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Statistical Assessment of Water-quality Parameters for Different Flow Regimes

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ABSTRACT

Groundwater and drainage-water sustainability is crucial to water management. Controlling the interaction between the groundwater and drain-water salinity at the watershed level has only been the topic of a limited number of studies. This study statistically compares salt concentration rate across time and four different flow regimes. We sampled water from 2014 to 2018. The study used R software to analyze water-quality parameters utilizing PCA and indices. Multiple water-quality indices were used to test irrigation water. A linear model with TDS as the response was fitted to the data. Another two-factor repeated-measurement covariate model was built. Water-quality indices suggest that measured water from varied flow regimes in the study area is suitable for irrigation. Based on the statistical models, Tukey's adjustment pairwise demonstrates considerable salinity variations between drain water and surface water. However, the main effect of the flow regime on TDS is significant. This indicates that the TDS value varies depending on the flow regime, not on time plus the interactions between these regimes.

Keywords: Total dissolved solids (TDSs), Groundwater, ANCOVA, Flow condition, Tile drain, PCA.

INTRODUCTION

Since the early 1990s, Total Dissolved Solids (TDSs) have been a growing problem in many areas around the world. Poorly-drained soils and excessive rainfall are the main reasons for increasing salinity around the world. As the water table rises near the ground surface in wet years, water is wicked to the surface. Once the water evaporates, the total dissolved salts are left behind on the soil surface and affect both plant growth and yield. When this process repeats for many years, the soluble salts can accumulate on the soil surface to a high level and reduce crop yields (Rengasamy 2010). Dissolved salts are environmentally harmful compounds that appear in tile drains and flow to natural water bodies. This is a water-quality issue that has become an important issue around the world. Most freshwater streams have low salinity values. However, Groundwater and tile drains have a high conductivity due to the high amount of dissolved salts present.

The impact of salinity on water quality and the subsequent issues have been the subject of several research. Ravichandran et al. (2023) used various statistical methods to calculate water-quality indices. Researchers found that water-quality indices decrease with time. According to Young et al. (2019), the suitability of surface water and groundwater for irrigation depends on the definition of the mineral components of water and soil. Hussein (2018) assessed the quality of drainage water for irrigation purposes in the area between Abo-Ghareeb and Al-Masib city. Graham et al. (2021) studied this topic and have shown that the growth of fragile agricultural crops is impacted by the presence of magnesium and chloride ions in groundwater. Shaji et al. (2021) examined the level and nature of pollution in the groundwater surrounding the lake created by a dam. Multi-variate statistics can be an effective technique for hydrological study in order to confirm and differentiate the factors that contribute to salinization and freshening as well as to ascertain the composition of groundwater (Cloutier et al., 2008). Seawater movement and the freshwater-saltwater interface were studied using Multi-variate statistical analysis (Sarker et al., 2021). It is a measurable method that enables classifying the samples into several groups, examining the relationships between the hydro-chemical variables and constituents and comparing the similarities between water-sampling sites (Han et al., 2022). Rajaveni & Muniappan (2023) used GIS and remote-sensing techniques to delineate the groundwater potential in the Nampiyar river basin in India. The classification of the groundwater optional zone into five categories depended on the available volume of groundwater. Shende & Sahoo (2023) analyzed multiple groundwater samples spatially in the Wardha district of India and compared the results with water drinking specifications. They found that some concentration levels were above the accepted standard limits. No watershed-scale model simulates salt transport in all essential hydrologic pathways (surface flow, drainage flow, groundwater flow and mixed flow) with time factor. This model is essential for watershed and basin-scale salt-movement assessment. The present study used statistical methods to analyze hydro-chemical data to categorize and investigate the difference in salt concentrations with time and between four different flow regimes, as well as to explain the main factors affecting groundwater and drain-water chemistry in the irrigation industry.

MATERIALS AND METHODS

Study Area

The study area is located in the southwest part of Swink city in the state of Colorado in the USA, as shown in Figure 1. The Rocky Ford CoAgMet weather station in the research region reported the highest temperatures during the study period, with a maximum temperature of 40°C (104°F), which was recorded on 23/7/2015. The same station's minimum temperature during the research period was -39°C (-38°F, recorded on 1/12/2014). The study area receives 29 cm (11.5 in) of precipitation annually on average. According to Morway & Gates (2012), the study area's geology can be characterized as a wide, shallow valley that is overlain by several sedimentary layers ranging in age from the late Cambrian to the Tertiary. Agriculture accounts for 90% of the land covered in the watershed, with urban land covering making up 6% and water making up 1%. Alfalfa is the most common crop, followed by corn, wheat, grass or pasture, sunflowers, melons, beans, oats, onions and sorghum. In the study region, 25 sampling sites with four different flow regimes (surface water (SW), groundwater (GW), drain water (DW) and mixed water (MW: a sampling point where surface and drainage water combine) have been investigated. A research team selected these sampling sites for the study to evaluate the salinity issue.

