Salinity in Drinking Water on Kansas State University Manhattan Campus

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<u>Abstract</u>

This study investigates the salinity concentration (µS/cm) of drinking water across Kansas State University's (KSU) Main Campus in Manhattan, KS , aiming to (1) assess health risks of drinking water with high salinity, (2) identify patterns between salinity and distance from the water distribution system's entry point, (3) find correlations between water quality parameters, and (4) identify possible factors responsible for change in salinity concentration along the distribution system. Utilizing a YSI MultiLab 4010-2W ion selective probe (ISE), water samples were analyzed in terms of electromagnetic conductivity of salt ions. The results of this study show a negative regression between salinity and distance from entry point. After three trial periods, KSU's water distribution system's entry point and the two closest buildings: Jardine and Throckmorton had the highest average salinity at averages of 446, 450 and 464 µS/cm respectively. Trends show that salinity decreases as distance from the entry point increases, which could be due to the deposition of salts onto pipes the water is transporting through. Causes of increased salinity and TDS could be due to degrading pipe from aging materials, as well as local salinity addition through road salting and other industrial practices. Other water parameters related to salinity were collected to detect correlation including pH, temperature at analysis, total dissolved solids (TDS), and oxidation-reduction potential (ORP). Using the same instrument, data collected was turned into a Pearson correlation figure. Results identify salinity correlations to pH at –0.46, to temperature at analysis at 0.78, TDS at .98 and ORP at .40 correlation values which are supported by previous studies. Results show that KSU's salinity concentration is significantly smaller than EPA standards (g/L), meaning KSU and the city of Manhattan, KS complies with EPA policy and does not require significant remediation. No health risks are associated with drinking water with salinity concentrations at this level, meaning KSU does not cause any health distress to its population of students.

1. Introduction

Freshwater resources are important for daily life, agriculture, industry, and the sustainability of the environment. In recent years, substantial environmental changes, such as alterations in precipitation patterns and increased temperature due to climate change, combined with intensified human activities such as extensive use of road salts, agricultural runoff containing fertilizers and pesticides, industrial wastewater discharges, urbanization increasing impervious surfaces, and mining operations have significantly increased freshwater salinity across the United States, especially in the Midwest region (Kaushal et al., 2018; Ombadi & Varadharajan, 2022). Salinity, predominantly measured by concentrations of dissolved salts such as chloride and sodium, thus critically influences water quality and its suitability for multiple uses (Kaushal et al., 2018). Chloride concentrations in urban streams have increased substantially since the 1960s, with the Midwest experiencing significant rises because of the road salt application and agricultural activities (USGS, 2011). Elevated salinity levels negatively impact ecosystem health, reduce agricultural productivity by damaging crops and soils, accelerate corrosion of infrastructure, and pose significant health risks, including hypertension and cardiovascular issues, to human populations (Herbert et al., 2015; Kelly et al., 2019). The U.S spends approximately $5 billion annually to repair infrastructure damage caused by road salt erosion (EPA, 2020).

1.1 Overview of Influencing Factors

Natural Factors

Freshwater salinity results from both natural and human factors. Naturally occurring salinity arises primarily from geological processes such as mineral dissolution from rock and soil formations, particularly in regions rich in salt-bearing minerals (Cañedo-Argüelles et al., 2013). For example, in parts of Kansas, baseline chloride concentrations in groundwater can naturally exceed 200 mg/L due to underlying geology (USGS, 2017). Climatic conditions also are part of an important role; arid climates with high evaporation rates tend to concentrate salts in water bodies, whereas regions with frequent precipitation can dilute salt concentrations, demonstrating how variability in climate directly influences freshwater salinity (Herbert et al., 2015). During droughts in Kansas, total dissolved solids (TDS) levels in some reservoirs have been observed to double, while floods can mobilize accumulated salts from urban and agricultural landscapes, temporarily elevating conductivity and chloride concentrations (Ombadi & Varadharajan, 2022).

Human Factors

Human-induced factors significantly amplify freshwater salinity. Agricultural practices, including the use of fertilizers and pesticides, introduce soluble salts into soils that can leach into nearby freshwater systems. Irrigation practices, especially in arid regions, can exacerbate this by mobilizing and concentrating these salts in the soil and groundwater (Pulido-Bosch et al., 2018).

Increase in agriculture has led to land use changes, such as wetland drainage and deforestation, further reducing the landscape's natural capacity to filter salts. Over 50% of wetlands in the U.S. have been lost, despite their demonstrated ability to mitigate chloride pollution. For instance, constructed wetlands planted with ornamental species have been shown to remove approximately 32% of chloride from domestic wastewater (Marín-Muníz et al., 2023). Deforestation increases runoff and soil erosion, potentially leading to higher chloride loading rates compared to vegetated watersheds.

The Midwest United States faces important challenges due to intensive agricultural activities, extensive winter road salt application, and rapid urbanization (Kaushal et al., 2018). In heavily farmed regions, agricultural runoff contributes to increased groundwater salinity, with studies indicating significant impacts on water quality due to the leaching of salts from the soil into the groundwater (Pulido-Bosch et al., 2018) . Agricultural runoff contributes to increased groundwater salinity in heavily farmed regions. Similarly, the widespread use of road salt—primarily sodium chloride—for winter ice control contributes significantly to salinization. The U.S. applies approximately 20 million tons of road salt annually (Penn State, 2023). This salt often runs off into nearby water bodies, elevating chloride concentrations in urban rivers during winter months, with some areas surpassing the EPA's drinking water limit of 3 mg/L (EPA, 2024). Urbanization further intensifies the issue by increasing impervious surfaces—such as roads and parking lots—by over 80% in the past four decades, which reduces infiltration and triples surface runoff, carrying accumulated salts into freshwater systems (Ombadi & Varadharajan, 2022).

Industrial activities such as mining operations are another significant contributor. These activities disturb geological formations, mobilizing mineral salts and generating saline wastewater, which considerably elevates salinity levels in adjacent water bodies (Li et al., 2014). In many industrial zones, surface waters exhibit sodium and chloride levels two to five times higher than in nearby rural areas (Kaushal et al., 2018). Additionally, old infrastructure such as water distribution systems contributes to salinity. Corrosion of metal pipes can release iron, copper, lead, and other trace metals into tap water while also altering pH and facilitating the accumulation of salts in standing water. Pipe corrosion is often exacerbated by high chloride concentrations and low alkalinity, forming a feedback loop that worsens water quality and infrastructure decay (Nguyen et al., 2011).

Knowing these interconnected natural and human factors and their mechanisms is for developing targeted and effective water quality management strategies. Salinity in tap water does not act in isolation; it correlates with other key water quality indicators such as pH, Temperature, Total Dissolved Solids (TDS), and oxidation-reduction potential (ORP). Understanding these relationships is important for identifying patterns of salinity fluctuations and their potential long-term effects on water quality.

K-State

At Kansas State University's main campus drinking water is supplied from surface water sources managed by the City of Manhattan, KS and delivered through an extensive municipal and internal water distribution system. While treated to meet and exceed federal safety standards, variations in salinity levels can still occur due to both external and internal factors. The campus includes a range of buildings—academic halls, laboratories, dormitories, and athletic facilities—

which are connected by a pipe infrastructure that may influence the chemical characteristics of tap water. Internal plumbing materials, pipe corrosion, and water stagnation can all contribute to localized increases in salinity, particularly in buildings with low water turnover or older systems (Nguyen et al., 2011). Additionally, external factors such as road salt application, agricultural runoff from nearby lands, and changing precipitation patterns in the region may affect the source water itself. The Flint Hills region, where the campus is located, experiences both seasonal droughts and urban development pressures, which can influence water quality in surrounding surface water bodies. These site-specific variables make Kansas State University a representative case study for assessing how broader salinity issues manifest at the institutional scale and what their implications may be for students, faculty, and infrastructure on campus.

