parameter has been selected to check in the third station (T30). The long term measurement for ten years (2010 to 2019) used to monitor and analyses the variation in water quality in these three stations.

Figure 2. The location of selected two monitoring stations (T27 and T28) on the Tigris river, located before and after the Kut dam. (MoH&E, 2010).

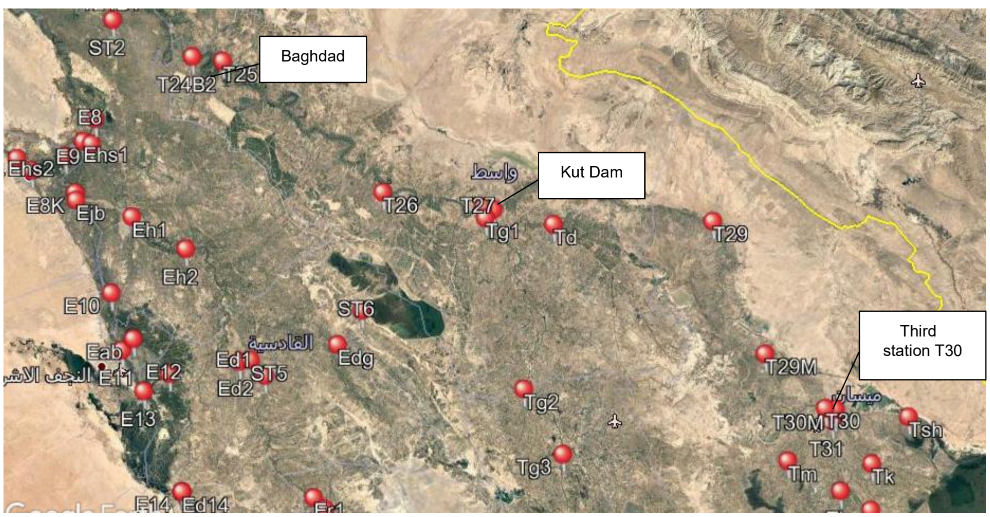

Figure 3. The location of selected third monitoring station (T30) on the Tigris river, 200km after Kut dam. (MoH&E, 2010).

RESULT AND DISSCUSSTION

The researcher selected two monitoring stations on the Tigris river to analyses the impact of the water barrier (dam) on the changing of water quality. The stations T27 and T28 in Wasit (Kut) city, 200 km southern Baghdad, were selected to illustrate effects of Kut dam, which use as a regulator for the flow, on the quality of water Tigris river. T27 locates about 2 KM upstream the Kut dam and T28 located about 3 km downstream the dam; Figure 2 shows the location of the two monitoring station and Fig 2 shows the location of the third station T30.

The Mosul dam flow measuring station at the north of Iraq (upstream) was selected for the Tigris river to present the flow rate of the river, this the only station available for measuring the flow rate. The study used the flow rate measured in one station upstream the river and supposedly that the extraction along the river is constantly the same. The data of flow rate for the river was calculated a monthly rate for the years from 2010 to 2019 (ten years). The figure (4) shows the flow chart of the flow rate for ten years for the Tigris river.

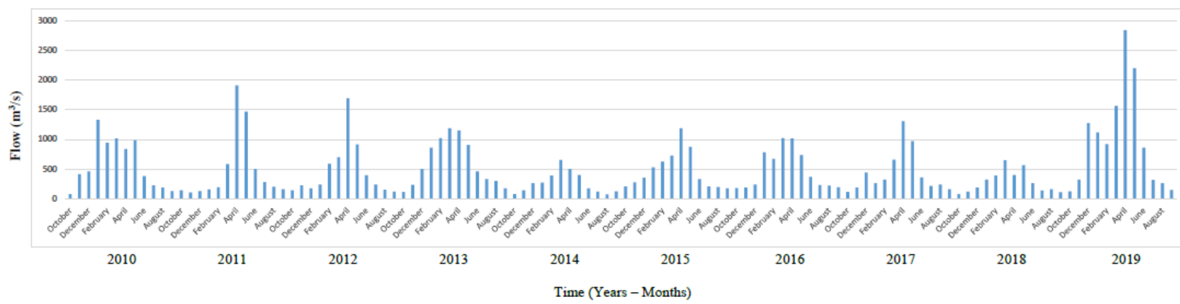

Figure 4. Monthly flow rate for the Tigris river from 2010 to 2019 measured at Mosul Dam station.