Sampling Techniques

Many spatial sampling locations were used to acquire parameter samples for most water-research procedures. Parameter types, like salt concentration, flow discharge, calcium, … etc., are in the third dimension, yet a planar sample site is located by two spatial coordinates (x; y). Hydro-geological processes are often described by single-sample status indicators. When samples are analyzed over time, time series develop, increasing the three dimensions to four with time as the fourth axis (Figure 2). First, the fundamental properties of environmental datasets and how to handle them are outlined before discussing the approaches. The researchers collected samples and measured water quality for each sampling period from the study-area sampling locations. Samples were collected from January 2014 to December 2018 for the study. Surface- and tile-drain water samples were collected mid-channel and placed in pre-rinsed HDPE and acid-washed bottles for laboratory testing. Groundwater samples were taken at each monitoring well using low-flow QED (PurgeScan Technology sampler). A pro bladder pump, two 0.635-cm (0.25-in) tubes and a flow-through cell extracted groundwater from each monitoring well. Depth, transparency, temperature, pH and conductivity were measured in the field, whereas the other parameters were measured in the lab. Orthophosphorus, total phosphorus, organic nitrogen (Kjeldahl nitrogen minus ammoniacal nitrogen), nitrite-nitrogen, nitrate-nitrogen, conductivity, chloride, total hardness, calcium, magnesium, sodium and potassium were measured in the lab within 24 hours of sampling using Golterman (1969) and APHA (American Public Health Association, 1926).

Stream Discharge and Salt Load

To create the stream-flow time series for this investigation, one measurement station, Timpas Creek station was considered. Data on stream flow was gathered by the US Geological Survey (USGS). Figures 3 shows the daily flow stream and observed TDS values over time at the gauge station for the research area. The sampling period for stream flow was the same as the time frame for water-quality sampling for groundwater and drain water. Meanwhile, both the salt concentration and stream discharge showed notable seasonal fluctuations connected to the variation from different flow regimes. Additionally, during the study period, salt content and river discharge showed the largest uniform seasonal variability.

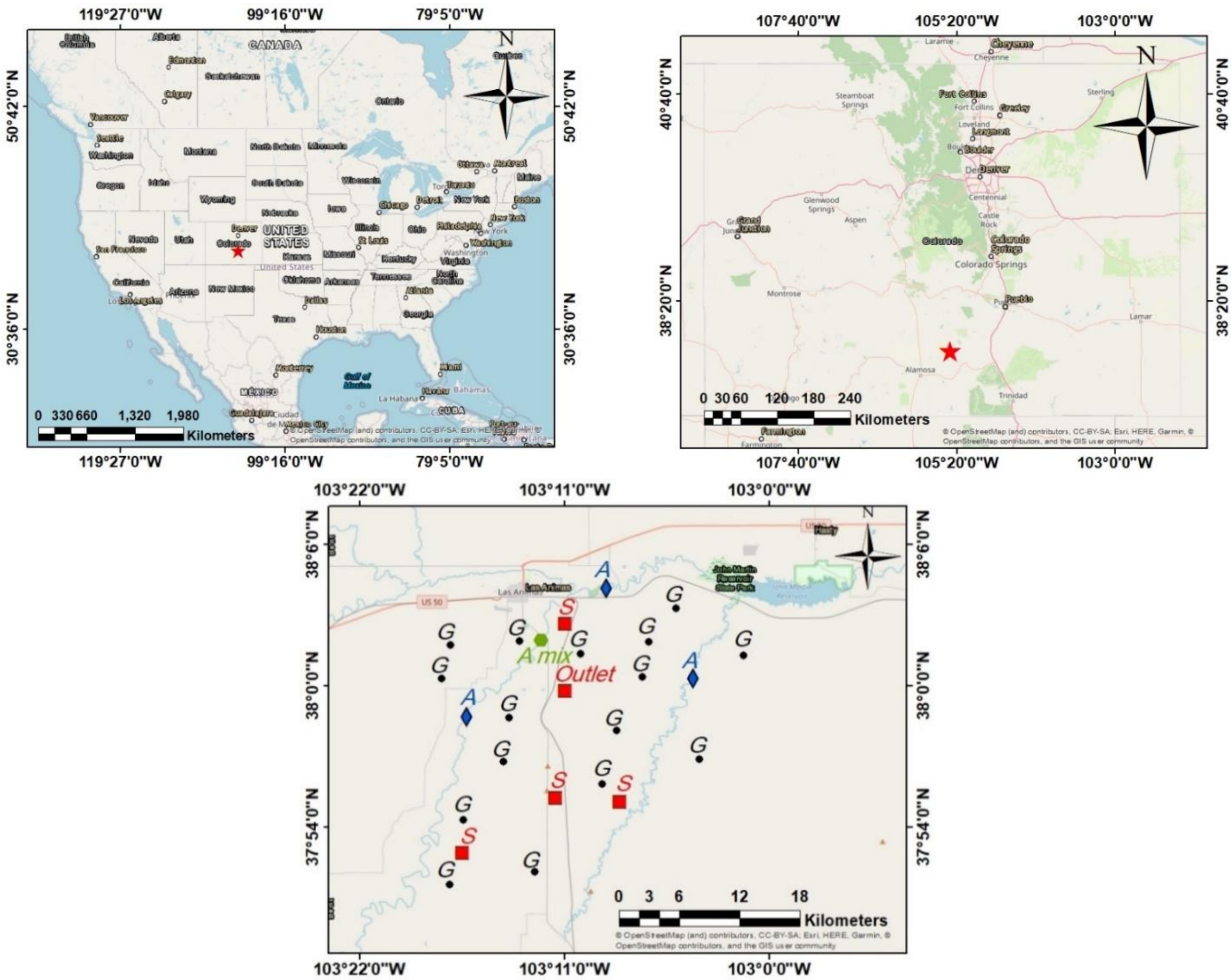

Figure (1): Maps of the study region showing (A) Colorado state where the study region is, (B) Sampling locations (G: groundwater, A: surface water, S: drain water and A mix: mixed water)

