Experimental Investigation about the Effect of Sand Storage Dams on Water Quality

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Abstract

Evaluation, planning, and management of water resources are raised to be one of important subjects in the human's life, particularly in arid and semiarid region, since precipitation is extremely limited spatially distributed and high evaporation losses with poorly available ground water supply.
In present study, the sand storage dam technique (sub surface storage dam) is used to reduce the evaporation effect. Many tests such as (Electrical conductivity, Ec , Total dissolved solids, TDS , sodium chloride, Nacl , magnesium, Mg , calcium, Ca , bicarbonates, Hco3 , potassium, K , sodium, Na) are achieved to check the quality of water storage in sand dam. Comparisons between raw water and water storage in sand dam are made to determine the differences among above parameters. Analysis of results included study the effects of soil properties (two different types of soil are used), and storage in sand dams on the water quality.
The present study shows, there is a significant improving of water quality, with increasing of the number of rainfall storms. Also, there is a good chance to use sand storage dam in arid region because decrease the evaporation losses and good storage capacity.

Key Word: Sand Dam, Water quality, water harvesting, irrigation indexes.

INTRODUCTION:-

Water resource availability in arid regions like Iraqi western desert is mostly depended on the characteristics of shortage and periodicity of rainfall which determine run-off during only short periods of year. Storage of water from the rainy season to the dry season is highly important [1]. Water use in arid region, is limited by lack of financial resources and suitable technology in addition to physical conditions. These considerations impetus the ministry of water resources in Iraq to use small dam reservoirs for water harvesting to provide water for humans, livestock and crops in the Western desert in Iraq [2]. These kinds of structures present favorable characteristics both in terms of efficiency and simplicity of realization. The challenge comes from the precipitation is extremely limited, spatially distributed, with poorly available of ground water supply and large evaporation make rainfall agriculture a risky enterprise.

In the newly suggested method of sub-surface storage is storing water by sand storage dams that are a small concrete check dams built in the valley bed perpendicular to the flow direction. Upstream the sand dam fast sedimentation occurs (figure 1), which is regarded a problem considering surface water dams. However, sand accumulating behind these dams has a large grain size diameter, thereby enlarging the natural aquifer. During the dry season water will be stored in the area for a longer period with an enlargement of groundwater storage capacity compared in comparison with a situation without a sand dam.

The technical approach in this study is directed to determine the effect of storage in the sand dam reservoir on water quality.

The water quality determination includes test of eleven parameters to prove the storage water is suitable or not for different use for humans, livestock and crops. These parameters are "hydrogen ions, pH, Electrical conductivity, Ec, Total dissolved solids, TDS, chloride, Cl, chloride sodium, NaCl, bicarbonates, HCO_3, sodium, Na, potassium K, magnesium Mg, and calsium Ca.

There are many methods used to reduce evaporation. One of these methods is the underground storage dam. The newly suggested method of sub-surface storage dam is storing water by sand storage dam, which is a small concrete check wall (dams) built in the valley bed perpendicular to the flow direction. Upstream of the sand dam fast sedimentation occurs, because of sediment load of runoff water (fig.1). However, sand accumulating behind these dams has a large grain size diameter, and leads to enlarge the natural aquifer. During the dry season water will be stored in the area for a longer period. The modern studies in many countries refer to the increasing of groundwater storage capacity is too much in comparison to situation without a sand dam. During the dry season, groundwater is abstracted manually by means of scoop holes (hand dug wells in the riverbed) as has been done traditionally for thousands of years in semi-arid and arid areas, [3].

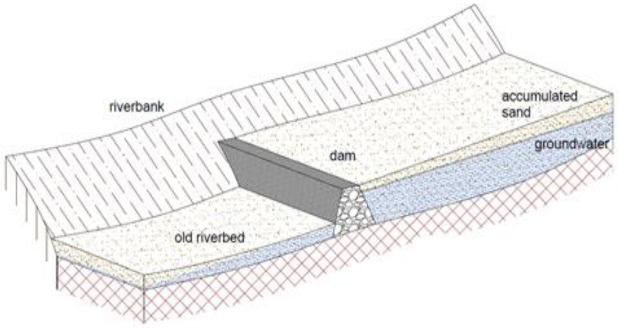

Figure1. Sand Storage Dam

The concept however is not new and the method has been applied in many places around the world since a long time. For example groundwater blocking structures were found on the island of Sardinia, Italy, where dams were built in Roman times. In Tunisia, North Africa, dams of similar age were found. In the eighteenth century sand storage dams were built in Arizona, United States of America. More recently various small-scale groundwater damming structures have been built in many parts of the world, but mainly in India, Brazil, South and East Africa and Pakistan. Although all these structures are more or less similar, different names are used in different parts of the world. For instance these structures are referred to as sand storage dams, sand dams, check dams, trap dams, sponge dams, or desert water tanks [4].
Presented suggestions for the development of sand dams to increase water availability in arid regions; includes the sand dam was constructed in an area of small to medium rocky canyons [5]. The stages and mechanism of sand dam operation are explained in figure 2.

