or cumulative pass by vertically on semi-log paper.To choose the appropriate aperture size for the well screen, the is chosen on the percentage of cumulative retained weight ratio curve that intersect line 40-50 percent on the vertical axis for the purpose of retaining fine and homogeneous composition materials, or the corresponding size of the ratio may be chosen between 30-50percent to reserve the course grained composition. Generally, we find that the diameter of the slot size ranges between 1-6mm.For classifications If the value of(Cu) $\leq$ 5the formation is poorly grade sand and If the value of(Cu $\geq$ 5the formation is good grade sand (3).

Figure (3) .A set of standard sieves are suitable for the classification of lose sediments.

7- Results and Discussions:

Sieve analysis test:

Table (2)Shows thesieve analysis data for Safola, sample1 (From Field data)

Test in accordance with AASHTO Design (T27-84)			Depth :	(200-460) ft
Date:	30.08.2022		Long.	32.652684
Location:	Safola. Khartoum South. Sudan		Lat.	15.450178
Sample№	Sample (1)		Total weight(mg)	**302.1gm**
№	Sieve Size (mm)	weight (gm)	%	Cumulative
1-	1.41	53.3	17.66	17.66
2-	1.00	24.3	8.05	25.71
3-	500	73	24.18	49.89
4-	250	101	33.46	83.35
5-	125	43.1	14.28	97.63
6-	62	5.1	1.68	99.31
7-	PAN	2	.66	**99.97**
	Total	**301.8**	**99.97**	

Table (3)shows the sieve analysis data for Safola, sample2 (From Field data)

Test in accordance with AASHTO Design (T27-84)			Depth :	(900-1125) ft
Date:	30.08.2022		Long.	32.652684
Location:	Safola. Khartoum South. Sudan		Lat.	15.450178
Sample№	Sample (2)		Total weight(gm)	**304.39gm**

№	Sieve Size (mm)	weight (gm)	%	Cumulative
1-	1.41	44.4	14.60	14.60
2-	1.00	19.1	6.28	20.88
3-	500	86	28.28	49.16
4-	250	111.5	36.66	85.82
5-	125	35.1	11.54	97.36
6-	62	6.68	2.19	99.54
7-	PAN	1.3	.42	**99.97**
	Total	**304.08**	**99.97**	

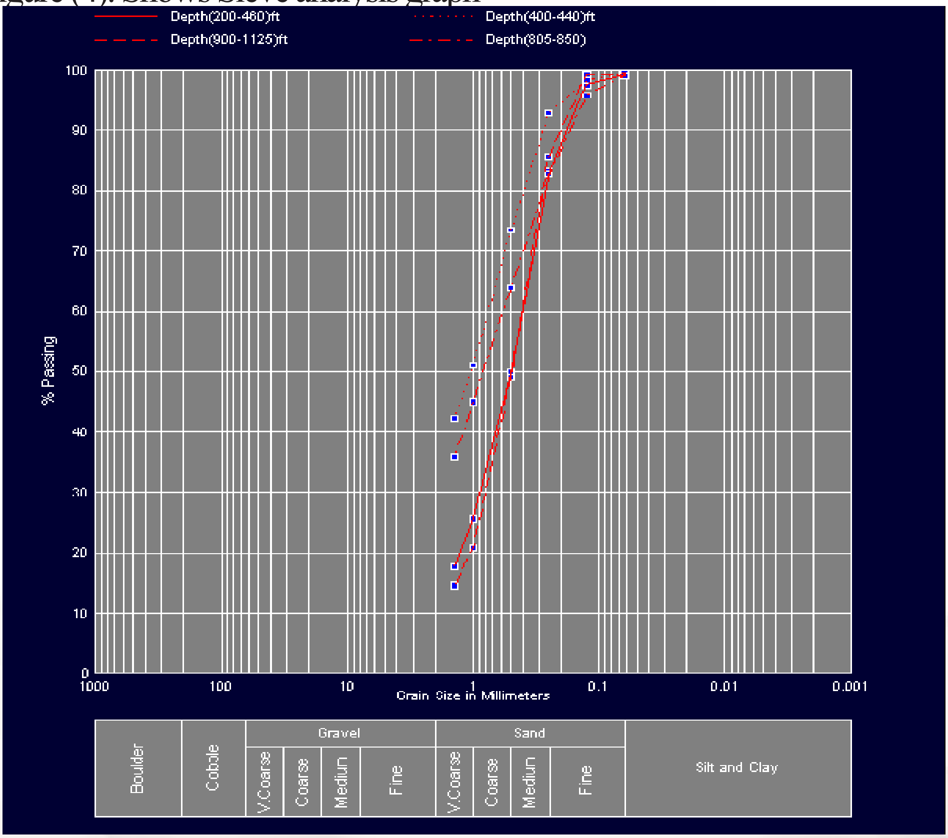
Table (4)Shows the sieve analysis data for Salama, sample1 (From Fielddata)

