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# Impact of brackish groundwater and treated wastewater on soil chemical and mineralogical properties

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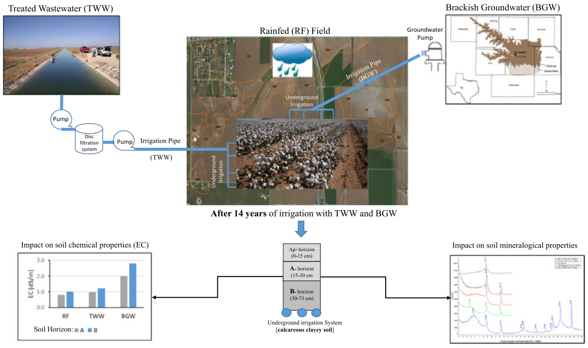
## HIGHLIGHTS

- Treated wastewater has a better quality than the brackish groundwater of the local aqufer
- Calcareous clayey soil showed no salinity or sodicity problems after long-term (15 years) irrigation with non-freshwater
- Clay mineralogy in this soil type is fairly stable and plays a major role in the fertility of the soil
- Treated wastewater and brackish groundwater are viable substitutes for freshwater irrigation in semi-arid and arid regions

## GRAPHICAL ABSTRACT



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## ABSTRACT

The long-term effect of using treated wastewater is not clearly defined: some researchers argue that it is better than freshwater for the soil health; others disapprove, claiming that irrigation with unconventional water resources causes soil degradation. This study assesses the impact of irrigation with non-traditional water on the chemical and mineralogical properties of a calcareous clayey soil from West Texas. The exponential rise in population and the realities of climate change contribute to the global increase in freshwater scarcity: non-conventional water sources, such as treated wastewater (TWW) and brackish groundwater (BGW), offer potentially attractive alternative water resources for irrigated agriculture. For this research, the differences between TWW and BGW were addressed by collecting and analyzing water samples for salt and nutrient content. Soil samples from three horizons (Ap, A, and B) were obtained from three different fields: Rainfed (RF), BGW irrigated, and TWW irrigated. Soil was analyzed for texture, salinity, sodicity, and carbon content. Clay mineralogy of the three different fields was analyzed using the B-horizons. The outcomes from the analysis showed that the BGW from the Lipan aquifer has higher salinity and is harder compared to TWW. Although the exchangeable sodium percentage (ESP), sodium adsorption ratio (SAR), and electroconductivity (EC) increased marginally compared to the control soil (RF), the soils were in good health, all the values of interest ($SAR < 13$, $ESP < 15$, $pH < 8.5$, and $EC < 4$) were low, indicating no sodicity or salinity problems. Smectite, illite, and kaolinite were

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identified in the three B-horizon samples using bulk X-ray diffraction (XRD). Overall, no major changes were observed in the soil. Thus, TWW and BGW are viable replacements for freshwater irrigation in arid and semi-arid regions.

## 1. Introduction

Water scarcity is one of the major threats facing humanity as competition for resources increases with population growth. As various sectors compete to supply the fundamental human needs, demand for water has increased. Globally, the agriculture sector consumes the greatest amount of water, nearly 70% compared to 10% for domestic use and 20% for industry (Food and Agriculture Organization (FAO), 2010). The impacts of climate change add to the burden of the deficit between demand and supply for water. In 2030, with a "business as usual model", the projected global water gap (shortage) will be 40% and one third of the population will live in water stressed regions (WEF-WRG, 2012). The projected increase in frequency of drought conditions (Intergovernmental Panel on Climate Change (IPCC), 2013) and the demand for freshwater (FW), will surely lead to rising prices, spurring the use of non-traditional water.

Wastewater (WW) is an untapped resource in a world where FW depletion rates are unprecedented. Yearly, 40 million ha (400,000 $km^2$) or 15% of all irrigated lands can be irrigated with the 330 $km^3$ (267.5 million acre-feet/year) municipal wastewater produced around the world (Mateo-Sagasta et al., 2015). Treated wastewater (TWW) has gained attention globally, especially in the agriculture sector. TWW is a highly valued resource in the face of this projected water shortage. TWW could be used to alleviate or prevent further exhaustion of the natural FW resources by helping to overcome shortages and mitigating the severe impact of drought on the underlying aquifer. Irrigation with TWW has been successfully applied in several countries: it contains nutrients that can replace fertilizers and soil conditioners (Jimenez-Cisneros, 1995; Qadir et al., 2007). In a study on the impact of TWW on grape yields and quality, the drip irrigation with treated municipal water increased grape production with no adverse effect on the soil (Mendoza-Espinosa et al., 2008). TWW is therefore a means to conserve resources, and potentially reduce fertilizer use.