Objectives

With the increasing salinization of freshwater resources and its correlation with water quality, infrastructure integrity, and public health, it is important to investigate salinity trends at the local scale more. This study focuses on tap water at Kansas State University's main campus, where both environmental and infrastructural factors may influence salinity fluctuations. The objectives of this study are to (1) analyze the potential health and infrastructure impacts of water salinity, (2) test salinity levels at different water sources across campus , (3) identify possible causes of salinity variations in drinking water—including environmental inputs and internal distribution factors—and (4) recommend strategies to improve the safety and quality of the campus water supply.

1.2 Research Questions

This study investigates salinity in campus drinking water by addressing important research questions through targeted hypotheses. First, we explore what health risks are associated with high salinity in drinking water. This can be known by analyzing the potential biological and infrastructure impacts, as elevated salinity can contribute to health concerns and long-term pipe degradation. Second, we examine how salinity concentration varies across K-State main campus. We hypothesize that salinity levels increase with distance from the main water entry point due to pipe interactions. This will be tested using linear regression to analyze trends and box plots to detect significant differences between buildings. Third, we ask how salinity correlates with other water quality parameters such as pH, temperature, total dissolved solids (TDS), and oxidation-reduction potential (ORP). We hypothesize that pH will increase with salinity, temperature will rise as salinity increases, ORP will decrease with higher salinity, and TDS will have a direct positive correlation with salinity. These hypotheses will be examined using Pearson correlation analysis to assess the strength and direction of these relationships. Fourth, we aim to identify the main sources of increased salinity in K-State's drinking water. Finally, we explore what steps can be implemented to manage and reduce high salinity levels in tap water on campus. Based on the outcomes of the salinity mapping and correlation analyses, this study will recommend interventions that can help to improve overall drinking water quality and mitigate long-term risks.

2. Literature Review (everyone)

2.1 Importance of Studying Salinity in Tap Water

Salinity in tap water is important because it affects both the environment and human health. Climate change, industrial waste, road salt, water softening treatments, and farming practices all contribute to increased salinity levels. Elevated tap water salinity can corrode plumbing, degrade water quality, and lead to health concerns. Studying these effects can help inform better water management and infrastructure planning.

2.2 Overview of Influencing Factors

Many factors affect tap water salinity. Natural sources like rising sea levels and underground minerals introduce salt into freshwater. Human activities, including industrial waste disposal, excessive fertilizer use, further increase salinity. Seasonal changes also have an impact, road salt in winter and droughts in summer can change groundwater salinity. These factors interact and influence water chemistry, affecting how safe and usable it is.

2.3 Defining Salinity and Key Parameters in Drinking Water (Richard)

Salinity in drinking water refers to the concentration of dissolved inorganic salts, with sodium and chloride often being the dominant ions, though calcium, magnesium, and sulfate also contribute significantly (Appelo & Postma Hem, 1985). Salinity can be measured as a concentration, typically in milligrams per liter (mg/L) representing the total dissolved salts (Richards, 1954), or in terms of electrical conductivity (EC) in micro siemens per centimeter (µS/cm), which can be indicative of the ionic strength and particularly correlated with chloride content (Fetter, 2000). The assessment of salinity involves several key parameters. Drinking water assessment also involves total dissolved solids (TDS), electrical conductivity (EC), pH, and temperature at assessment. Total Dissolved Solids (TDS), measured in mg/L, quantifies the total amount of dissolved substances (Richards, 1954). Electrical conductivity (EC), expressed in µS/cm, provides a rapid measure of the ionic strength of the water, directly correlating with the concentration of dissolved salts (Fetter, 2000). Exceeding recommended TDS levels (e.g., 500mg/L as suggested by WHO, 2017) can impact the palatability of drinking water due to taste issues.

Beyond overall salt concentration, the specific ionic composition is also crucial. The Sodium Adsorption Ratio (SAR) is a significant parameter, particularly when considering the source water's potential impact on soil if used for irrigation. SAR reflects the relative abundance of sodium compared to calcium and magnesium (Ayers & Westcot, 1985) and has implications for drinking water. SAR can have health effects on individuals on sodium restricted diets due to hypertension. Understanding these parameters provides a comprehensive view of the salinity characteristics of drinking water, moving beyond just the total salt content to include factors that influence taste, potential for corrosion, and suitability for other uses.

2.4a Sources of Salinity in Tap Water - Global (Eliana)

Salinity in tap water within the United States arises from both natural and human induced sources, reflecting broader global patterns. Naturally occurring salinity commonly results from geological interactions as groundwater moves through soil and rock layers, dissolving minerals such as sodium chloride (common salt), gypsum, and magnesium sulfate, thereby increasing overall salt concentrations (U.S. Geological Survey [USGS], n.d.). Salinity levels are elevated in regions like the Southwest as minerals are naturally dissolved from sedimentary rocks into groundwater. Human activities further exacerbate these problems across the nation through agricultural runoff and extensive use of road salts. Agricultural runoff containing potassium-based fertilizers significantly contributes to higher chloride levels, especially prevalent in farming-intensive regions such as the Midwest and California's Central Valley (Ecosoft, 2022). The extensive use of road salts for winter road de-icing in northern and midwestern states, such as Minnesota, Wisconsin, and Illinois, also introduces substantial amounts of chloride into local waterways and groundwater. Industrial processes, including mining operations and chemical manufacturing, contribute additional saline discharges into waterways, complicating water management strategies in various states (USGS, n.d.). Also, in coastal areas such as California, Florida, and Texas, seawater intrusion significantly elevates groundwater salinity due to extensive groundwater pumping that draws ocean water into freshwater aquifers (USGS, n.d.).

2.4b Sources of Salinity in Tap Water - Local (Katie)

In this study, we will investigate local factors like geological features, land use, weather, and the water distribution system that could affect salinity in drinking water in Manhattan, KS.

In western Kansas, irrigation from shallow alluvium groundwater has increased salinity because of the accumulation of salts on the surface left by evaporated water (Kansas Geological Survey, 2025). Central Kansas contains several oil field brines which have been pumped to the surface with the oil and later kept in storage at the site or by injecting brine into designated disposal wells (Schoewe, 1943). Manhattan, KS has a coal gas plant located downstream of Tuttle Creek Reservoir which could introduce pollutants into the surrounding area, but Manhattan's drinking water is pumped from ground water wells.

Manhattan, KS receives its water from the Big Blue River which runs from central Nebraska into the Missouri river by passing through Kansas. The Big Blue River is partially fed by alluvial aquifers. Past data collection on alluvial aquifers typically shows salinity concentration below EPA Salinity standards at 1,000 mg/L, but concentration may increase when local consolidated rocks in the aquifer, causing total dissolved solids to exceed 9,000 mg/L and increase water hardness (Baker & Hansen, 1987).

Regarding land use in Kansas, the Big Blue watershed land use is about 27% agriculture with 288 Confined Animal Feeding Operations (CAFOs) which would contribute poor water quality if management plans were poorly designed to prevent pollutants from entering the Big Blue River (Douglas-Mankin & Sheshukov, 2012). Agricultural practices can increase ground water salinity through leaching salts in unsaturated soil into groundwater and saltwater intrusion from pumping water lowering the water table (Suarez, 1989). CAFOs increase surface water salinity through high potassium and sodium content in manure and are a main nutrient stressor in freshwater (EPA, 2004). Seepage rates of animal waste into groundwater are still uncertain.