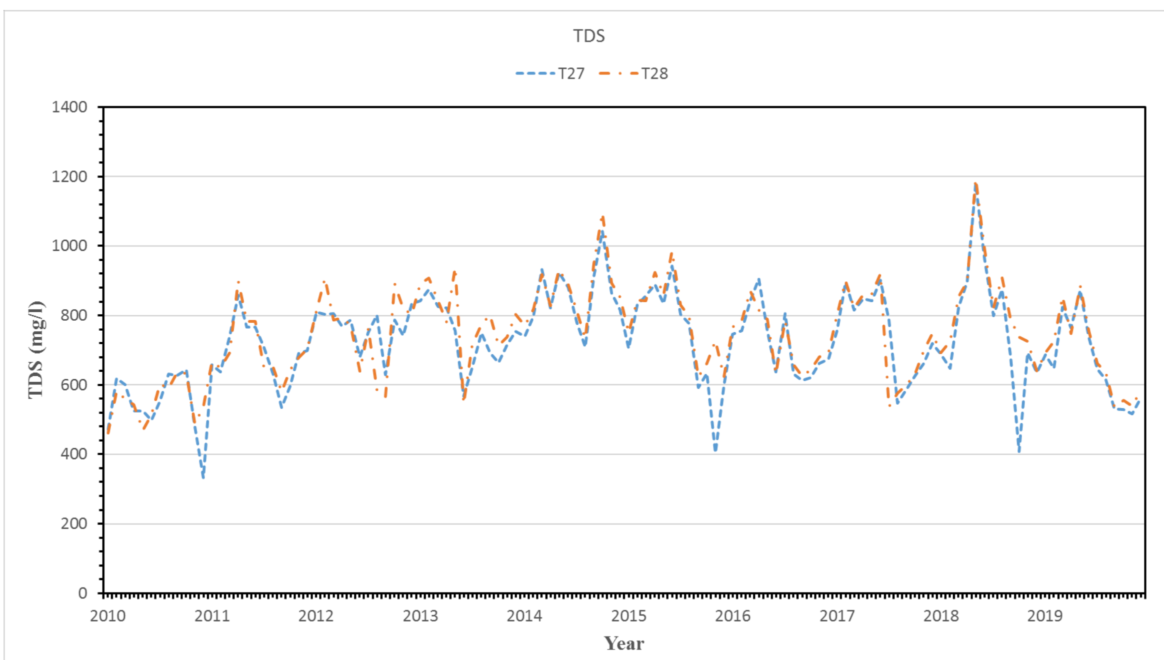

Figure 5. The concentrations of the TDS shown in two monitoring stations (T27 and T28) before and after the Kut dam on Tigris river for the years from 2010 to 2019.

The results of parameters TDS, TH and So4 are presented in figures (5, 6 and 7) for both station T27 before the Kut Dam and T28 after Kut Dam. The results show clearly that the Dam doesn't have a significant impact on changing the water quality before the dam and directly after the Dam. This is because the Kut dam as the regulator flow dam, use to control the water level in the river upstream the dam, there is no storage lake for the dam. The water quality was good in both stations and improved through the last ten years. The reason that these selected stations are not far downstream, they are nearly in the middle of Iraq where the e-flow was maintained, the water quality degradation downstream the river in southern Iraq as a reason of significant reduction in the flow below the e-flow. The results illustrate a consistency between the measurements in T27 and the measurements in T28, confirming the reliability of measuring data. The results show clearly the impact of the quantity of flows in the river on the water quality, the values of the parameters raised when the flow was low in the drought season and tend to decrease with increasing of the flow rate.