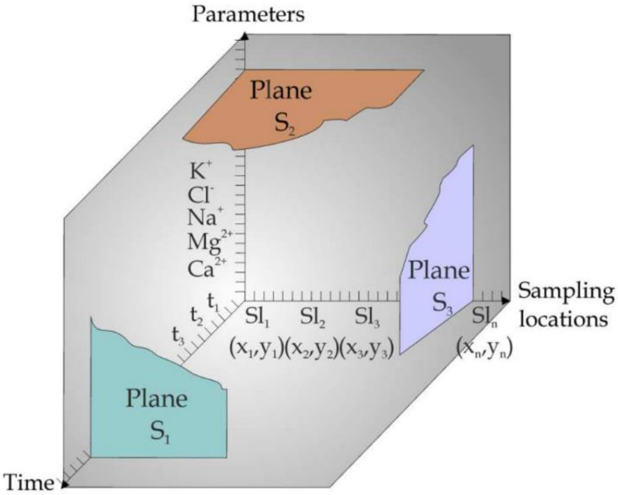

Figure (2): Data in four dimensions:
sampling locations (xi; yi), parameters and time (Kovács et al., 2012)

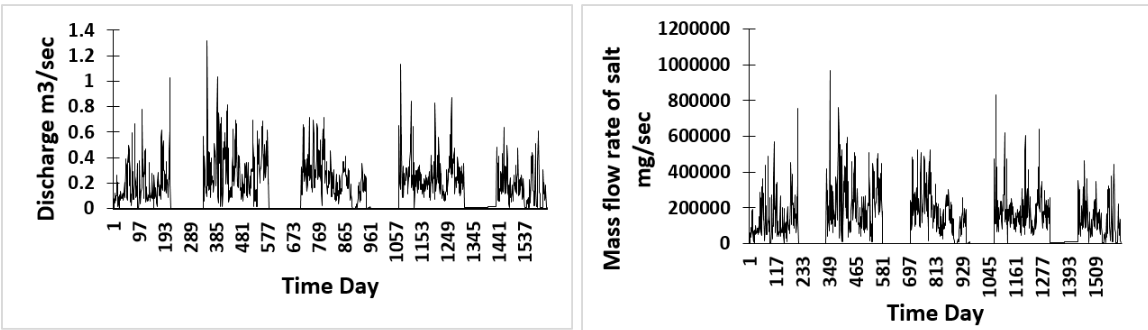

Figure (3): Time series of stream flow and the mass flow rate of salt

RESULTS AND DISCUSSION

Hydro-geochemical Classification of Water Samples

Anion and cation triangle combinations that share a baseline are called Piper trilinear diagrams. To determine the source of the water, inferences are drawn from the positions of the analyses displayed on the Piper diagram in mg/l. From Piper diagrams, the following characteristics are concluded: water type, precipitation or solution, mixing and ion exchange. From observations, the high salinity in the groundwater and drain water in the study area, which is brought on by the presence of salt minerals, mainly gypsum ($CaSO_4$), has a negative impact on the area. As Figure 4 displays, salt-ion proportions are determined using Piper-diagram analysis of the samples gathered in the study area (Piper, 1944). Piper claims that it is possible to see the chemistry of significant ions by looking at the relative quantities of the principal ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^-, Cl^-, NO_3^- and SO_4^{2-}) in a water sample. The Piper diagram for the research area (Figure 4) shows a range of major-ion chemistry and water facies. The majority of samples contain a mixed type of water and a general type of calcium chloride. Most samples have a general anion preponderance of sulfate and a cation dominance of calcium.