Test in accordance with AASHTO Design (T27-84)			Depth	(400-440) ft
Date:	30.08.2022		Long.	32.287502
Location:	Salama. Khartoum South. Sudan		Lat.	15.480508
Sample№	Sample (1)		Total weight(gm)	291.78gm
№	**Sieve Size (mm)**	**weight (gm)**	**%**	**Cumulative**
1-	1.41	123.27	42.37	42.37
2-	1.00	25.55	8.78	51.15
3-	500	65.30	22.44	73.59
4-	250	56.34	19.36	92.95
5-	125	16.18	5.56	98.51
6-	62	3.22	1.10	99.61
7-	PAN	1.05	.36	99.97
	Total	**290.91**	**99.97**	
Test in accordance with AASHTO Design (T27-84)			Depth :	(805-850) ft
Date:	30.08.2022		Long.	32.287502
Location:	Salama. Khartoum South. Sudan		15.480508	

Sample№	Sample (2)		306gm	
№	Sieve Size (mm)	weight (gm)	%	Cumulative
1-	1.41	109.9	35.93	35.93
2-	1.00	28	9.15	45.08
3-	500	58	18.96	64.04
4-	250	57.3	18.73	82.77
5-	125	40.46	13.22	95.99
6-	62	10	3.26	99.25
7-	PAN	2.20	.71	99.96
	Total	**305.86**	**99.96**	

Table (5)Shows the sieve analysis data for Salama, sample2 (From Field Data)

Figure (4). Shows Sieve analysis graph



7.1-Calculations:

*** location№ (1) Safola. Sample №1...Depth(200—460) ft:**

From the graph:

1- Effective grain size, reading 90%=0.9

2- Uniformity coefficient (Cu) = $\frac{D40\ D40}{D90\ D90}$**=(Cu) =**$\frac{0.650.65}{0.900.90}$ **=.72**

Reading 40% = 0.65

3- Slot size=$\frac{D40 \quad D40}{25factor25factor}$ **=** $\frac{0.650.65}{25 \quad 25}$ **= 0.026≈0.030**

4- Gravel pack = Cu* D 70 =0.72*0.33=0.2376 ≈0.2mm

D 70=0.33

*** location№ (1) Safola. Sample№2...Depth(900—1125)ft :**

1- Effective grain size, reading 90%=0.9

2- Uniformity coefficient (Cu) = $\frac{D40\ D40}{D90\ D90}$ **=**$\frac{0.620.62}{0.900.90}$**=.68**

3- Slot size= $\frac{D40 \quad D40}{25factor25factor}$ **=** $\frac{0.620.62}{25 \quad 25}$**= 0.0248≈0.030**

4- Gravel pack = Cu* D 70 =0.69*0.34=0.2346 ≈0.2mm

D 70=0.34

*** location№(2) Salama. Sample№1...Depth(400—440)ft :**

1- Effective grain size, reading 90%=0.28

2- Uniformity coefficient (Cu) = $\frac{D40\ D40}{D90\ D90}$ **=**$\frac{1.501.50}{0.280.28}$ **=5.35**

