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

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ABSTRACT

Water resource availability in arid regions depends on the characteristics of shortage and periodicity of rainfall which determine run-off during only short periods of the year. Water use is limited by lack of financial resources, suitable technology, and physical conditions. The challenge comes from the limited precipitation and spatially distributed, with poorly available ground water supply. These problems, with large evaporation, make rainfall agriculture a risky enterprise and impede the formation of perennial streams capable of satisfying environment and population's requirements. The sand storage dam technique is used to reduce the evaporation effect. Many tests like (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. Comparisons between raw water and water storage in the sand dam are made to determine the differences among above parameters. The present study shows, there is a significant improving water quality, with increasing the number of rainfall storms. Also, there is a good chance to use sand storage dam in the arid region because decrease the evaporation losses and good storage capacity.

INTRODUCTION

Water resource availability in arid regions like Iraqi western desert mostly depends on the characteristics of shortage and periodicity of rainfall which determine run-off during only short periods of the year. Storage of water from the rainy season to the dry season is highly important. Water use in the 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. 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 and spatially distributed, with poorly available ground water supply. These problems, with large evaporation, make rainfall agriculture a risky enterprise, and impede the formation of perennial streams capable of satisfying environment and population's requirements.

In the present study, the underground storage dam is suggested to reduce evaporation. The newly suggested method of sub-surface storage is storing water by sand storage dams that are 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.

This technology might be considered 'simple' but 'effective', to reduce the evaporation losses from reservoirs. A challenge is to develop an effective strategy combining effective, cheap and fast construction with a community-based approach, which includes supply water with an effective tool for quantity and good water quality, therefore; 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 a 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, HCO3, sodium, Na, potassium K, magnesium Mg, and calcium Ca.

SAND STORAGE DAMS

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 enlarging 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 the 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, (Hoogmoed 2007).

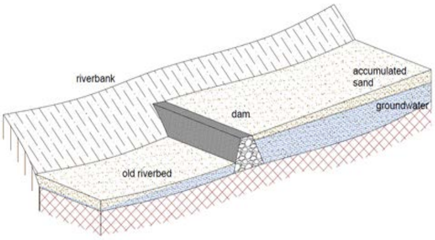


Fig. 1 Sand Storage Dam

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 (Haveren, 2004).

(Sivils and Brock, 1981), presented suggestions for the development of sand dams to increase water availability in arid regions; they are mentioned that the sand dam was constructed in an area of small to medium rocky canyons. Construction was begun with the loose sand and gravel being cleared from a rock bottomed ephemeral stream. A masonry dam, anchored in the rock base, and approximately 1 meter in height was constructed with a 2.5 cm plastic outlet pipe. Numerous lengths of 30.5 cm diam aluminum pipe were used to construct the holding basin. The aluminum pipe had 1.3 cm holes drilled in its top third about 2.5 cm apart, down the entire length of the pipe. The aluminum pipes were then interconnected with drainage capacity into the plastic outlet pipe.

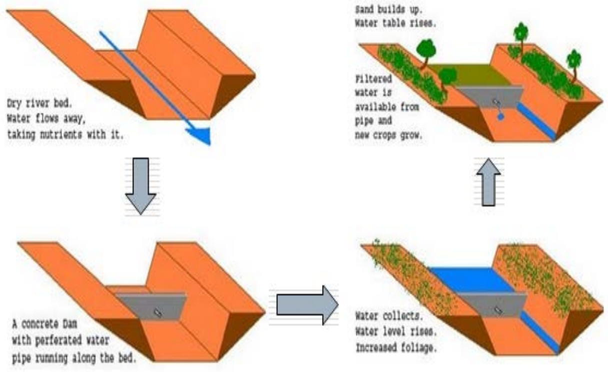


Fig.2 the mechanism of Sand Storage Dam

(Bleich and Weaver,1983) they mentioned suggestions for improving the efficiency, dependability, and simplicity of the sand dams described by Sivils and Brock, these suggestions are: It is not necessary to drill holes throughout the top third of the culverts as suggested by Sivils and Brock, because the ends of the culverts are not tightly sealed. 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 where (Borst and de Haas, 2006) studied Hydrology of Sand Storage Dams case study in the Kind catchment, Kitui District, Kenya They result were using the sand storage dams technique , about 2,800 M3 was available during the period from March to October , which is about $11m^3$ per day. Quilis, (2007) studied Modelling sand storage dams systems in seasonal rivers in arid regions. 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.

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 of the effect the storage water in a sand dam or sub-surface dam on the water quality in the arid or semi-arid region.

THE METHODOLOGY

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

Fig. 3 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 the plat (100cm * 45 cm) and provided with 2.5 cm diameter pipe passing through it. The pipe is perforated and associated with a valve to discharge water from the reservoir and surrounded by lattice mineral wire to prevent the passing of fine soil. The dam was filled with a sample of soil 350000 cm 3 volume (125*100*28 cm). Two types of soils are used to simulate the soil of dam reservoir and fig. (4), shows the sieve analysis of two soils. Depending on the 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.

The raw water (rainfall) is added by nozzles to a 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 at the end of the pipe to determine the volume of water that can be stored in the 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 and tables (1, and 2) show the results and calculations of experiments. 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 analyzed in the laboratory to measure the concentration of the quality parameters using American Public Health Association standard methods (APHA, 1995). 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. Chloride concentration was measured by silver nitrate titration. Bicarbonate concentrations were measured by acid-base titration. The comparison between the concentration of these parameters for raw water and water storage in the sand dam is made to determine the differences and study the effects of sand dam storage on the water quality. The rainfall storm repeated for three times and these tests are achieved in every time to study the effect of the 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).