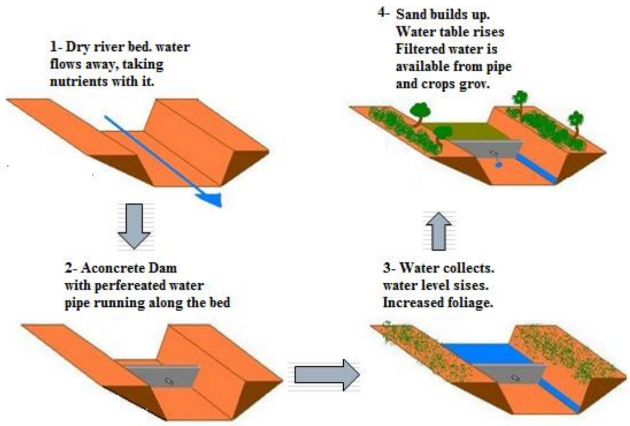

Figure2. The Mechanism of Sand Storage Dam

Then, improving the efficiency, dependability, and simplicity of the sand dams was made. The improving suggestions are: It is not necessary to drill holes throughout the top third of the culverts, because the ends of the culverts are not tightly sealed [6]. A few large rocks, or heavy wire screen placed over the ends of the culverts will allow the culverts to fill and drain and the float valve failures have been a major problem in guzzlers installed for mountain sheep in California. In the arid and semi-arid region there are some of newly studies about SSD, studied Hydrology of Sand Storage Dams case study in the Kiindu catchment, Kitui District, Kenya [7]. They result were using the sand storage dams technique, about 2,800 cubic meter was available during the period from March to October, which is about 11 cubic meter per day. Application to Kitui district (Kenya) they conclude that from the first year after the sand storage dam was built the gain on water volume (compared with the situation with no dam) increased every year. After 40 years, the gain in water volume remained the same every year. Thus, not only the dams were useful to store water from the wet to the dry season but also to store water between years [8].
There are many hydrologic studies that referred to a good quantity of runoff water in the Iraqi Western Desert can be harvested. As well as there are more than 14 dams with storage capacity between (4-32) million cubic meter for every dam. All studies in this region depend on hydrologic measurement and analysis the collecting data to determine the quantity of water that will be harvested and there is not any study about water quality and how the water quality can be affected. The present study can give a simple indication for the effect the storage water in sand dam or sub-surface dam on the water quality in arid or semi-arid region.

THE METHODOLOGY:-

In present study, the instrument in (fig.3) is designed to simulate the reservoir of sand dam.

Figure3. The model of Sand Storage Dam

The reservoir constructed with dimensions, 125 cm in length, and 100cm in width and 40 cm in depth. The simulated wall dam is made from plat (100cm * 45 cm) and provided with 2.5 cm diameter pipe passing through it. The pipe is perforated and associated with valve to discharge water from the reservoir and surrounded by lattice mineral wire to prevent passing of fine soil. The dam was filled with sample of soil 350000 cubic centimetres volume (125*100*28 cm). Two types of soils are used to simulate the bed of dam reservoir. Depending on unified soil classification system, the soils are classified into poorly graded with silt and gravel (SP-SM) for the sample 1 and poorly graded with silt (SP-SM) for sample 2. Figure 4; shows the results of sieve analysis for two samples soils.