Across the United States, flooding has been shown to significantly decrease salinity primarily due to dilution, but this is dependent on surrounding conditions like aridity and urbanization (Ombadi & Varadharajan, 2022). According to the National Weather Service, Kansas usually floods after significant snowmelt events or heavy storms which usually occur between May and June (Kansas Adjutant General's Department, n.d.; US Department of Commerce, n.d.). The beginning of a flood can be diluted especially in urban environments due to increased impervious surfaces, but concentration can vary widely as the water recedes. In Manhattan, KS there are significant floods every few years between April and July (NOAA, 2025).

In the winter of 2023, Kansas roads were salted with 82,000 tons of road salt to ensure safety, but this increases salinity in urban waterways to about 20 times higher than EPA standards at 230mg/L (Hill, 2024).

Campus Water Distribution System

After the Manhattan, KS Water Treatment Facility treats water from wells along the Big Blue River, the water is transported through pipes around the Kansas State University campus. On the Kansas State University Manhattan Campus, approximately 62% of the pipes in the water distribution system are presumed to be made of cast iron which rust and corrode easily, leading to leaks and rust encrustation (BG Consultants, 2013). An increase in ions contributing to salinity or total dissolved solids can increase corrosion in pipes, leading to metals leaching into the water or damaging a water system (Water Resources Mission Area, 2019). Manhattan's water is treated with chloramines, mostly likely monochloramines (City of Manhattan Kansas, n.d.; EPA, 2009). Treating water with monochloramines, instead of free chlorine, can slightly reduce the amount of iron released from cast iron pipes (Hu et al., 2018).

<u>2.5 Effects of Salinity on Health (Rachel)</u>

The USEPA daily requirement of sodium in adults and children 10 and over is 5 g/day, this is because sodium is an essential nutrient that is responsible for many bodily functions. While sodium in appropriate amounts is essential for life, there are health risks associated with consuming excess sodium through daily food and water. The World Health Organization (WHO) has reported cases of consuming drinking water with sodium concentrations higher than 3 g/L have led to hospitalizations. Generally, sodium intake is flexible due to the kidney's ability to filter and excrete excess sodium. However, when humans are exposed to excess sodium over time, health effects like hypertension and heart disease are a risk (EPA, 2003)

Short-term effects

Short-term effects caused by excess sodium consumption include dehydration, painful inflammation, ulceration in the gastrointestinal tract, and congestion of internal arteries. In extreme cases, a sodium overdose could cause convulsions, confusion and even comatose. Sodium intake tracking is even more important with children, as their kidneys are not flexible enough to excrete all excess. Instances where babies have accidentally been fed formula made with water with high salinity drinking water resulted in 6 deaths out of 14 infants due to high blood sodium concentration (EPA, 2003).

Long-term effects

Although it cannot be solely linked, high blood pressure could be linked to lifetime overconsumption of sodium. High blood pressure and hypertension are conditions linked to age as well as health history, and can cause medical emergencies like heart disease, vascular disease, and stroke (EPA, 2003).

Salinity influenced factors effects

Chlorides are a key ion we associate with water salinity. While chlorides do not typically lead to health risks in the presence of drinking water (Pal, 2017), it is important to note it's commonly found as sodium chloride in water. Sodium chloride can have negative health effects in high amounts. Along with this, chlorides have a powerful corrosive nature, which can affect the taste and health of our drinking water as it reacts with piping (Kumar, 2012).

Water salinity has a significant effect on concentration of dissolved oxygen (DO), an essential component of drinking water that can drastically affect human health. Studies show that both high total dissolved solid and high salinity concentration in drinking water significantly decreases dissolved oxygen concentrations (Salam, 2021). Dissolved oxygen is the measurement of how much gaseous oxygen is dissolved in water by the process of diffusion, aeration, and photosynthesis byproduct (Kumar, 2012). Low presence of DO in freshwater significantly decreases water quality, allowing higher rates of bacterial and microbial growth. Dissolved oxygen is also responsible for removal of harmful substances through metabolic processes and the sustenance of beneficial bacteria in drinking water (Rubel, 2019).

ORP is a water quality parameter used to conclude whether a water sample had more oxidative reagents or reductive reagents like organic matter. While water salinity does not directly affect ORP measurements, there is an indirect correlation because salinity significantly changes EC and DO, which are parameters related to change in ORP. Heath risks contributed to ORP are organic matter presence and potential for bacterial growth. Low ORP correlates to bacterial growth and can cause contamination with pathogens such as E. coli. Data suggests that ORP with a value of >850 mV is necessary to kill E. Coli in drinking water (Stevenson, 2004). In addition to bacterial growth risk, ORP is also linked to poor male reproductive health. A study on oxidative stress was able to find correlations between patients with high ORP levels and signs of infertility like low sperm count, poor movement, and morphology. Reasoning for this is that a low proportion of antioxidants to oxidants through drinking water can cause infertility in men (Agarwal, 2017).

High salinity drinking water can cause a normally neutral pH to skew towards alkaline. Alkaline water had adverse effects on human health with strong dependence on other factors. A research review discovered mostly positive short- and long-term effects of high alkalinity drinking water. 9 reviewed paper claims that alkaline water hydrates the body faster, increases metabolic function, improves gastrointestinal symptoms, stomach acid balance, exercise performance, improves blood glucose levels, postprandial lipemia, decrease cardiovascular risk, gallbladder emptying, and bone strength (Hamirudin, 2020). Diabetic people also benefit from drinking alkaline water, but do not experience as much short-term benefits. Postmenopausal women were studied, and a positive outcome was found in sleep quality, metabolic function and muscle strength factors when drinking alkaline water. The only health concern in this study was over-hydration, since this demographic screws towards an older age which commonly struggles with over-hydration (Chan, 2022).

2.6 Physical Effects of Salinity in Drinking Water Systems (Richard)

Elevated salinity in drinking water can trigger several adverse physical effects within water distribution systems. One significant concern is increased corrosivity due to saline water's higher ionic strength accelerating leaching of metals like iron, lead, and copper from pipes and plumbing fixtures (AWWA, 2017). These physical effects highlight the importance of controlling salinity in drinking water not only for health reasons, but also for maintaining the integrity of the water distribution infrastructure and ensuring consumer satisfaction with water quality. The increased corrosivity can lead to long-term damage and costly repairs. This not only damages infrastructure but also poses serious health risks to consumers. Another noticeable physical effect is the alteration of water's taste, often described as salty or brackish, which can make the water unpalatable even at concentrations below those considered immediately harmful and, taste issues can erode public trust in the water supply (Bruvold, 1970). Changes in water density caused by elevated levels of dissolved solids can result in stratification within storage reservoirs, which may disrupt vertical mixing and impact water quality at different depths (Hecky et al., 2023). Increased salinity can interfere with the efficiency of certain physical water treatment processes, such as sedimentation and filtration, potentially requiring adjustments to treatment protocols (Edzwald, 1993).

2.7 Remediation Management Practices for High Salinity Drinking Water

Salinity in drinking water is a growing global problem with serious health and environmental consequences. High salt levels can cause health issues like increased blood pressure, especially for vulnerable groups. It also harms ecosystems and can lead to economic burdens. Factors like seawater intrusion and road salt use contribute to this issue, making effective remediation crucial, especially as climate change worsens. This section will examine physical, chemical, and biological methods for removing salinity from drinking water, providing examples and quantitative data for each technique based on peer-reviewed research. The report will cover physical, chemical, and biological techniques.