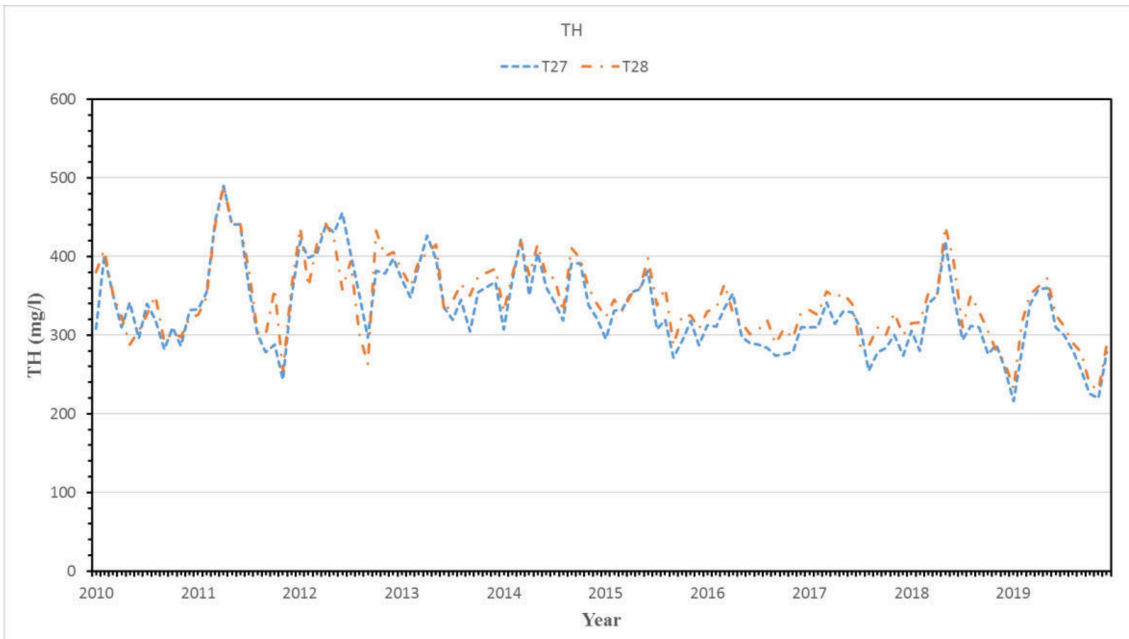

Figure 6. The concentrations of the TH shown in two monitoring stations (T27 and T28) before and after the Kut dam on Tigris river for the years from 2010 to 2019.

The study went further to check the water quality downstream of Tigris River, station number T30 in Missan city, 400 Km south of Baghdad and 100 km northeast Basra were selected to demonstrate the degradation in water quality of the river. The results present in figure (8) shown the TDS concentrations in the Tigris river for the three stations. The TDS is significantly increased in this station T30 compared with the value of the TDS in stations T27 and T28. This clearly because the flow rates of the Tigris river sharply reduce at this station because the extraction for irrigation and human uses along the 200 km path of the river. There is no tributaries to feed the river along with this distance. The river is maintained the e-flow even in drought years as the parameter of pollutant TDS, is still within the limit required by the environment Iraqi regulation. The maximum TDS level required by environment Iraqi regulation should not exceed the 1500 mg/l, so results presented for the TDS in T30 is critical and authority should be tried to maintain the level of the flow rate available in T30 for the downstream of the river. In general, Kut Dam found to have a positive impact on regulating the level of water upstream and flow rate downstream maintained the e-flow until monitoring station T30 and water quality within limits required by Iraqi regulation. The challenges that the water resources faced in Mesopotamia (Iraq) are serious and water quality has a significant degradation downstream in southern Iraq as a consequence of climate change and misuses. The misuse of the Euphrates and Tigris waters by local stakeholders and the overexploitation and contamination of water with liquid wastewater, together with the discharge of irrigation water rich in pesticide and fertilisers to the rivers, had a significant impact on water quality. Additionally, the construction of many dams upstream of the two rivers in addition to climate change increased the salinity of the water downstream and reduced its flow. Therefore it is urgent and important for the water authority in Iraq to design the scenarios of the future management for the water resources in Iraq to provide the clean water quantity and maintain the quality for human uses. And bases on the type of ground topographic in the south of Iraq (flat area), the authors recommended of using the regulator Dam in the main cities downstream the Kut Dam such as Missan city where the T30 located. These regulator Dams provide an effective way to control and manage the water resource and using along the Iraqi rivers.