The raw water (rainfall) is added by nozzles to sample of soil and controlled by flow meter device to save the rainfall intensity constant for all experiments. The sample of soil is left for three days to make all water inter the soil and it became saturated with water. Then, the storage water will empty from the valve in the end of the pipe to determine volume of water that can be stored in sand dam (capacity) and real discharge from the pipe. The percentage of water storage in sand dam reservoir from the rainfall volume is calculated to determine the efficiency of sand dam as explained in tables (1 and 2). The tests of raw water were made to determine the physical properties like pH, Ec, and TDS. Then the tests of physical properties, NaCl, Cl, HCO3, CO3, Na, K, Mg, and Ca are achieved for collected water. Collected samples were analysed in the laboratory to measure the concentration of the quality parameters using American Public Health Association standard methods [10]. pH, EC, TDS, Ca, Mg, Na, K, HCO-3, and NaCl were the major ions in groundwater or water from sand storage dam. Sodium and potassium concentrations were determined by using a flame photometer. The rainfall storm repeated for three times and these tests are achieved in every time to study the effect of number of soil washing (rainfall storm) during the season or life of dam on the water quality. Table (3, and 4), shows the results of physical properties and water quality parameters.
The concentrations were interpreted and calculated with irrigation indexes using the following formula of Permeability index (PI), Magnesium hazard (MH), and Sodium adsorption ratio (SAR).

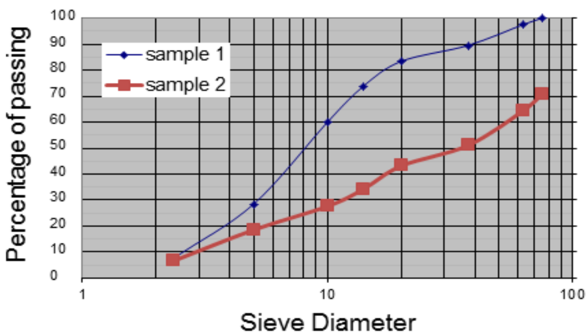

Figure4. Seive Analysis for two samples of soil

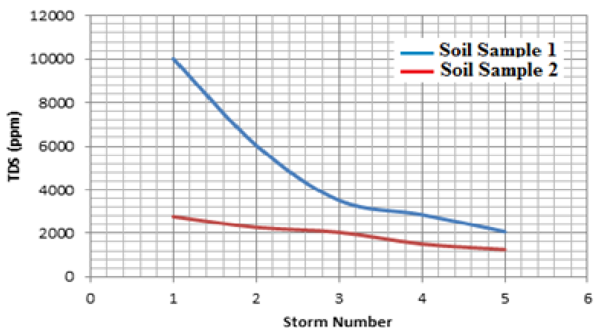

Figure5. TDS comparison between two samples

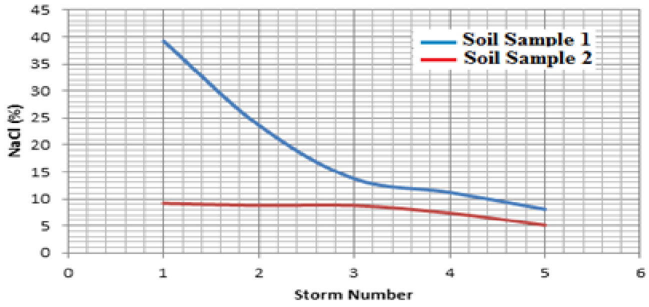

Figure6. NaCl comparison between two samples

RESULTS AND DISCUSSION:

Simple inexpensive technology is used and the dam can be constructed by local communities mainly with locally available materials.
Water storage and extraction depend on the riverbed material. Water extraction can be most profitable when extracted from riverbeds containing coarse sand than from riverbeds with fine textured sand. The average extracting water or withdrawal water from the sand storage with soil sample 1 (41.4%) is greater than average extracting water from the sand storage with soil sample 2 (38.2 %). Fig.(4) shows the soil sample 1 have percentage of coarse rather than soil sample 2 and this is the reason cause the withdrawal water from sample 1 more than water withdrawal from soil sample2. The storage capacity of the sand dam in present study is varying from 24%-49% which is satisfied with other studies about sand storage capacities over the world. Literatures review refers to dry riverbeds can be classified into 3 classes [10] for potential water extraction through sand dams (or subsurface dams):

1. The most potential riverbeds have hilly and stony catchments that produce coarse sand where up to approximately 350 liters of water can be extracted from1 cubic meter of sand
   - Extraction rate: 35%
2. Gullies originating from stony hills have a potential for sand dams consisting of medium coarse sand where approximately 250 liters of water can be extracted from 1 cubic meter of sand
   - Extraction rate: 25%
3. Riverbeds having catchments of flat (farm)land usually contain fine textured sand (or silt or even clay) that can only yield a maximum of approximately 100 liters of water from 1 cubic meter of sand
   - Extraction rate: 10% (or less).