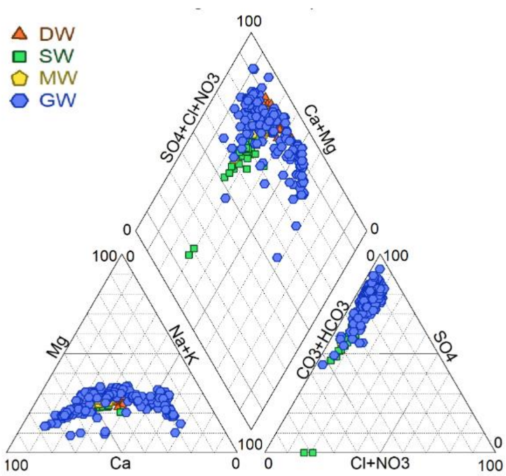

Figure (4): Piper diagram of water samples from the study area

Hydro-chemical Analysis for Ion Concentrations

Based on the local hydro-geological circumstances, water samples were categorized into four categories: groundwater, drain water, mixed water and surface water. The study area has a variety of major characteristics and hydrochemistry of the water that was sampled (Figure 5). For groundwater, the average total dissolved solid (TDS) content was 3483 mg/L, with Na+ as the dominant cation with 423 mg/l and SO_4^{2-} with a value of 1912 mg/l as the dominant anion(s). A rapid increase in the major ion concentration along the flow path was found in drainage water. The content of sulfate (SO_4^{2-}), which fluctuated between 1245 mg/L and 3705 mg/L, was the most variable of anions in drain water. TDS is quite comparable to $SO_4^{2-}$and varied from 2260 mg/l to 6245 mg/l (Figure 5), followed by HCO_3^- (366 mg/L) and Cl^- (86 mg/L). The main dominant cation, Ca^+, had a concentration range from 11mg/L to 400 mg/L, whereas Na^+'s concentration ranged from 223mg/Lto 949 mg/l. The concentrations of minor cations, such as Mg^{2+} and K^+, were generally steady. The typical total dissolved solid (TDS) level for mixed water was 2026 mg/L. The most variable anion in the mixed water was sulfate (SO_4^{2-}), which varied in concentration between 189 mg/l and 2319 mg/L. Ca^+, with a concentration of 255 mg/l, was the most dominant cation. Additionally, HCO_3^- (295 mg/L) and Cl^- (57 mg/L) concentrations were reported. The surface water included the majority of the freshwater samples that have TDS levels under 733 mg/L. 309 mg/l was the amount of sulfate (SO_4^{2-}) present. The content of Ca^+ ranged from 38 mg/L to 205 mg/L. Furthermore, the concentration for Na^+ was (63±5.2 mg/L). Other small anions and cations, however, were generally present in steady amounts.