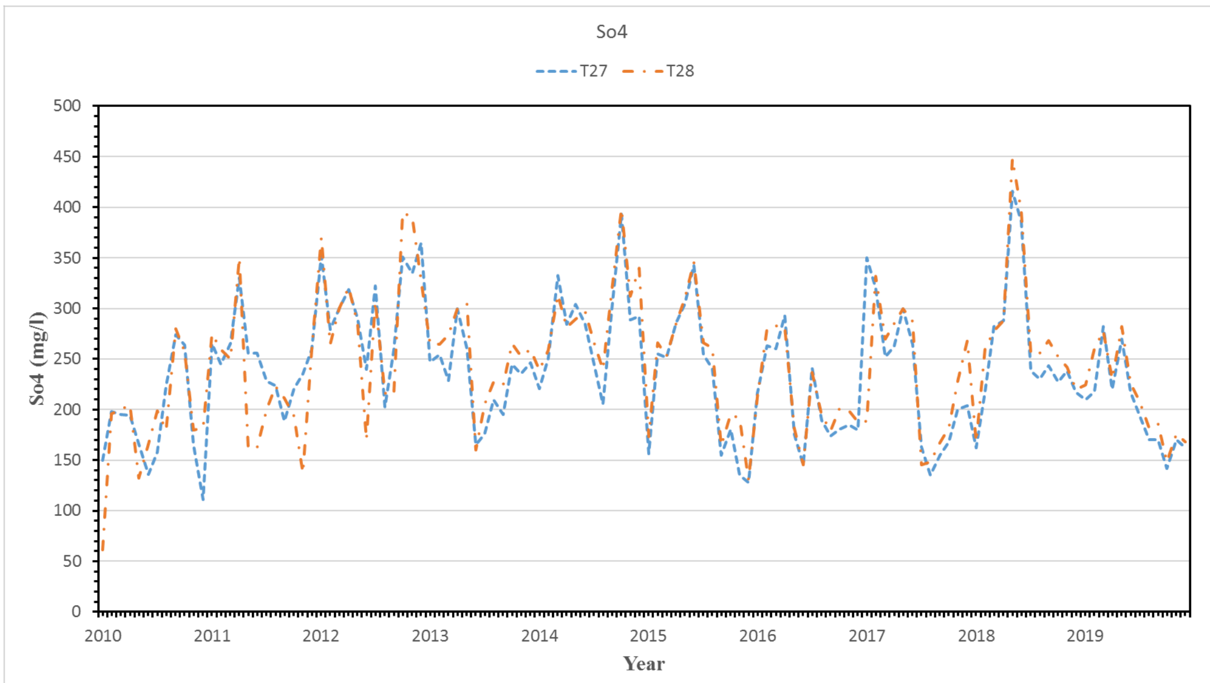

Figure 7. The concentrations of the So4 shown in two monitoring stations (T27 and T28) before and after the Kut dam on Tigris river for the years from 2010 to 2019.

CONCLUSION

The study investigates the impact of the Kut Dam (regulator Dam) on the water quality upstream, directly downstream and 200 km after the dam downstream. Three monitoring stations, used by the long term program of the Ministry of Health and Environment in Iraq, were selected (T27, T28 and T30). Three main parameters have been chosen as an index for water quality (TDS, TH and So4). The results showed no main effects for the regulator dam (Kut Dam) on the Tigris water quality; the dam plays a positive role for maintaining the level of water upstream the dam for irrigation uses and the e-flow downstream by regulating the effluent from the dam. The water quality was at a critical level at station T30 using the TDS as an index; therefore the study recommended for the authority to monitor and maintain the flow rate downstream the T30 within the e-flow limit. Reduces the flow below the e-flow it can cause a serious impact on the life of many southern Iraqi cities. The shortage in flow rate downstream of the Tigris and Euphrates rivers is the main reason for this degradation beside the pollutants discharges from many activities to the river without treatment, therefore providing the e-flow is essential.