Physical

Reverse osmosis (RO) is a leading physical method for desalination, utilizing pressure to drive water through a semi-permeable membrane that blocks salts (Water Consultants International, 2006), Seawater reverse osmosis (SWRO) is a key application at a large scale, providing substantial drinking water to coastal regions facing water scarcity, with facilities processing over 40 million liters daily (Water Consultants International, 2006). Quantitatively, RO demonstrates high effectiveness, achieving salt removal rates exceeding 92% in groundwater treatment in Sri Lanka (Wijewardhana et al., 2021). For brackish water, a pilot plant study showed a 72.02% recovery rate (El-Sayed et al., 2017), while systems designed for both potable and irrigation water reported 97% and 88% rejection rates, respectively (El-Sayed et al., 2017)

Chemical

Building upon methods, chemical techniques offer an alternative approach to desalination. Ion exchange is a chemical technique where unwanted ions are replaced with less objectionable ones using a resin. A specific example involves the desalination of brackish water using hydrotalcite (HTC) and a permutite-like material (Xu et al., 2013). This two-step process achieved a significant reduction in (TDS) from 2,222 ppm to 25 ppm in simulated brackish water (Xu et al., 2013). When applied to actual produced water (wastewater generated during oil and gas extraction) with a high initial TDS of around 11,000 ppm, this ion exchange method, combined with lime softening, lowered the TDS to 600 ppm (Xu et al., 2013). Additionally, ion exchange-based advanced treatment (XBAT) of wastewater effluents has shown a 74% removal rate for chloride and an overall 50% net reduction in TDS (Xu et al., 2013), highlighting the versatility of ion exchange in treating various saline water sources.

Biological

Shifting towards biological strategies, Microbial Desalination Cells (MDCs) offer a biological approach, using electroactive bacteria to desalinate water and treat wastewater simultaneously (Lefebvre et al., 2019). An air-cathode MDC, used for treating brackish water, demonstrated desalination efficiency exceeding 90% for initial salinity levels of 7.5 to 10 g/L of NaCl (Lefebvre et al., 2019). An air-cathode MDC treating coastal saline-alkaline soil-washing water achieved a salt removal rate of up to 99.13% (Guo et al., 2020). An up-flow MDC showed even greater effectiveness, removing over 99% of NaCl from a salt solution with an initial TDS of 30 g/L, resulting in water that met drinking water standards (Lefebvre et al., 2019). These examples illustrate the potential of MDCs as an energy-efficient and sustainable method for salinity remediation in different types of water.

2.8 EPA Salinity Standards

The EPA recommends that human adults shouldn't drink water that contains more than 3 g Na/L and children are recommended even less (EPA, 2003). This maximum concentration level (MCL) is recommended based on the health risks associated with high salinity drinking water. Additionally, the EPA recommends secondary maximum contaminate levels (SMCL) for drinking water salinity. This SMCL states that freshwater salinity should not exceed 1,000 mg/L, slightly saline water is 1,000 – 3,000 mg, moderately saline water is 3,000 – 10,000 mg/L, and very saline 10,000 – 35,000 mg/L which is the approximate salinity of seawater (EPA, 1994). A SMCL is a non-enforceable guideline for regulation of natural resources like drinking water. Although these guidelines are unable to be enforced as strict limits through the USGS, they can aid domestic water systems to improve the taste, odor, and color. Unlike MCL's, which are enforceable limits, SMCLs are based less on health risks and more on aesthetic elements of available natural resources.

3. Materials and Methods

3.1 Study Site Selection and Location

Our study was conducted on the Kansas State University Campus in Manhattan, KS. The campus was originally built in 1863 with most of the development occurring between 1948 and 2008(K-State Housing and Dining, 2022). In 2024, there was a total enrollment of 20,294 students and 4,733 faculty and staff (K-State DAIR, 2025). We chose to sample buildings with the highest average monthly demand in 2024, distance from K-State's water source, and if they were commonly used by students. Although some buildings have high average monthly demand, usage such as consumption, sanitation, and maintenance are not specified. Since students make up the majority of K-State Manhattan campus, we noted that buildings with high average monthly demand not commonly used by students were using water for sanitation and maintenance. We sampled once every week for three weeks at the same drinking fountain for each building between February 27th and March 14th. These buildings were Jardine Building 5, Throckmorton Hall, Kramer Food Center, Derby Food Center, Fielder Hall, Hale Library, Seaton Hall, KSU Student Union, and the College of Business Building. We also sampled at the beginning of the water distribution system—on the corner of Kimball and Denison Avenue as shown in Figure 1.

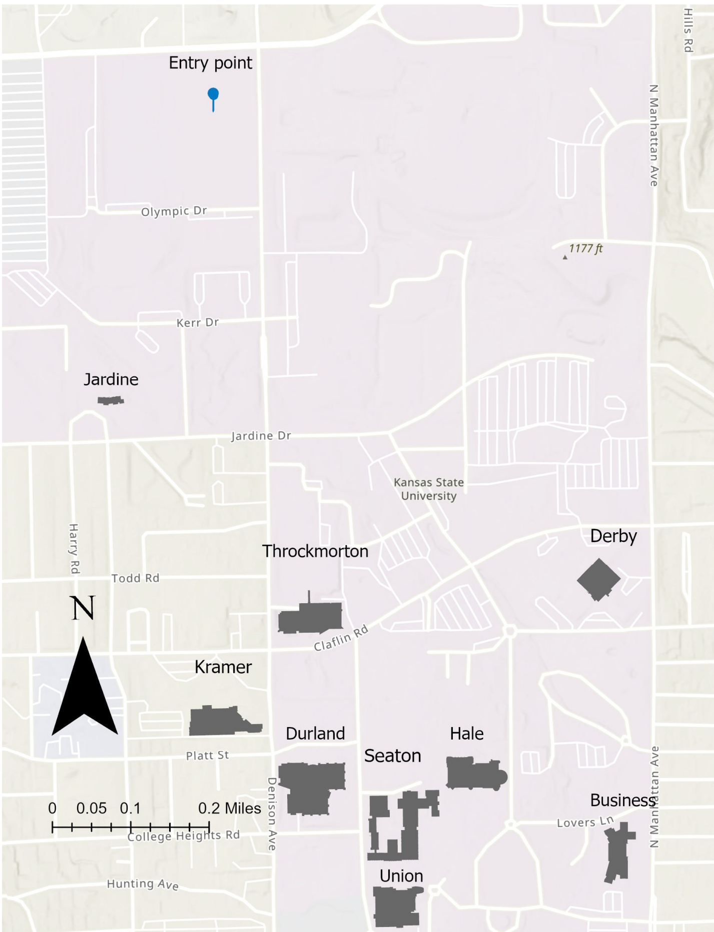

Figure 1: **Sampling sites on K-State University, Manhattan, KS.** The selection of buildings across the Kansas State University campus for salinity test was based on several key factors. Primarily, the buildings are used significantly by students for sources of drinking water. Buildings were chosen strategically distributed across the main campus to allow for more geographical diversity in the sampling.

3.2 Collection Procedures

Sample collection and Storage

During our sample collection, we adhered to EPA water quality protocol to ensure data integrity (EPA, 2025). Our sampling procedure was strictly maintained, using a single 225 ml sampling bottle per site, a mercury thermometer, and white paper to report color irregularities in the water. Contamination is a major concern when collecting water samples because our bodies contain high levels of salinity and can affect other parameters like pH, temperature, TDS, and ORP that we are testing for. To prevent contamination of our samples, we made sure to touch only the outside of our sampling bottles and place the lids up when setting it down. To ensure our sampling bottles are free from any factory debris, we rinsed the insides with the sample water three times before taking our sample. Temperature is an important factor in our research because it is directly related to salinity levels in water. Using a portable glass thermometer, we took temperature samples directly from the faucet to understand the conditions for chlorine ions to be present (Kjerfve, 1979).