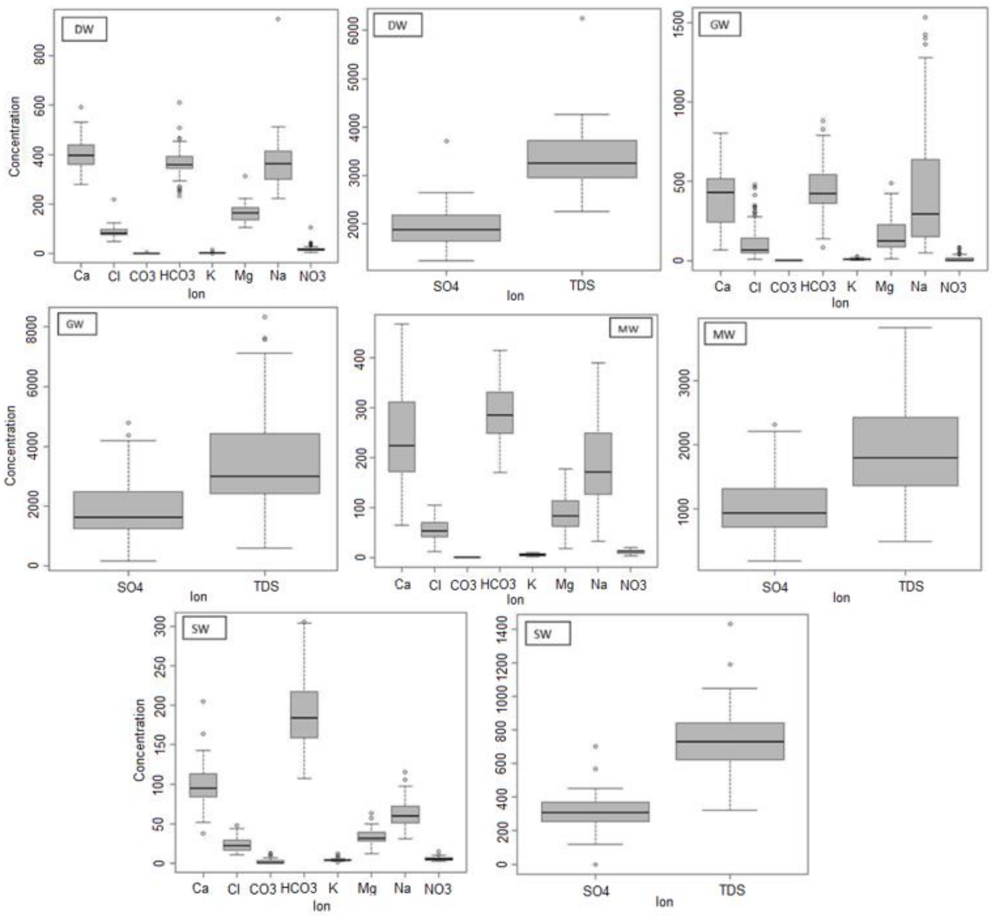

Figure (5): Boxplot of the water samples of the major ions

Data Analysis and Summary of Statistics

This study used R software to create a mixed model with two-factor repeated measure analysis, utilizing flow regime as the between-subject factor and year as the within-subject factor. This study included the subject's field ID as a random effect to account for repeated measures. This study's experimental data includes one continuous response, TDS and two categorical predictors, flow regime and year. Surface water, groundwater, mixed water and drain water from the fixed flow regime. Year is another fixed element with five levels (2014, 2015, 2016, 2017 and 2018). Covariates included year-flow regime interaction. Flow ID, a random factor representing 25 sampling locations: (S1, S2, S3, S4, Outlet (drain location), A1, A2, A3, A4, G1, G2, G3, G4, G5, G6, G7, G8, G9, G10, G11, G12, G13, G14, G15 and G16) and more details about the location and the type of each sampling site are provided in Figure 1. Since the experiment consists of two factors: a year with five levels (2014, 2015, 2016, 2017 and 2018) and a flow regime with four levels (surface water with 2 locations, groundwater with 16 locations, mixed water with 1 location and drain water with 6 locations), the total sample size is {5*2+5*16+5*1+5*6 = 125}. In other words, we can say that we have 25 locations (Flow ID) and 5 repeated measures, which is equal to 25*5 = 125. Table 1 summarizes the sample size, number of observations, mean, standard error and standard deviation of the total dissolved solids (TDSs) for each year (2014-2018). As we see, the highest TDS mean was for 2017. Also, Figure 6 summarizes the statistics of the total dissolved solids for each flow regime. The summary of statistics for TDS within the boxplot includes outliers, maximum, minimum, first quartile, third quartile and median. The boxplot figure would not give us enough information; so, the interaction plot would provide us with more information about the observed data, as shown in Figure 7. The lines of the four flow-regime levels are not parallel at some levels of the year. So, we might expect that there would be a statistically significant interaction that will be examined in the model.

Table 1. Summary of statistics

Year	n	mean	sd	SE
2014	25	2845	1095	219
2015	25	3110	1184	237
2016	25	3254	1729	346
2017	25	3376	1551	310
2018	25	3190	1375	275

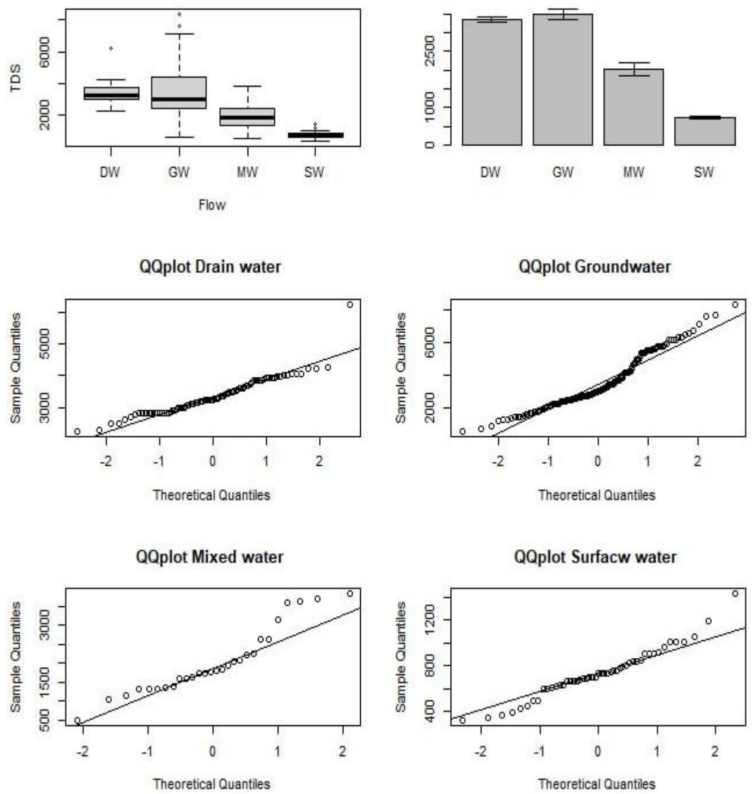

Figure (6): Boxplot, bar plot and Q-Q plot for observed data (TDSs)

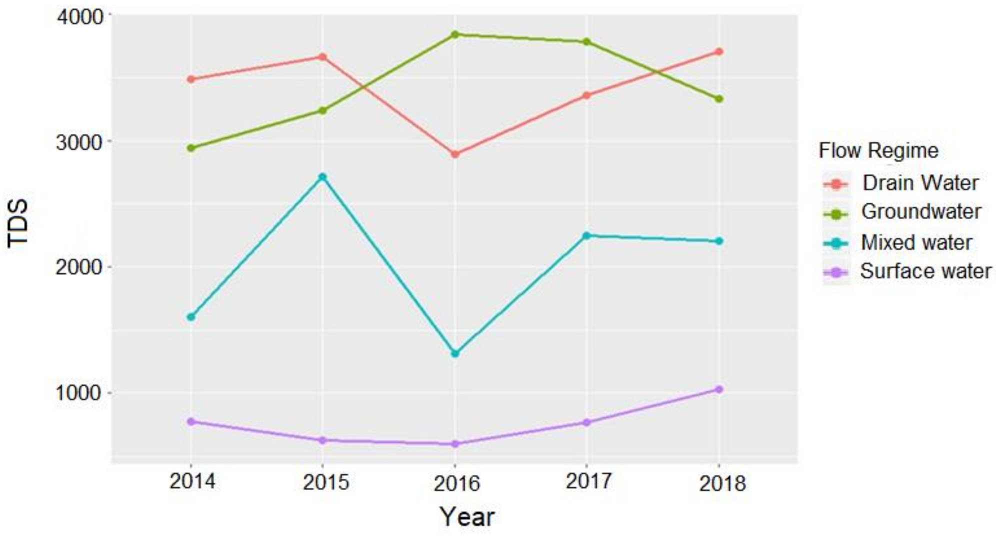

Figure (7): Interaction plot of observed data

Results of Two-factor Repeated Measured Model

Since the value of TDS has become a water-quality issue in recent decades, it's important to understand how salt concentrations change with time and flow regime. A model of 2-factor repeated measures with covariate design was built using R and five packages. A mixed model was fit using total dissolved solids (TDSs) as the response. Fixed effects included flow regime and year plus (flow regime * year). Flow ID was included as a random effect to account for repeated measures. The model of 2-factor repeated measures with covariate design is:

$$Y_{ijk} = \mu + \alpha_i + \beta_{j(i)} + \tau_k + (\alpha\tau)_{ik} + \epsilon_{ijk} \quad (1)$$

where Yijk is the response variable that refers to the TDS value in our study. μ, αi, βj (i) and (ατ)ik are fixed effects in the model, τk is the effect of the k^{th} level of flow regime in the model, ϵijk is the independent factor in the model, i is the level factor (year), j is the level factor of flow ID, k is the level of flow regime, αi is the effect of the i^{th} level of year, βj is the effect of the j^{th} level of flow ID, (αβ)ij is the interaction effect when the i^{th} level of year and the j^{th} level of flow regime are used together.

This model requires independent, normally distributed variables with zero means and two homogeneous variances. We tested three models with different covariance structures. In the first simple model, compound-symmetric covariance is assumed. The second model used unstructured covariance. The final model used auto-regressive covariance. Table 2 shows that model #3 has the lowest AIC; so, we chose it. Model #3's random effect has a flow ID standard deviation of 916.0979 and a residual standard deviation of 803.8041. This study will examine model 3 using a diagnostic plot. In the diagnostic plot (Figure 8), the residuals *vs.* fitted values plot shows that errors have a wide range of values. The surface-water regime, where total dissolved solids vary less, could clarify this variance. In Table 2B, The ANOVA table shows that year-flow regime interaction is not significant (P value = 0.2063 > 0.05). Time does not affect TDS value with a p-value of 0.4578 in the test of the main effect of the year (time). The main effect of the flow regime on TDS value is significant (p-value = 0.0067). So, each flow regime has a different TDS value. The ANOVA table shows no significant interaction between time and flow regime; so, emmean outputs are calculated to check pairwise comparison using Tukey (a single-step multiple comparison procedure used to find significantly different means) adjustment to analyze the main effects of factors and compare flow-regime levels at each year level. Since the contrasts are not statistically significant, Table 3A shows that TDS value does not change with time for all flow regimes. Also, Table 3B shows a significant contrast output between surface water and drain water for most of the time, indicating that the two tested flow-regime levels affect the TDS value, which makes logic, since surface water has a lower TDS value. Since averaging over the year is not significant, Table 3C shows the outcome. In the emmean result, all confidence intervals except for surface water don't include zero, indicating that flow-regime levels affect TDS value.

Also, drain water has a higher estimated mean for TDS than other flow regimes.

Table 2A. Model comparison according to AIC

Model Number	df	AIC
Model1	22	1842.066
Model2	32	1841.875
Model3	23	1833.134

Table 2B. ANOVA output

Year	numDF	denDF	F-value	p-value
(Intercept)	1	84	59.80747	<.0001
Year	4	84	0.91746	0.4578
Flow regime	3	21	5.36049	0.0067
Year, Flow regime	12	84	1.35088	0.2063

Table 3A. Pairwise comparisons for different flow regimes

Flow regime = Drain water					
Contrast	**Estimate**	**SE**	**df**	**t-ratio**	**p-value**
2015 - 2014	177.48	394	84	0.451	0.9461
2016 - 2014	-591.76	487	84	-1.214	0.5497
2017 - 2014	-129.80	530	84	-0.245	0.9873
2018 - 2014	216.36	552	84	0.392	0.9612
Flow regime = Groundwater					
Contrast	**Estimate**	**SE**	**df**	**t-ratio**	**p-value**
2015 - 2014	296.24	241	84	1.229	0.5404
2016 - 2014	901.34	298	84	3.020	0.0124
2017 - 2014	839.69	325	84	2.585	0.0405
2018 - 2014	389.33	338	84	1.152	0.5897
Flow regime = Mixed water					
Contrast	**Estimate**	**SE**	**df**	**t-ratio**	**p-value**
2015 - 2014	1111.88	964	84	1.153	0.5888
2016 - 2014	-288.00	1194	84	-0.241	0.9877
2017 - 2014	646.97	1299	84	0.498	0.9320
2018 - 2014	599.14	1352	84	0.443	0.9483
Flow regime = Surface water					
Contrast	**Estimate**	**SE**	**df**	**t-ratio**	**p-value**
2015 - 2014	-145.40	682	84	-0.213	0.9908
2016 - 2014	-174.21	844	84	-0.206	0.9915
2017 - 2014	-6.47	919	84	-0.007	1.0000
2018 - 2014	254.57	956	84	0.266	0.9845