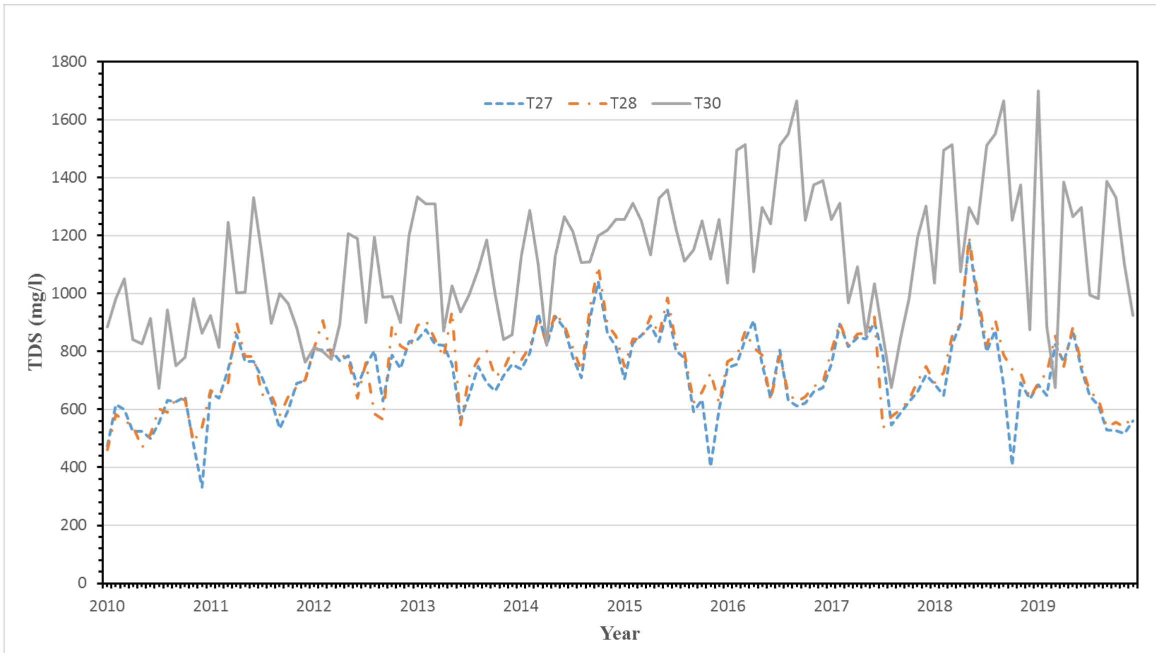

Figure 8. The concentrations of the TDS shown in the three monitoring stations (T27, T28 and T30) along the Tigris river for the years from 2010 to 2019.

REFERENCES

Abdullah, M., Al-Ansari, N., and Laue, J. (2019). "Water Resources Projects in Iraq: Barrages: Water Resources Projects in Iraq: Barrages". *Earth Sciences and Geotechnical Engineering,* 9(*4*), pp.153-167.

Al-Ansari, N. (2013). "Management of water resources in Iraq: perspectives and prognoses". *Engineering*, 5(6), 667-684.

Jackson, Donald C., and Guthrie Brown, J. (2020). "Dam" Encyclopædia Britannica, https://www.britannica.com/technology/dam-engineering.

Declaration, B. (2007, September). The Brisbane Declaration: environmental flows are essential for freshwater ecosystem health and human well-being. In *10th International River Symposium*, Brisbane, Australia (pp. 3-6).

Hayes, D. S., Brändle, J. M., Seliger, C., Zeiringer, B., Ferreira, T., and Schmutz, S. (2018). "Advancing towards functional environmental flows for temperate floodplain rivers". *Science of the Total Environment*, 633, pp.1089-1104.

Karakoyun, Y., Dönmez, A. H., and Yumurtacı, Z. (2018). "Comparison of environmental flow assessment methods with a case study on a runoff river–type hydropower plant using hydrological methods". *Environmental monitoring and assessment*, 190(12), p.722.

Ministry of Health and Environment (MoH&E). (2010). *Water quality monitoring atlas* MoH&E, Iraq.

Overton, I. C., Smith, D. M., Dalton, J., Barchiesi, S., Acreman, M. C., Stromberg, J. C., and Kirby, J. M. (2014). "Implementing environmental flows in integrated water resources management and the ecosystem approach". *Hydrological Sciences Journal*, 59(3-4), pp.860-877.

Richter, Brian D., and Thomas, Gregory A. (2007). "Restoring environmental flows by modifying dam operations." *Ecology and society* 12.1.