Sample Storage

Samples were kept at a temperature of 4 degrees Celsius in a refrigerator in our labratory. To ensure our analysis was as accurate as possible, we analyzed samples no later than 24 hours after collection (EPA, 2025).

3.3 Analysis Procedure

Laboratory Analysis

We employed the YSI MultiLab 4010-2W instrument to measure salinity, total dissolved solids (TDS) and temperature at ambient conditions. Oxidation-Reduction Potential (ORP) and pH were measured using the Oakton PH550 Benchtop Meter. Each benchtop instrument was equipped with ion selective electrode (ISE) probes tailored to each specific parameter under investigation. Deionized water (18.2 MΩ·cm) was used as a control due to its negligible salinity. All instruments were calibrated prior to sample analysis following standard protocols—for instance, the PH550 meter was calibrated using pH buffer standards of 4.0, 7.0 and 10.0. For sample preparation, 40ml aliquots were extracted from each sample bottle using an electronic pipette and transferred into individually labeled test tubes. Standard laboratory safety procedures were strictly followed, including the use of gloves, lab coats, and eye protection. To minimize cross-contamination, all probes were thoroughly rinsed and dried with Kim-Tech Delicate Task Wipers between analyses.

Data Analysis

Data analysis was conducted using R Statistical Software (v 4.4.0; R Core Team 2024), with RStudio serving as the integrated development environment for data visualization and interpretation. Data exploration included the generation of box plots, linear regression models, and Pearson correlation matrices. The readxl, tidyverse, and dplyr packages were used to import and organize our data (Wickman et al, 2019; Wickham et al.,2023; Wickham and Bryan, 2025). Summary statistics were obtained using the metan package (Olivoto, 2020). Visualization of data was performed using Hmisc, ggplot2, PerformanceAnalytics, ggbreak, and ggpmisc (Aphalo, 2024; Harrell, 2025; Peterson and Carl, 2024; Xu et at., 2021; Wickman, 2016). Linear regression models were developed using the car and MASS packages, while correlation and analyses were conducted with the corrr package (Fox and Weisberg, 2019; Kuhn et al., 2022; Venables and Ripley, 2002). The EPA standard for salinity, originally provided in g/L, was converted to µS/cm using the following equation.

1 microsiemens/centimeter [µS/cm, uS/cm] = 0.1 millisiemens/meter [mS/m]

4. Results

Through water sample collection and laboratory analysis, our study produced important results to understand water salinity concentrations across KSU's main campus. Our results include concentration of salinity based on ion EC measurements of µS/cm and its relation to distance from the drinking water system entry point, as well as correlations to other parameters which salinity effect. In all, we measured salinity (ion EC µS/cm), pH, temperature at collection and analysis, TDS, and ORP of the university's campus. These results point us towards potential causes for salinity concentration variation between buildings which is important as we consider any remediation strategies.

4.1 Salinity Concentration in Selected Areas

Location	Salinity	Remarks	Study
Seattle, Washington	~ 50 µS/cm	Very low mineral content because of the pristine snowmelt and surface water sources from the Cascades. Typical soft water supplies in the Pacific Northwest (EPA, 2018; Water Quality Association, 2022).	Water Quality Association (2022); EPA Secondary Drinking Water Regulations.
Houston, Texas	~ 517 µS/cm (median; range 314–856 µS/cm)	Sourced from deep municipal wells in southeast Texas.	U.S. Geological Survey Scientific

		Elevated levels stem from naturally occurring dissolved ions and saltwater mixing in aquifers (USGS, 2009).	Investigations Report 2009
Antelope Valley, California	~ 660 µS/cm (range 40–770 µS/cm)	Elevated because of the arid climate and groundwater sources influenced by mineral leaching and evaporation. It is common in Southern California desert regions (Los Angeles County Waterworks District, 2022).	Los Angeles County Waterworks District No. 40 Consumer Confidence Report (2022).
Southwestern U.S. (Arizona, New Mexico, West Texas)	~ 1000–1500 µS/cm	Among the highest in U.S. tap water due to high TDS well sources, arid climate, and possible saltwater intrusion. Reported near EPA's taste threshold and upper recommended limit (EPA, 2018; Texas Water Development Board).	EPA Secondary Drinking Water Standards; Texas Water Development Board Groundwater Quality Reports.
New York City, New York	~115 µS/cm (average; range 73–468)	NYC tap water is sourced primarily from protected Catskill/Delaware watershed reservoirs. It is naturally soft and low in mineral content, resulting in low electrical conductivity (New York City	NYC Drinking Water Supply & Quality Report (2019)

		Department of Environmental Protection, 2020).	
Milwaukee, Wisconsin	~305 µS/cm (median; range 305–390)	Milwaukee sources its drinking water from Lake Michigan. The conductivity reflects moderate dissolved mineral content, typical of large surface freshwater lakes (Milwaukee Water Works, 2022).	Milwaukee Water Works Water Quality Data (2021)
Denver, Colorado	~306 µS/cm (avg; range 150–440)	Tap water in Denver comes from high-elevation snowmelt, which introduces moderate levels of naturally occurring minerals, leading to conductivity in the 300 µS/cm range (Denver Water, 2024).	Denver Water Quality Report (2024)
Raleigh, North Carolina	~200 µS/cm (finished water)	Raleigh's tap water is soft, drawn from surface sources like Falls Lake, and treated to maintain low conductivity levels (City of Raleigh, 2023).	City of Raleigh Drinking Water Report (2023)
Columbus, Ohio	~283–697 µS/cm (varies by source)	Columbus uses a mix of surface and well sources. Well-fed plants show higher conductivity (~697 µS/cm), while reservoir-sourced	Columbus Water Quality Report (2023)

		water is lower (~283 µS/cm), reflecting local source geology (City of Columbus, 2023).	
Manhattan, KS	~ 436-464 µS/cm		Salinity in Drinking Water on Kansas State University Manhattan Campus