D 40 = 1.5

3- Slot size= $\frac{D40 \quad D40}{25factor25factor}$**=**$\frac{1.501.50}{25 \quad 25}$**= 0.06≈0.040**

4- Gravel pack = Cu* D70 = 5.35*0.59=3.15 ≈3mm

D 70=0.59

*** location№(2) Salama. Sample №2...Depth(805—850)ft :**

From the graph:

1- Effective grain size, reading 90%=0.17

2- Uniformity coefficient (Cu) = $\frac{D40\ D40}{D90\ D90}$ **=** $\frac{0.620.62}{0.170.17}$**=3.64**

D 40 = 0.62

3- Slot size= $\frac{D40 \quad D40}{25factor25factor} = \frac{0.620.62}{25 \quad 25}$ **= 0.0248≈0.030**

4- Gravel pack = Cu* D 70% = 3.64*0.39=1.41 ≈1.5mm
Reading 70%=0.39

8-Results:

Table (6) Showstheresult of grain size analysis (From sieve analysis data):

№	Location	Sample №	Effective grain size	Uniformity coefficient (Cu)	Slot Size (mm)	Gravel packing (mm)
1	Safola	1	0.9	.72	30%	0.2
		2	0.9	0.68	30%	0.2
2	Salama	1	0.28	5.35	40%	3
		2	0.17	3.46	30%	1.5

Table (7) Shows thesummary of classifications and grades (From sieve analysis data):

Location	Safola	Soil fraction percentage Sand				Classification
Sample№	Depth (Ft)	Course	Medium	Fine	V.Fine	
1	200--460	150.6	101	43.1	7.1	Poorly grade sand
2	900--1125	149.5	111.5	35.1	7.98	Poorly grade sand

Table (8) Shows the **summary of classifications:**

Location	Salama	Soil fraction percentage Sand				Classification
Sample№	Depth (Ft)	Course	Medium	Fine	V.Fine	
1	400—440	214.12	56.34	16.18	4.27	Good grade sand
2	805—850	195.90	57.30	40.46	12.20	Poorly grade sand

8.1-Water quality analysis results of the nine well samples, the following Summary is given in tables.

Table (9) Shows the**Water wells quality Data.(From lab Data).**

NO	Location	long	Lat	Depth(m)	S.W.L (m)	Hco3 (mg/l)	Fe (mg/l)	K m/d	No3 (mg/l)	TDS (PPM)	TH	PH
1	Mayo B31	32.556	15.518	85	22.45	317	-	120	5.28	704	266	8.2
2	Gabra (7)	32.558	15.550	119	16.30	104	-	7	7.4	1800	410	8.6
3	Soba (1)	32.583	15.416	106	16.5	170.8	-	10	13	2571	285	7.9
4	Azhari	32.538	15.516	122	15.8	30.5	-	-	4	2303	110	8.6
5	Mayo B3	32.543	15.481	236	48.67	250	.05	7.6	1.3	590	260	7.6
6	Kalakla	32.4946	15.4642	191	9.21	290	.09	5.5	6.6	496	104	7.8
7	Elmansora	32.5291	15.4791	201	46.02	255	-	-	1	861	255	7.5
8	MayoSoug6	32.5291	15.4945	250	41.15	304	.05	2.6	6.2	594	72	7.7
9	KalaklaEltorki	44.3313	17.0992	183	13.72	318	.01	5.27	5.1	601	154	7.8

Table (10) Shows the degree hardness in water (4)

Description	Hardness (mg/l) $caco_3$
Soft water	0 – 60
Moderately hard water	61 – 120
Hard water	121 – 180
Very hard water	181 – 500
Extremely hard water	500 – above

Table (11) Shows the Drinking Water (WHO) Standards 2010. (11):