Experimental and Numerical Study of Salt Transport under Unstable Conditions

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ABSTRACT

The rate of salt transport from an unstable source into the underlying porous media containing fresh or brackish water was determined by experiments and then verified through numerical solutions. The rate of mass transport was determined through four experiments, conducted over 9.0–14 days, using a rectangular plexiglass model (1.82, 0.61, and 0.61 m). A finite mass of “source” solution with a saltwater concentration of 36 kg/m^3 was placed over a saturated porous media containing freshwater or brackish water with salt concentrations of 9.0, 18, and 27 kg/m^3. A three-dimensional numerical model SEAWAT was used to determine the rate of mass transport under the experimental conditions. The numerical solutions showed a good match with the experimentally determined rates of salt mass transfer. The apparent dispersion coefficient values used in the numerical model ranged from 4.05×10^{-09} to 1.26×10^{-08} m^2/s. The analysis showed that there is a direct linear correlation between the apparent dispersion coefficient and the difference between the initial source concentration and porous media concentration. The percentage salt mass transported from the source into the porous media after 1 day was found to be 42.9% when the porous media contained freshwater, and 27.0%, 13.6%, and 3.9% when the porous media saltwater concentrations were 9.0, 18, and 27 g/L, respectively. These results show that a significant amount of salt may transfer from the finite unstable source, such as an estuary, into the underlying aquifer under some conditions, and this knowledge could be important in maintaining the estuary salt balance.

INTRODUCTION

There are many real-world situations when the denser or heavier saltwater overlies the lighter freshwater. Some examples of these situations are; saline contamination from saline disposal basins into underlying freshwater (Simmons and Narayan 1997). Several researchers have also observed the phenomenon of downward salt transport into underlying freshwater bodies in various lagoons, lakes, and estuaries (Fujinawa et al. 2008; Kirkegaard et al. 2011; Viezzoli et al. 2010; Simmons and Narayan 1998; Smith and Turner 2001; Pandit et al. 2011). In unstable flows, the downward movement of the heavier fluid establishes additional hydraulic gradients and the resulting fluid movement due to these gradients is termed as “free” convection (Gebhart et al. 1988). Salt transport in systems with free convection occurs in the form of “fingers.” When both forced and free convection are present, the resulting system is termed mixed convective flow (Gebhart et al. 1988). In forced convection systems, the transport of salt is primarily due to either dispersion or convection or both. However, in free or mixed convective systems, an additional transport mechanism, termed “gravitational: transport (Bachmat and Elrick 1970; Schincariol and Schwartz 1990; Simmons et al. 2002; Mamoua et al. 2017) occurs because of the formation of fingers.

Accurate numerical simulation of salt transport from the unstable source into the underlying porous media requires selecting appropriate values of the diffusion coefficient. Schincariol and Schwartz (1990), among others have pointed out that additional studies, both theoretical and experimental, are needed to determine the values of dispersion used in unstable conditions. The values for diffusion coefficients, D, electrolytes in water are generally cited in the range of $1.0*10^{-9}$ to $2.0*10^{-9}$ m^2/s at 25 degrees Celsius Fetter (1999). However, the coefficients are temperature dependent and maybe as much as 50% smaller at 5 degrees Celsius (Freeze and Cherry 1979; Flury and Gimmy 2002). For chloride in water at 25 degrees Celsius, the molecular diffusion coefficient is $2.0*10^{-9}$ m^2/s (Fetter 1999). The value of the diffusion coefficient, D, used by various researchers in various numerical models simulating used as a benchmark problem for stable and unstable density-dependent flow transport is highly variable. For example, the diffusion coefficient values used in Henry's problem which depicts stable salt transport are $D_m = 6.6 * 10^{-6}$ m^2/s (Henry 1964; Voss and Souza 1987); $D_m = 1.886 * 10^{-5}$ m^2/s (Simpson and Clement 2003); $D_m = 2.31 * 10^{-5}$ m^2/s (Pinder and Cooper 1970). The diffusion coefficient values used in the Elder problem which depicts unstable salt transport, are $D_m = 3.565 * 10^{-6}$ m^2/s (Voss and Souza 1987; Frolkovic and Schepper 2001; Prasad and Simmons 2002; Ashtiani et al. 2014). Pandit et at. (2020) found that the apparent diffusion coefficient values used in the unstable finite source above the porous media fully saturated with fresh water are a function of initial source concentration and source height, i.e., the initial finite mass of the source.

There are three main transport mechanisms that occur under unstable flow conditions have been investigated by several researchers via laboratory (physical model) and/or numerical experiments a) the transport of saltwater from the overlying salt layer to the underlying porous media (e.g., Wooding 1959; Bachmat and Elrick 1970; Wood et al. 2004; Mamoua et al. 2016; Mamoua et al. 2018; Pandit et al. 2020), b) the transport of the saltwater through the porous media (Schincariol and Schwartz 1990; Webster et al. 1996; Simmons et al. 2002; Post and Simmons 2010; Johannsen et al. 2006; Kneafsey and Pruess 2010; Goswami et al. 2012; Hejaz and Azaiez 2013; Tailor 2016; Mamoua et al. 2017, and c) the upward transport of freshwater from the underlying porous media into the source as a result of displacement by the denser saltwater (Webster et al. 1996; Simmons et. al. 1999). The purpose of this study is to investigate the rate at which mass transfers from the finite unstable source to the porous media.