Table 3B. Contrast output for each year

Year = 2014					
Contrast	**Estimate**	**SE**	**df**	**t-ratio**	**p-value**
Groundwater - Drain water	-545	571	21	-0.955	0.6503
Mixed water - Drain water	-1884	1289	21	-1.462	0.3540
Surface water - Drain water	-2715	974	21	-2.787	0.0300
Year = 2015					
Contrast	**Estimate**	**SE**	**df**	**t-ratio**	**p-value**
Groundwater - Drain water	-427	571	21	-0.747	0.7742
Mixed water - Drain water	-949	1289	21	-0.737	0.7801
Surface water - Drain water	-3038	974	21	-3.119	0.0144

Year = 2016					
Contrast	**Estimate**	**SE**	**df**	**t-ratio**	**p-value**
Groundwater - Drain water	948	571	21	1.660	0.2624
Mixed water - Drain water	-1580	1289	21	-1.226	0.4843
Surface water - Drain water	-2297	974	21	-2.358	0.0736
Year = 2017					
Contrast	**Estimate**	**SE**	**df**	**t-ratio**	**p-value**
Groundwater - Drain water	424	571	21	0.743	0.7768
Mixed water - Drain water	-1107	1289	21	-0.859	0.7089
Surface water - Drain water	-2591	974	21	-2.661	0.0393
Year = 2018					
Contrast	**Estimate**	**SE**	**df**	**t-ratio**	**p.value**
Groundwater - Drain water	-372	571	21	-0.652	0.8256
Mixed water - Drain water	-1501	1289	21	-1.165	0.5211
Surface water - Drain water	-2677	974	21	-2.748	0.0326

Table 3C. Emmeans and confidence-interval output

Flow regime	**Emmean**	**SE**	**df**	**Lower CL**	**Upper CL**
Drain water	3421	386	24	2623.7	4218
Groundwater	3426	237	21	2934.4	3918
Mixed water	2017	946	21	49.3	3984
Surface water	757	669	21	-633.9	2149

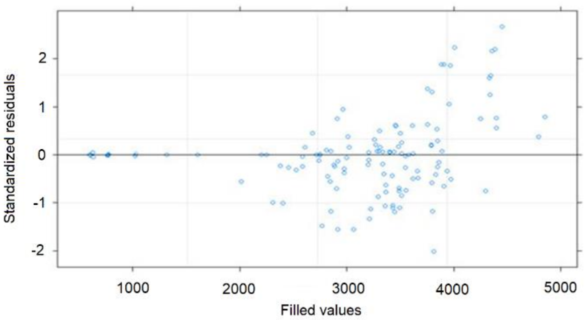

Figure (8): Diagnostic plot

Analytical Methods for Assessment of Water Quality

To determine whether drainage water was suitable for irrigation, EC, pH and major-anion and- cation values were used to calculate SAR (Sodium Adsorption Ratio), % Na, RSC, KI, MR, LSI, PI and PS. First, electrical conductivity can indicate crop-salinity risk. The high salt content of irrigation water increases soil-solution osmotic pressure. Water salinity is classified as low when EC<0.25 and medium when EC ranges between 0.25 and 0.75. Also, water is classified as having high salinity when EC values are between 0.75 and 2.25. Last, when EC > 2.25, water is classified as having a very high salinity level (Güngör & Arslan, 2016).

Comparing field data (EC 3.38±0.18), we are 95% confident that the water in the research area contains significant salinity, affecting crop development.

The majority of plant and soil species can survive in low salinity. Moderately salt-tolerant plants can grow in medium-salinity waters. With proper management, high-salinity water can be used for irrigation, but very high-salinity water is only for plants that can tolerate extreme salt levels. Salt content (SAR) is another irrigation water-quality chemical indicator (Arslan & Demir, 2013). SAR is calculated using Equation (2) (Abdel Khalek et al., 2023). All equations include ion concentrations. Comparing field data to standard SAR limit values, a 95% confidence interval suggests that most water samples are unsuitable for irrigation purposes. The SAR-estimation confidence interval is 21.8 ± 1.7. Water quality is classified as excellent when SAR is <10 and good when SAR ranges between 10 and 18. Also, water is classified as having a doubtful water quality when SAR values are between 18 and 26. Last, when SAR> 26, water is classified as having an unsuitable water-quality level.

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}. \quad (2)$$

Salt content in irrigation waters is generally reported as a percentage. Water's irrigation suitability is also determined by Na percentage. %Na was calculated using Equation (3). According to Wilcox and Durum (1967), water sample classification is based on the percentage of Na. Comparing field data and maximum limitations, irrigation water has a satisfactory sodium content. We have 95% confidence that the %Na value is 37.9±1.5. Water quality is classified as excellent when %Na is <20 and good when %Na ranges between 20 and 40. Also, water is classified as having a permissible water quality when %Na values are between 40 and 60. while water is classified as having a doubtful water quality when %Na values are between 60 and 80. Last, when %Na > 80, water is classified as having an unsuitable water-quality level.