The model results appear to be realistic. Therefore the model can be used to evaluate the hydrological processes of sand storage dam reservoirs in situations where measured data are scarce.
The quality standards for drinking water have been specified by the World Health Organization (WHO). The behaviour of

major ions (Ca, Mg, Na, K, HCO3, Cl) and important physico-chemical parameters such as pH, (EC), (TDS), and total hardness (TH) and the suitability of groundwater in the study area are discussed below.

(pH)

For aesthetic reasons the range should be within pH 6.5 to pH 8.5 [11]. The pH value of sample 1 varies from 7.1 to 7.6 while it varies from 6.1 to 7.4 for sample 2, which clearly shows that the water discharge from the sand reservoir is slightly base in nature for sample 1 and varies between acid and base in nature for sample 2. While extreme pH values (<4 and >11) may adversely affect health. In the environment, many plants and animals are harmed, or even killed, as a result of acidification. Many varieties of fish and aquatic life are extremely sensitive to changes in water temperature and composition. Water that has a pH greater than 8.0 can be difficult to disinfect. The World Health Organization recommends that the pH of the water be less than 8.0, because basic water does not allow for effective chlorination.

(EC)

EC is a measure of water capacity to convey electric current. The most desirable limit of EC in drinking water is prescribed as 1,500 µmhos/cm [12]. The EC of the groundwater is varying from 64.02 and 2199.57 µmhos/cm with an average value of 514 µmhos/cm. Higher EC in the present model of sand storage reservoir indicates the enrichment of salts in the two samples of water. According to tables (3, and 4) the EC decreases about 80% after storm number 5 which it is reflects the good effect of the number of storm to improve the storage. The value of electrical conductivity may be an approximate index of the total content of dissolved substance in water. It depends upon temperature, concentration and types of ions present [11]. The effect of saline intrusion may be the reason for enrichment of EC in the present model. The effect of pH may also increase the dissolution process, which eventually increases the EC value.

(TDS)

According to WHO specification TDS up to 500 ppm is the highest desirable and up to 1,500 ppm is maximum permissible. In present study the TDS value increases from 600 ppm to **10010 ppm for sample 1 and 2770 ppm** for sample 2, because of the high salinity of soil samples. After storm 5, the TDS decreases to 2070 ppm for sample 1 and 1260 ppm for sample 2 indicating that rainfall water can improve the water quality of the sand storage reservoir as explained in figure (5)

Sodium and potassium (Na and K)

Sodium ranks sixth among the elements in order of abundance and is present in most of natural waters. Sodium is generally found in lower concentration than Ca and Mg in freshwater. The maximum permissible limit of sodium is 200 mg/l and it reveals that few samples are exceeding the permissible limit of WHO and ISI. The intake of high level of Na causes increased blood pressure, arteriosclerosis, oedema and hyperosmolarity. Groundwater with high Na content is not suitable for agricultural use as it tends to deteriorate the soil. The Na concentration can be measured also by concentration of NaCl. Figure 6 shows the NaCl comparison between two samples for five storms.

Potassium is a naturally occurring element; however, its concentration remains quite lower compared with Ca, Mg and Na. Its concentration in drinking waters seldom reaches 20 ppm. The concentration of K is observed between 29 and 57 ppm for sample 1 and varied between 25 and 30 ppm for sample2. The maximum permissible limit of potassium in the drinking water is 12 ppm and it was found that the samples are up the permissible limit of WHO. In comparison with Na, the low concentration of K is due to the high resistance of potash feldspars to chemical weathering in the soil samples. According to tables (3, and 4) the Na, concentrations decreases about 61% after storm number 5 for sample 1.While Na concentration decreases about 23% for sample 2 which it is reflects the good effect of the number of storm to improve the storage.

Permeability index

A classification based on PI was proposed by World Health Organization for assessing suitability of groundwater for irrigation purpose. The soil permeability is affected by long term use of irrigation water. A criterion for assessing the suitability of water for irrigation was based on PI water and can be classified as class I, Class II and Class III orders. Class I and Class II water was categorized as good for irrigation with 75% or more maximum permeability. Class III water was unsuitable with 25% of maximum permeability [13]. In the present study variable between, 60 and 65% for sample 1 and about 65% for sample 2; hence, the groundwater quality was suitable for irrigation.

$$PI=[Na+(HCO3)^{0.5}] * 100/[Na+Ca+Mg]. \qquad (1)$$

The results are given in table 5.