In physical model studies, heavier fluids containing salt were placed on top of a column or tank filled with saturated porous media containing freshwater. Some of these experiments were continuous injection experiments in which the salt concentration was kept constant (Webster et al. 1996; Simmons et al. 2002; Fujinawa et al. 2009; Mamoua et al. 2016), while others were finite mass source experiments in which the overlying, denser fluid, has a finite mass (Wooding 1959; Bachmat and Elrick 1970; Wood et al. 2004; Johannsen et al. 2006; Pandit et al. 2020). To the best of our knowledge, there have been two studies conducted (Bachmat and Elrick 1970; Mamoua et al. 2017; Pandit et al. 2020) that studied the mass transport of the unstable finite source into the porous media with time by measuring source depletion curves (SDCs). A source depletion curve is defined as a graph of the source concentration C_t versus time. In both these studies, the porous media used in the experiments contained freshwater. Pandit et al. (2020) found that a numerical model was able to predict the measured source depletion curves for all values of initial source concentration and source height. They also found the value of the apparent diffusion coefficient, used in the numerical model, varied linearly with both the initial source concentration and source height. Pandit et al. (2020) used the term apparent diffusion coefficient since it accommodated both gravitational, due to the unstable nature of the source, and also the diffusive transport. Although it is expected that the salt concentration of the groundwater in the porous media would affect the mass transfer of salt from the unstable source into the underlying porous media, none of the papers mentioned above, conducted experiments with porous media containing brackish water or determined the rate of mass transfer from an unstable saltwater source into the underlying porous media when the porous media contained brackish water.

Objectives: The purpose of this paper is to 1) to conduct experiments with the porous media, under the unstable finite source, containing brackish water at different concentrations, and to measure the resulting SDCs, 2) to determine the effect of the difference in the source and porous media salt concentrations on salt mass transfer, and 3) to determine relationships between the apparent diffusion coefficient, used in the numerical model with various parameters.