Table 1: **Summary table of previous salinity studies.**

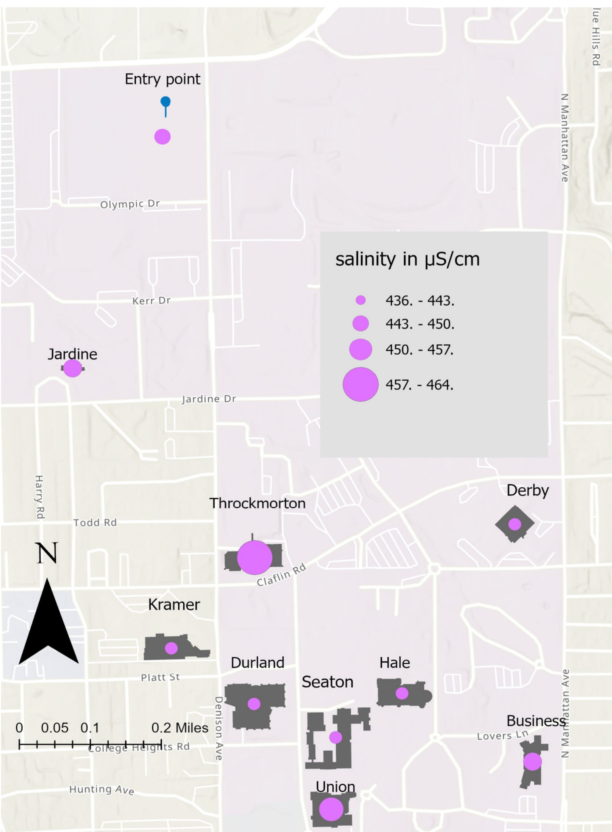

Figure 2: **Salinity concentration (µS/cm) on Kansas State University Manhattan Campus**. **(Richard)** displays the salinity concentration (µS/cm) across the Kansas State University Manhattan Campus. The map shows several buildings, including Jardine, Throckmorton, Kramer, Durland, Seaton, Hale, Union, and Derby, each marked with a purple circle representing the salinity level at that location. The size of the circle corresponds to the salinity concentration, as indicated by the legend: the smallest circles (436 - 443 µS/cm) are at Jardine, the next size up (443 - 450 µS/cm) is at the "Entry point," the next size (450 - 457 µS/cm) is at Derby, Kramer, and Union, and the largest size (457 - 464 µS/cm) is observed at Throckmorton, Durland, Seaton, and Hale. Therefore, the figure illustrates the spatial distribution of varying salinity concentrations across different buildings on the K-State campus.

4.2 Salinity Related to Distance from Entry Point

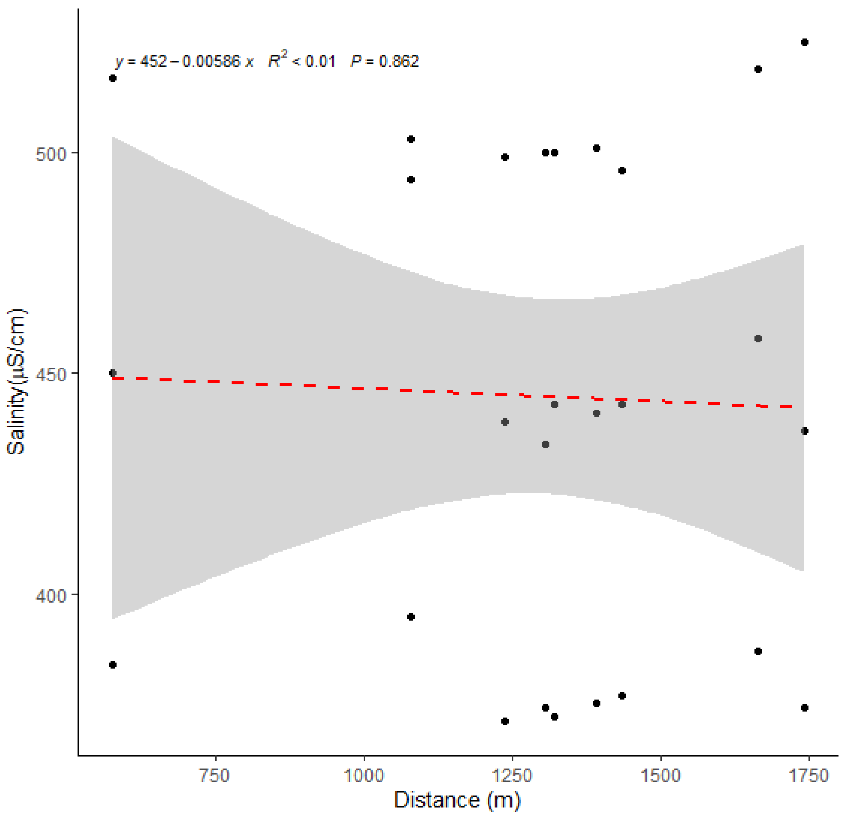

Figure 3: **Linear relation of distance on salinity on K-State's water distribution system.** This linear regression looks at the relationship between distance from the entry point and salinity (µS/cm). The gray area is standard error. There is a weak negative correlation between distance and salinity, but it is not significant.

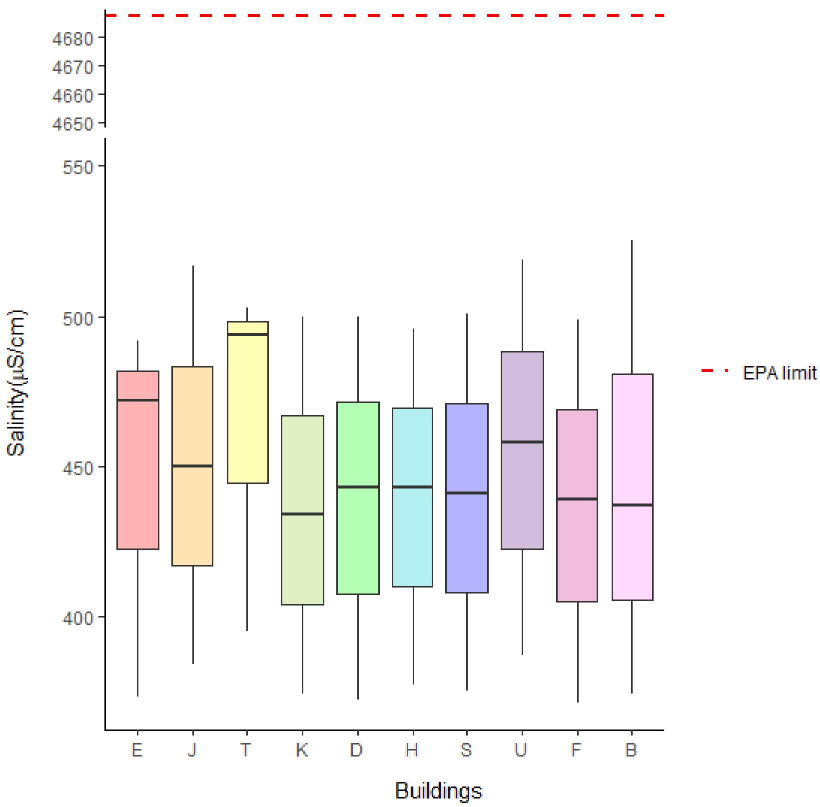

Figure 4: **Salinity concentration (µS/cm) by building on Kansas State University Manhattan Campus**. This figure shows a box plot of salinity concentration at the water distribution entry point and buildings Jardine, Throckmorton, Kramer, Fielder, Hale, Seaton, Union, Business, and Derby (from left to right). The buildings are organized based on distance from the entry point. The EPA standard is 4,687.5 µS/cm. There was no significant difference between any of the sites.