Table1. The Test Results of Sand Storage Reservoir for Soil Sample 1

Storm	VR(L)	Vd(L)	Qm(L/min)	SR(%)
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

VR=rainfall volume, Vd=Volume of water Discharge from sand Reservoir, Qm=Max. Discharge, SR=Sand Storage Ratio

Table2. The Test Results of Sand Storage Reservoir for Soil Sample 2

Storm	VR(L)	Vd(L)	Qm(L/min)	SR(%)
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

RESULTS 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 a 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.

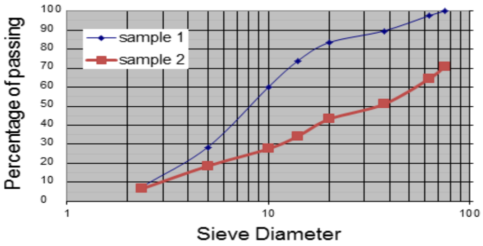


Figure4. Sieve Analysis for two samples of soil

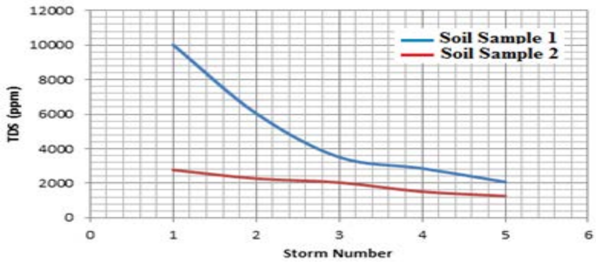
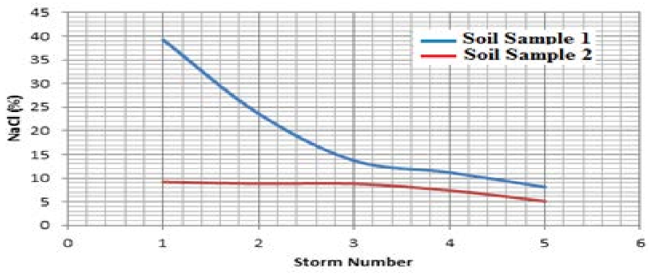


Figure5. TDS comparison between two samples



Figure,6 NaCl comparison between two samples

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		366.1	807.1	20.1	87.6	88.2
Storm1	7.1	20000	10010	39.2	146.4	3848	57.1	337.2	2217
Storm2	7.4	12000	6040	23.6	109.8	3186	44.6	282.6	1768
Storm3	7.6	7000	3510	13.7	97.6	2145	33.0	197.7	1068
Storm4	7.6	5720	2860	11.2	85.4	1908	31.1	178.5	909.5
Storm5	7.6	4140	2070	8.1	73.2	14823	29.2	143.9	638.8

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

The storage capacity of the sand dam in the 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 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) in 2004. The behavior of major ions (Ca, Mg, Na, K, HCO3, Cl) and important physicochemical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), and total hardness (TH) and the suitability of groundwater in the study area are discussed below.

HYDROGEN IONS (pH)

pH is a measure of the balance between the concentration of hydrogen ions and hydroxyl ions in water. The pH of water provides vital information in many types of geochemical equilibrium or solubility calculations [9]. The units for pH is the “Standard pH unit” (Std pH Units) and there is no health related guideline value for pH. However, for aesthetic reasons the range should be within pH 6.5 to pH 8.5 [10]. 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, there are insufficient data to set a health guideline value. It should be noted that rainwater is always acidic (pH varies between about pH 4.5 to pH 6.5) since moisture (H2O) in the air absorbs carbon dioxide (CO2) producing carbonic acid (H2CO3). Some pH characteristics are as follows:

- <pH 6.5 may be corrosive
- pH 8 progressively decreases efficiency of chlorination
- >8.5 may cause scale and taste problems

ELECTRICAL CONDUCTIVITY (EC)

Electrical conductivity 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 (WHO 2004). 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 reflects the good effect of the number of the 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 on upon temperature, concentration and types of ions present [9]. The effect of saline intrusion may be the reason for the enrichment of EC in the present model. The effect of pH may also increase the dissolution process, which eventually increases the EC value.

TOTAL DISSOLVED SOLIDS (TDS)

According to WHO specification TDS up to 500 ppm is the highest desirable and up to 1,500 ppm is maximum permissible. In the 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 the natural waters. Sodium is generally found in a 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 the high level of Na causes increased blood pressure, arteriosclerosis, edema, 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 the 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 reflects the good effect of the number of storms to improve the storage.

PERMEABILITY INDEX

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 (Reddy, 2013). In the present study variable between, 60 and 65% for sample 1 and about 65% of sample 2; hence, the groundwater quality was suitable for irrigation.

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

MAGNESIUM HAZARD

In most waters calcium and magnesium maintain 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. For the present study, two samples can be used for irrigation because MH less than 50%.

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

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 (Magesh 2012). SAR is a measure of alkali/sodium hazard to crops and it was estimated by the following formula:

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

Table (5) shows the results of 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	18.1
2	99.48	61	13.8	78.7	-	17.9
3	85.3	63.2	15.6	-	-	-
4	81.8	64	16.4	72	65.7	18.5
5	74.95	65.8	18.4	72.1	-	21.6

Table5. Irrigation indexes for two samples.

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 a number of the storm on the water quality for water storage in the sand dam; the physical properties of water quality are improved with the increase of the number of rainfall storms.
- The sand storage dam represents a very good tool for water harvesting (quantity and quality).

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