Magnesium hazard

In most waters calcium and magnesium maintains a state of equilibrium. A ratio namely index of magnesium hazard was developed by Paliwal and it was an important factor in irrigation water quality (Reddy, 2013). According to this, high magnesium hazard value (greater than50 %) has an adverse effect on the crop yield as the soil becomes more alkaline. Mg is in water as ions, which are easily absorbed in the physiological processes which take place at the gastrointestinal tract, comparing with metals related to the organic compounds from food. It is appreciated that Mg in drinking water can assure 20%-40% from the daily necessary; Mg intake on this way can prevent the Mg deficit at persons who drink water with an increased content on this element.

$$MH= Mg^{2+} * 100/(Ca^{2+} + Mg^{2+}). \quad (2)$$

For present study two samples can be used for irrigation because MH less than 50%.
The results are given in table 5.

Sodium adsorption ratio

Sodium adsorption ratio (SAR) is a measure of the suitability of water for use in agricultural irrigation, because sodium concentration can reduce the soil permeability and soil structure [10]. SAR is a measure of alkali/sodium hazard to crops and it was estimated by the following formula:

$$SAR = Na/[(Ca+Mg)/2]^{0.5} . \quad (3)$$

It is important to note that sodium is an essential nutrient. The Food and Nutrition Board of the National Research Council recommends that most healthy adults need to consume at least 500 mg/day, and that sodium intake be limited to no more than 2400 mg/day.
The results are given in table 5.

Conclusions:

- The storage capacities of sand storage dam varied between 24% to 49% that are satisfied the all studies about the capacities of sand dams in arid regions,
- The study indicates medium salinity -low sodium water, which can be used for irrigation for two types of soil without danger of exchangeable sodium.
- There are good effects for number of storm on the water quality for water storage in sand dam; the physical properties of water quality are improved with increase of number of rainfall storms.
- The sand storage dam represent very good tool for water harvesting (quantity and quality).

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TABLE1. The Test Results of Sand Storage Reservoir for Soil Sample 1

Storm	Rainfall Volume (L)	Volume of water Discharge from sand Reservoir (L)	Max. Discharge (L/min)	Sand Storage Ratio (%)
1	65.67	29	0.524	44
2	50	18	0.497	36
3	83.33	35	0.49	42
4	83.33	39	0.42	47
5	50	19	0.44	38

TABLE2. The Test Results of Sand Storage Reservoir for Soil Sample 2

Storm	Rainfall Volume (L)	Volume of water Discharge from sand Reservoir (L)	Max. Discharge (L/min)	Sand Storage Ratio (%)
1	133.33	44	0.65	33
2	116.67	28	0.70	24
3	66.67	33	0.71	49
4	83.33	40	0.75	48
5	83.33	31	0.72	37

TABLE3. The Test Results of Water Quality for Soil Sample 1

	pH	Ec µmhos/cm	TDS ppm	Nacl %	Hco3 ppm	Na ppm	K ppm	Mg ppm	Ca ppm
Raw Water	7.4	1200	600		366.06	807.05	20.151	87.552	88.176
Storm1	7.1	20000	10010	39.2	146.42	3847.8	57.113	337.2	2216.9
Storm2	7.4	12000	6040	23.6	109.82	3185.6	44.594	282.64	1768.1
Storm3	7.6	7000	3510	13.7	97.62	2145	33.038	197.71	1068.12
Storm4	7.6	5720	2860	11.2	85.41	1908.5	31.112	178.46	909.51
Storm5	7.6	4140	2070	8.1	73.21	1482.8	29.186	143.92	638.81

TABLE4. The Test Results of Water Quality for Soil Sample 2

	pH	Ec µmhos/cm	TDS ppm	Nacl %	Hco3 ppm	Na ppm	K ppm	Mg ppm	Ca
Raw Water	7.4	1200	600		366.06	807.05	20.151	87.552	88.176
Storm1	7	5650	2770	9.2	134.22	1566.46	30.2	150.78	681.36
Storm2	6.7	4500	2270	8.8	-	1536	29.81	136.2	625.24
Storm3	6.5	4140	2040	8.8	-	-	-	-	617.23
Storm4	6.7	3110	1510	7.4	109.82	1383.94	28.02	136.2	601.2
Storm5	6.1	2520	1260	5.1	-	1209.21	25.96	121.6	440.88

TABLE5. Irrigation indexes for two samples.

Storm	Sample1			Sample 2		
	SAR	*PI*	*MH*	*SAR*	*PI*	*MH*
1	107.7	60.3	13.2	76.8	65.8	18.12
2	99.48	61	13.8	78.7	-	17.9
3	85.3	63.2	15.62	-	-	-
4	81.8	64	16.4	72	65.73	18.5
5	74.95	65.8	18.4	72.1	-	21.62