No	Parameter	Levels likely to Give Rise to Consumer Complaints
1	**Inorganic Constituents:** Aluminum Ammonia Chloride Hydrogen Sulfide Iron (total) Sodium Sulfate Total Dissolved Solids (TDS) Zinc	 0.2 mg/L 1.5 m/L 250 mg/L 0.05 mg/L 0.3 mg/L 200 mg/L 250 mg/L 1000 mg/L 5 mg/L
2	Organic and nonorganic component	Completely free
3	Dissolved Oxygen at 25° c	8 – 5 mg/L
4	Electric conductivity at 18° c	0.0004 micro Moths/ centimeter^2
5	Thermal conductivity at 40.8° c	1.555 Watt/m°
6	Optical reflection factor at 20° c	1.33 unit
7	Vapor Pressure at 20° c	17.62 millimeter
8	Dissolved $CO_{2\ at}$ 25° c	2 – 3 mg/l

9-Discussions:

The discussions resulted in the following facts:-

9.1-From sieve analysis test, table (6):

- Because the effective grain size ranged between0.2to 0.9 which is greater than 0.1 the well screen is needed for artificial gravel packing which is ranged between 0.2mm to 1.5mm.

- The uniformity coefficient Cu in well number one is 0.7 which less than 5 that indicates the aquifer formations is poorly grade ,while in the well number two the uniformity coefficient Cu value is 5.35 which greater than5 ,so the formations is in good grade.
- Commonly and practically the slot size varying from 0.2mm to5mm, so because the result of slot size in both tested wells is ranged between 0.30mm to 0.40mm ,so using of screen with slot openings 0.40mm is highly recommended.

9.2-**From water quality test,table (9):**

- Highly amount of TDS (1800, 2303and2571 PPM) Shown in Shallow wells depths(119,122 and106m respectively). Table (11)
- Low amount of TDS (496,590and 594PPM) Shown in deep wells depths (191,236 and250m respectively).
- Iron appears in deep depths ranging from183m to 250m which indicates the characteristics of Nubian sand stone formations.
- Highly amount of Total hardness TH (410, 285and266) Shown in Shallow wells depths(119,106 and85m respectively).
- Low amount of Total hardness TH (72, 110and104) shown in deep wells depths(250,122 and191m respectively),table (10)
- PH value in permissible limit (7.5, 7.6and7.7) appear on deep depths which is(201, 236and250 m respectively) while high value shown at shallow depths(8.2, 8.6and7.9)with corresponding depths(85, 119and106 m respectively).
- The amount of potassium K (120 mg/l) is high in shallow depth 85m.
- The amount of nitrate NO_3 (13) is high in shallow depth 106m while low amount

(1 mg/l) shown in deep depth (201m).

- All above parameters are helps to get proper design and sustains highly ground water quality and highly well life.
- From the above results the upper aquifer is subjected to

contaminations and salinity which affects the ground water quality for all consumptions, while the lower zones is fit for human, agricultural and industrial consumptions.

10- Conclusions:

Groundwater is significant resource for human consumption and its preservation in term of its quality and for future generations is of utmost importance. This study combined between sieve analysis test method for aquifer formations and water quality test to determine the water bearing formation grade and water quality result to ensure good well design and fit water forhuman consumptions. The main important findings are listed as below:

1. Minimum distance between wells must be at least 200m to avoid wellinterferences.
2. The location of water wells must far enough from existed source of pollutions.
3. Drilling and designing water wells supposed to be in lower zones on depth more than 200m with screen slot opening 40% with gravel size 1.5mm.
4. Sealing of the upper aquifer from (0 to 125m) through cementing job to prevent the percolation of contaminants and salinity to the lower aquifer is highly recommended.
5. Proper backwashing with proper gravel packing is recommended.
6. For good inserting of the gravels the diameter of borehole should be with twice of the recommended diameter of final casing.
7. Starting water well Development must be urgent.
8. The depths of salinity and contaminants must be identified through geophysical logging to detect the zones of salinity and pollutions to protect the lower aquifer.
9. Good and close supervisions must be done for collecting samples and registering the penetration rate to assist the designer to correlate the data from logging with lithological descriptions and penetration rate if no samples were to be carried out.

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