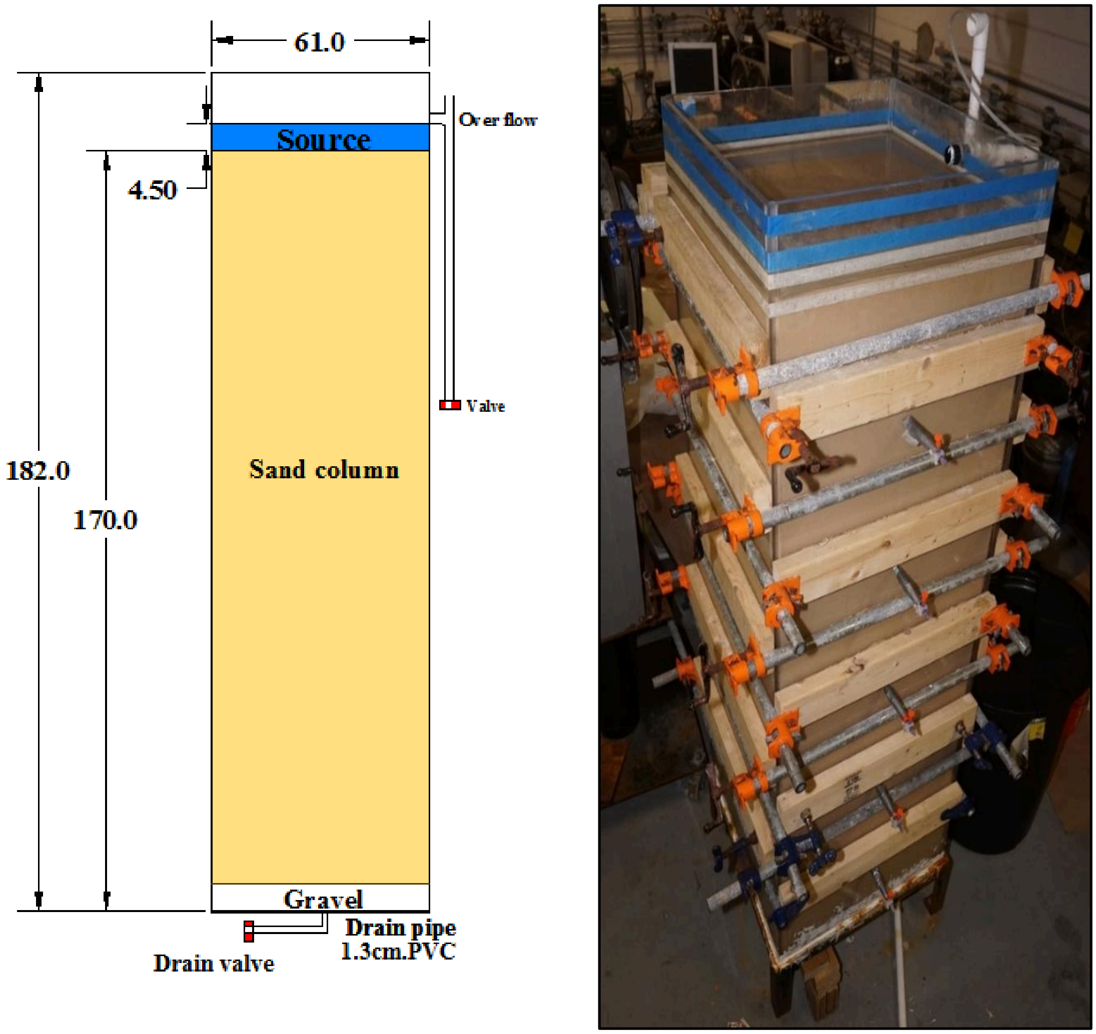

Figure 1. A schematic diagram of the physical model

METHODS

Description of Physical Model and Experimental Procedure

The 1-cm thick plexiglass model has a height of 182 cm and a base of 61cm by 61 cm, as shown in (Figure 1). The model consists of a source area at the top. The sand used in this study was 40F from Standard Sand and Silica Company. The hydraulic conductivity of the sand was determined to be 7.6 m/d using constant head tests. The sand was placed inside the sand column in three steps. First, sand was filled up to a depth of 1.695 m in increments of 25 cm. Each increment was fully saturated with water before adding the next increment of sand. Saturation was assured by allowing water to stand on top of the sand for a period of one day and observing the water level. The sand was considered saturated if the water level did not drop. This procedure was repeated after adding every 25 cm of sand increment and the entire process took approximately one week. Second, water was passed through the sand column until the inflow was equal to outflow.

Water was allowed to flush through the sand column for a period of six hours after inflow became equal to outflow to ensure that there were no structural changes in the sand column as a result of the fluid passing through the porous medium and to remove any entrapped air bubbles. Third, the drainage valve was closed, and the source area was filled with fresh water to the desired level. The water was allowed to sit in the sand column for a period of one week to ensure that the water loss was only due to evaporation and that the sand column was fully saturated and devoid of any air pockets. The source area was covered by a thin plastic sheet to minimize evaporation losses for all experiments. Salinity and temperature measurements were taken using a YSI salinity meter, which measured conductivity and converted it into salinity. Experiments were started by adding saline water solutions (sodium chloride) to the source area to the desired depth, (4.5 cm) and this procedure took less than one minute. Source salinity measurements were taken by inserting the salinity meter into the source; no samples had to be extracted. Salinity measurements at the source were taken after 1, 5, 15, 60, 120, 240, and 360 minutes in the first six hours, then after every six hours until the end of day 2 (48 hours), then every 12 hours till the end of day five (120 hours), and then every 24 hours until the end of the experiment Table 1.

Table 1. Sampling Schedule at Source

Duration day	At source
0 - 0.25	1,5,15,30,60,120, 240, and 360 minutes
0.25 - 2	every 6.0 hr
2 - 5	every 12 hr
5 - End	every 24 hr

DESCRIPTION OF EXPERIMENTS

Four experiments, having durations (t_d) ranged between 9 days and 14 days, were directed to determine the rate of salt mass transport from an unstable finite source to underlying porous media contained brackish water with time using variety of initial porous media concentrations while the source concentration was kept constant. Experiments 1 to 4 were conducted by keeping the initial source concentration (C_{S0}) of 36 g/l and the source height equal to 4.5 cm while changing the