4.3 Water Parameter Correlation

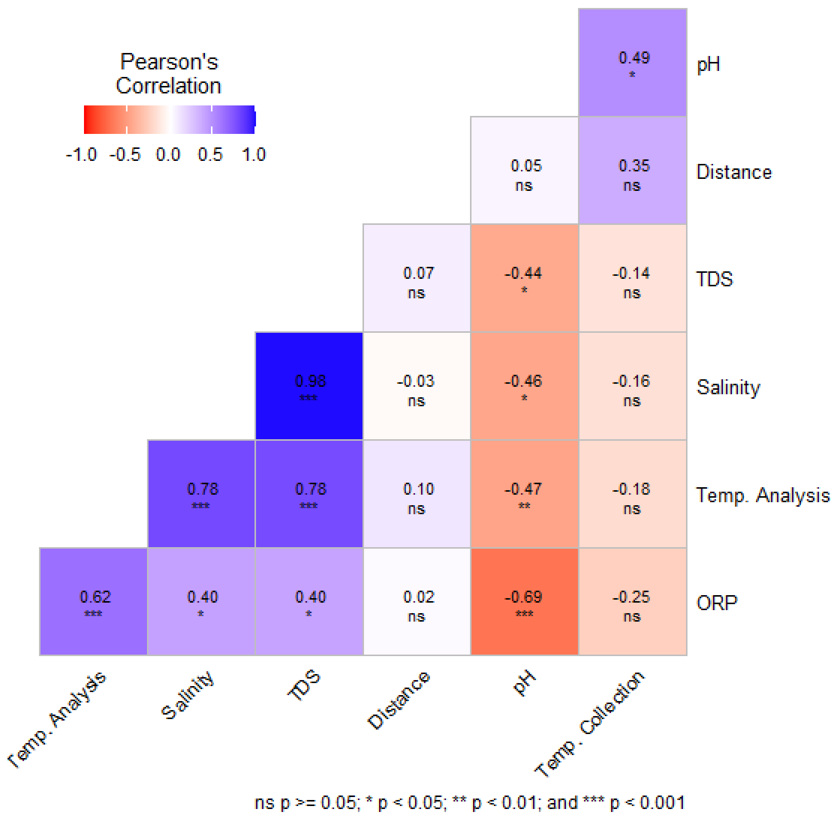

Figure 5: **Pearson correlation table for water testing parameters**. This figure shows Pearson correlation coefficients between pH, ORP, temperature at sample collection, temperature at sample analysis, salinity, and TDS.

4.4 TDS Correlation with Distance

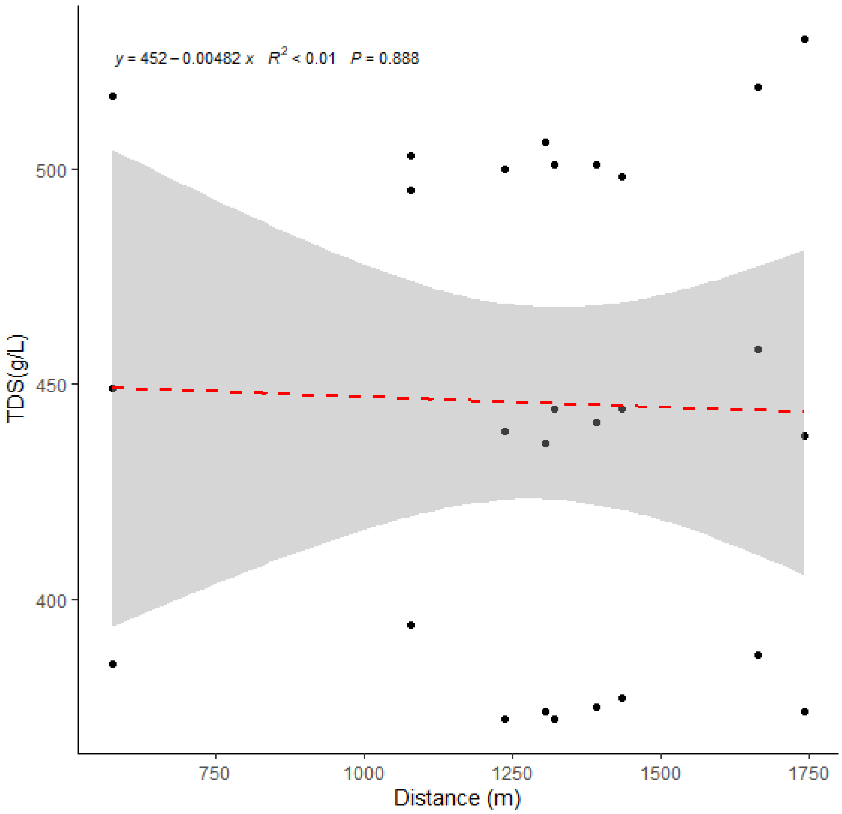

Figure 6: (Linear Regression) **Linear relation of distance on TDS on K-State's water distribution system.** This linear regression looks at the relationship between distance from the entry point and TDS (g/L). The gray area is standard error. There is a weak negative correlation between distance and TDS, but it is not significant.

5. Discussion

5.1 Study Limitations

During this study, we faced some problems such as limited research time, limited trial abundance, and laboratory conditions beyond our control. This research project was conducted over a 15-week period from start to finish. Because of a lack of time, our sampling period was shorter than we would prefer for this research. If time had permitted, we would have extended our sampling period by 1 or 2 more weeks to allow more for more data comparison and less error. Along with this, we faced challenges due to a laboratory technical issue. The biotechnical laboratory deionized (DI) water which we used as our control for the study as well as for ensuring analytic probes were clean between samples was compromised during our analysis period. This means that during the second week of data analysis the deionized water was not being treated properly, and we were essentially working with tap water. This compromised our study control and certainly has tainted the results of our laboratory analysis. These limitations should be considered as the reader proceeds through this paper.

5.2 Comparison with EPA Standards

The EPA standard is almost ten times higher than our maximum salinity concentration sampled. Our samples fall between 256 mg/L to 320 mg/L. According to the EPA's SMCL for drinking water salinity, these samples still fall within the freshwater category which shows that K-State Manhattan Campus drinking water has safe water in terms of salinity (EPA, 1994; EPA, 2003). There were no noticeable odors, or discolorations in water samples. Since USGS focuses on taste, odor, and color, our samples do not appear to need any change in domestic water system management according to USGS standards.

5.3 Factors Affecting Tap Water Salinity at K-State

Tap water salinity at Kansas State University is a complex issue that is influenced by environmental and infrastructure factors. Weather patterns in Kansas have been getting more and more unpredictable, particularly snowmelt and rainfall. The winters can be brutal, and with the snow comes snow salt or other de-icing agents (estimated 500 tons applied to campus roads and walkways each winter); this leads to around 2 inches of water runoff in a 48-hour period of heavy snowfall. This can lead to an increase of around 50 µS/cm of salinity in the aquifers.

Additionally, the aging campus water pipes, some of which date back over 50 years, could contribute to salinity through corrosion of pipe materials. Galvanized steel is used in a few buildings, which can lead to contamination in the water. This contamination can lead to lower water flow rates, which can exacerbate the leaching process of salinity into the water.

Long-term climate change trends in Kansas also have a major influence on water quality. The increased frequency of droughts over the past two decades and the rise in intense rainfall events impacts groundwater salinity. Extended droughts can concentrate existing salts, which in some cases could increase salinity by 100 µS/cm. On the other hand, sudden heavy rainfall after a drought or a dry spell can flush these accumulated surface salts, which at times can reach concentrations of 2000 mg/L of TDS, into aquifers. So, when thinking about salinity in our tap water, we must account for all these variables and how they interact with each other and how they can help predict future water quality of the campus.

We noticed that in the K-State Water Distribution System, as the distance from the entry point increases, salinity decreases. This doesn't support our hypothesis. This could be due to dissolved salts sticking to the sides of the pipes, decreasing the salinity further away from the entry point (Al-Naamani and Azwadi, 2018).

5.4 Possible Sources of Contamination

Although K-State Manhattan's campus drinking water salinity is well below EPA standards, there are other water quality characteristics that were not analyzed. One main concern is that any salinity in the water could cause corrosion in the water distribution system leading to contamination. The average salinity concentration from Manhattan Water Treatment Facility in 2024 was 268.8 mg/L which was slightly lower than our sample average at 273.3 mg/L. This means that between the Manhattan Water Treatment Facility and the K-State University water distribution system, there could be a salinity contamination. We sampled at the end of winter, a few weeks after the last snow melted. There was still some salt spread on sidewalks and roads. However, snowmelt on campus flows into stormwater drainage systems and to the Manhattan Wastewater facility which shouldn't affect our results because it is downstream. The Manhattan Wastewater facility treats nutrients and biological pathogens from sewage and stormwater runoff before flowing into the Wildcat Creek Basin (BG Consultants, 2003).