Conversely, some researchers rejected replacing FW with TWW due to the risk of degradation of the soil's physical properties as a result of increased salinity (Klay et al., 2010; Hasan et al., 2014). Qian and Mecham studied the effects of long term application of TWW on golf courses, which resulted in increased soil salinity due to the higher salinity of the reclaimed water (Qian and Mecham, 2005). The most common problem in arable land is soil salinization, particularly in arid and semiarid areas where precipitation is insufficient to prevent salt accumulation that leads to reduced yield (Francois and Maas, 1994; Munns, 2002). However, in semiarid regions with an annual precipitation >20 in (508 mm), the rain is sufficient to prevent long-term salt accumulation in the root zone when irrigated with secondary TWW (Lado et al., 2012).

Public health and safety are among the major issues when applying marginal quality water in countries with unenforced regulations. In developed countries, such as the United States, the use of TWW is regulated through governmental (US Environmental Protection Agency) and local agencies. The Texas Commission on Environmental Quality (TCEQ) regulates places constraints on the use of treated wastewater, classified into either Type I or Type II (Table 1). The end use of the categories differs according to the quality of each type. Type I can be applied where public contact is likely; Type II is restricted to areas where human contact is unlikely, thereby ensuring that health risks are minimal to nonexistent.

Brackish groundwater (BGW) contains from 1000 to 10,000 milligrams per liter (mg/l) of dissolved solids. The classification of water based on TDS is: Freshwater < 1000 mg/l, Slightly Saline (Brackish) 1000–3000 mg/l, Moderately Saline (Brackish) 3000–10,000 mg/l, Highly Saline > 10,000 mg/l, Seawater ≈ 35,000 mg/l, and Brine > 100,000 mg/l (Stanton et al., 2017). Desalination methods are expensive and produce highly saline concentrate (brine). BGW has been successfully used for irrigation and proved helpful for crop production. An 8-year study of field experiments using BGW to irrigate winter wheat and maize established that slightly brackish water was the most beneficial irrigation scheme, although freshwater (FW) is needed for leaching accumulated salt if precipitation events are rare (Ma et al., 2008). Some researchers have shown the promising potential of brackish water irrigation during the dry season and in climatic conditions with an average annual rainfall of 15 in–24 in (381 mm–609.6 mm) in which accumulated salt is leached with the rain (Hamdy et al., 2005; Kiani and Mirlatifi, 2012).

The main issue with BGW is salt build-up in the soil: it can be harmful for sensitive crops (Rengasamy, 2010; Ramos et al., 2012; Wang et al., 2015). However, BGW can be used and salt accumulation avoided with a proper irrigation schedule. The main crop in the area of interest is cotton, a highly salt tolerant crop with a soil of 7.7 deci-Siemens per meter (dS/m) EC threshold (Bernstein and Ford, 1959). Cotton is also the most valuable crop in Texas, which leads the US with sales of $1.6 billion in cotton and cottonseed (United States Department of Agriculture (USDA), 2015).

The state of Texas has a massive BGW reserve, found in nearly all its 30 aquifers. According to a study done by LBG-Guyton Associates in 2003, for the Texas Water Distribution Board (TWDB), the estimated amount of BGW is >2.7 billion acre-feet (ac ft) (3330.396 $km^3$), particularly widespread within the major and minor aquifers (LBG-Guyton Associates, 2003).

Several components may influence soil function, but its texture and mineralogy dominate the reaction to unusual additions, such as irrigating with TWW or BGW. The impact of marginal water quality on soils differs with the clay content and mineralogy, particle surface charge characteristics, pH, and organic matter content (Huang et al., 2012). Researchers argue that sodic conditions are more likely to occur in soils with a higher clay content (Leal et al., 2009; Chen et al., 2013). Also,

**Table 1**
Water quality parameters for using reclaimed water adapted from 30 Tex. Admin. Code § 210.33–210.34.

| | Type I | Type II |
|---|---|---|
| Quality standards (30 day average) | • $BOD_5/CBOD_5 = 5$ mg/l<br>• Turbidity = 3 NTU<br>• Fecal coliform < 20 or <75 CFU/100 ml (single grab) | • $BOD_5 = 20$ mg/l<br>• $CBOD_5 = 15$ mg/l<br>• Fecal coliform < 200 or <800 CFU/100 ml (single grab)<br>• For a pond system: $BOD_5 = 30$ mg/l, fecal coliform < 20 or <800 CFU/100 ml (single grab) |
| Sampling/analysis frequency | Twice per week | Once per week |