The salinity contamination is likely to have occurred from within pipes between Manhattan Water Treatment Facility and the K-State University water distribution system. As of 2025, most of the pipes in the K-State Water Distribution System are made of an unknown material, but due to when the unknown pipes were built, they are assumed to be cast iron (BG Consultants, 2013). This means over 80% of the K-State Water Distribution System are cast iron. Although, Manhattan's water is treated with chloramines, most likely monochloramines, which could decrease the amount of corrosion within the cast iron pipes, salinity and TDS changes throughout the K-State Water Distribution System are likely attributed to the corrosion of cast iron pipes. Cast iron pipes are known to be more brittle and corrosive than ductile iron, plastic PVC, copper and galvanized pipe. There have been several instances during the winter and early spring months when the K-State Watermain has fractured causing leaks. This could lead to intrusion of materials from soil surrounding the pipes.

5.5 Implications for Water Quality and Policy

Salinity concentration is strictly regulated by the EPA stating that 3 g Na/L or more generally 5 g/L TDS (EPA 2024) is considered as the maximum concentration level for US drinking water. Any concentration above these limits is a water quality risk affecting color, taste, and odor of drinking water. Consumption of drinking water above the maximum concentration level of salinity poses multiple health risks like dehydration, diarrhea, gastrointestinal inflammation, or ulceration. Long-term consumption can cause hypertension, higher risk of heart disease, vascular disease, or stroke (EPA,2003). Additionally, the U.S. EPA has secondary maximum contamination levels (SMCL) which are considered non-enforceable water quality statures that influence aesthetics rather than health risk. Drinking water distributions are not required to test for TDS contamination at any certain time intervals. However, remediation strategies will be suggested by the EPA once the water system is found to be at risk of contamination.

Salinity Level (mg/L)	Category	SMCL Implications	Health Risk Implications
<1,000	Natural	Freshwater	Adult: No health risks are accocated with water that is not considered elevated or contaminated with excess salinity. Other water quality issues could be cause for concern, however, salinity is not a factor.
			Child: No health risks are accociated with water that is not considered elevated or contaminated with excess salinity. Other water quality issues could be cause for concern, however, salinity is not a factor.
1,000 - 3,000	Elevated	Slightly saline	Adult: slightly saline water is not considered a risk to human health by EPA's standards. However, studies show that drinking elevated saline water can be correlated with increased frequesncy of hospital visits due to diherrea, and abdominal pain. Mild short-term effects such as dehydration could also be affected by elevated salinity (Chakraborty, 2019).
			Child: Children are particularly sensitive to elevated salinity in drinking water because of the immaturity of their kidneys. While adults are flexibly with daily sodium intake, children are less flexible. Slightly saline drinking water could cause a range of side affects, although these are not well known. Monitoring a childs daily sodium consumption is essential for their health.
>3,000	Contaminated	Moderately saline	Adult: Adults who consume moare than 3 g/L are considered by the EPA to be at risk for short-term health concerns like dehydration, gatrointestinal inflamation and even ulceration. A lifetime of consumption could lead to long-term effects such as hypertension, high blood pressure, heart disease, vascular disease and stroke.
			Child: Drinking water contaminated with salinity at or over 3 g/L used to mix with formula has resulted in death of infants due to high blood sodium concentration. Total dissolved solids higher than 5 g/L have lead to low total dissolved oxygen (DO) levels in drinking water. DO at a low concentration mixed with formula can result in low blood oxygen concentration, resulting in methemoglobinemia also known as "blue baby syndrome".

Table 2: Health Risks Associated with Various SMCL Categories for Adults and Children

Commented [KJ1]: top health risk implication box for freshwater adults has a typo "accocated"

6. Conclusion and Recommendations

6.1 Summary of Findings

We found that as distance from the entry point increases, salinity and TDS decreases. This doesn't support our hypotheses that as distance increases so do salinity and TDS. However, we found strong positive correlations between salinity and TDS, salinity and temperature at analysis, TDS and temperature at analysis, and ORP and temperature at analysis (Figure 6). We also saw a strong negative correlation between salinity and ORP, and pH and ORP. This supported our hypothesis that as salinity increases, ORP decreases and TDS increases. We saw no significant relationship between salinity and temperature at collection.

6.2 Recommendations for Campus Water Management

Managing tap water salinity at Kansas State University requires addressing several key areas of concern. However, it's crucial to remember that the primary water source is the City of Manhattan's municipal supply. Despite this, the same factors influencing salinity throughout Manhattan also affect Kansas State. These include factors like de-icing salt runoff from roads and sidewalks, and various other environmental issues. We can enhance the monitoring of tap water on campus while also collaborating with the city to better understand these problems.

Long-term strategies for Kansas State will have to include updating infrastructure, such as aging and corroding pipes within campus buildings. While Kansas State cannot directly influence the City of Manhattan's policies, the university can expand its research and education programs to spread awareness of climate change and even initiate public outreach and engagement programs. Also, collaborating with and advocating for city-wide sustainable practices, even in seemingly small areas like de-icing methods and water management, can be a defining factor in the fight against climate change and the health of our water sources.

One specific change we could make would make a big difference in reducing the use of road salts. Research has shown that there are alternatives that can be used. For instance, potassium succinate which is an organic salt that is effective in melting ice and is noncorrosive to metals. Acetate based products like calcium magnesium which are derived from acetic acid like vinegar and are not harmful to the environment. Another option is Formate based deicers like potassium formate, which are biodegradable and work quickly in cold conditions. These alternative options may cost a little more but would benefit the water quality on campus and around the city in the long run.

6.3 Applications on a Global Scale

The patterns observed at K-State reflect challenges seen across the country, where salinity in tap water is rising due to a combination of environmental and human factors. Our analysis shows that even treated water can have an increase in salinity because of the distribution systems, especially in areas with older pipes or low water flow.

These findings show the importance of implementing localized water quality monitoring throughout distribution networks, rather than just focusing on data from treatment facilities. In many places across the United States routine point-of-use testing is important to detect hidden variations in water quality. Applying simple, cost-effective strategies allows for early detection of salinity fluctuations, enabling timely maintenance, infrastructure upgrades and informed water management decisions across diverse settings in the country.

6.4 Future Research Directions

Because Kansas State University has not had any past drinking water salinity data collection, we are not able to include anything about long-term changes through time. Due to limited time, our research team was only able to measure 3 weeks during the winter of 2025. It may be worthwhile to conduct a long-term study based on our short research project to understand how climate change and human industry will affect salinity concentration over time. Additionally, we acknowledge that salinity changes significantly due to seasonality. Future directions could include a long-term study that pays special attention to seasonal differences and how this changes salinity concentration on KSU’s main campus.

6.5 Acknowledgements

The authors would like to acknowledge the College of Arts and Sciences, specifically the division of Natural Resources and Environmental Sciences for creating a research opportunity for undergraduates. Thanks to Dr. Sean Hutchinson for coordinating the NRES Capstone. Special thanks to Dr. Hu Tuan Tran for providing constructive feedback and guidance through the research process. Our acknowledgements also go out to the Biotechnology Lab and for allowing us to utilize lab supplies and equipment.

7. References

7.1 Use of AI

This project used AI to help structure the table of contents.

7.2 Journals, Articles, Papers, and other References

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