$$\%Na = \frac{Na*100}{(Na+Ca+Mg+K)}. \quad (3)$$

Residual sodium carbonate (RSC) is excess carbonate and bicarbonate over calcium and magnesium in sampled water. RSC categories of drainage water are classified according to Eaton (Eaton, 1950). Every RSC result below 1.25 indicates a satisfactory water quality. Water salinity is classified as good when RSC < 1.25 and medium when RSC ranges between 1.25 and 2.5. Last, when RSC > 2.5, water is classified as unsuitable.

$$RSC = (HCO_3 + CO_3) - (Ca + Mg) \quad (4)$$

Waters in our study having an index value less than one (0.73±0.06) are considered to be appropriate for irrigation, according to Kelly's index (Kelly, 1940). Equation (5) is used to calculate the Kelly index.

$$KI = \frac{Na}{Ca+Mg}. \quad (5)$$

The magnesium ratio (MR) in irrigation fluids should be less than 50%, since values higher than 50% may cause a sodicity issue in the soil. For our case study, the MR value is equal to (0.282±0.09), which is less than 50%, making water suitable for irrigation. Equation (6) (Szabolcs, 1964) is used to compute MR.

$$MR = \frac{Mg}{Ca+Mg}. \quad (6)$$

When soil moisture is less than 50%, potential salinity (PS) determines the risk of a high salt concentration from Cl and SO_4, raising the soil solution's osmotic potential. This measure divides waters into excellent (3mmolc L1), moderate (3-15mmolc L1) and not recommended (>15mmolc L1) (Delgado et al., 2010). Potential salinity was calculated using Equation (7). According to our field data, the PS value of (6.6±0.37) indicates moderate irrigation water.

$$PS = Cl + \frac{1}{2}SO_4. \quad (7)$$

Na-, Ca-, Mg-and HCO_3-rich water impacts soil permeability over time. According to Doneen (1964), waters with permeability-index (PI) values over 75 are class 1 and best for irrigation, followed by class 2 (25-75) and class 3 (< 25). The PI value of (41.4±1.47) obtained from Equation (8) indicates modest irrigation-water availability.

$$PI = \left[\frac{Na+\sqrt{HCO_3}}{Ca+Mg+Na}\right] \times 100. \quad (8)$$

The water used in drip irrigation should not clog the drippers. The clogging risk of emitters is based on the Langelier saturation index (LSI). The LSI is positive and supersaturated with $CaCO_3$ if the actual pH exceeds pHs. In this situation, the water is prone to forming scale and capable of clogging the drippers (Langlier, 1936). Equation (9) is used to determine the Langelier saturation index (LSI). Since LSI for our study area is nearly equal to zero, it is concluded that the sampled water is appropriate for irrigation.

$$LSI = pH - pH_s; \quad (9)$$

where, pH = actual pH of the water and
pHs = pH at which water having the same alkalinity and calcium content is just saturated with calcium carbonate.

All water-quality index boxplots for all flow regimes in the study area are shown in Figure 9. RSC clearly dominates all flow regimes. For the study region, drain water, groundwater, mixed water and surface water had the highest indices, successively. These indices indicate that saline water in the research area is suitable for irrigation.

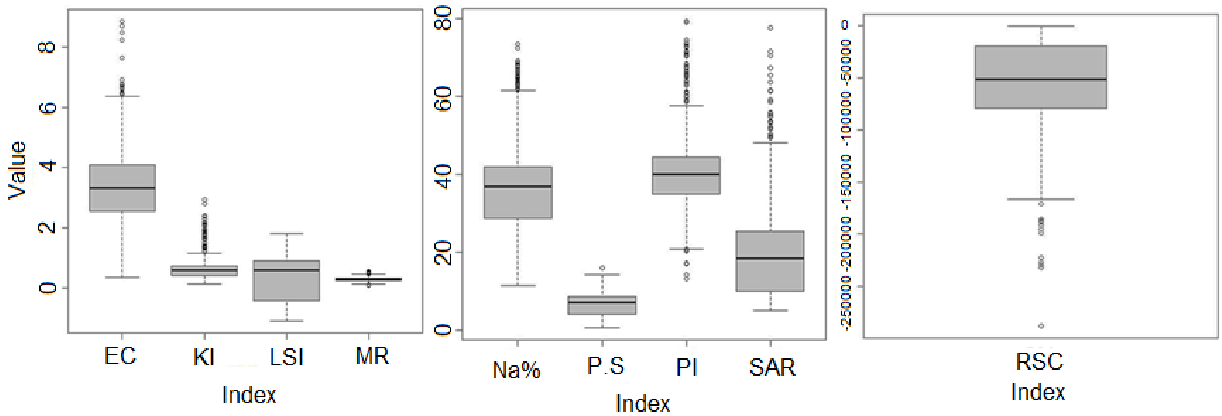

Figure (9): Boxplots for water-quality indices

Principal Component Analysis (PCA)

This study uses PCA, a popular multi-variate method. The PCA data-reduction method specifies how many variables are needed to understand data variance. PCA can explain the same variance with fewer variables (Wu & Wang, 2007). PCA also attempts to describe the relationship between observations using underlying characteristics (Yu et al., 2003). This research used R's (prcomp) function for PCA analysis. Figure (10) shows that the first two principal components explain 58% of data variation. The PCA plot separates flow regimes effectively. PCA showed that temperature, specific conductivity and total dissolved solids explain most water-quality differences.

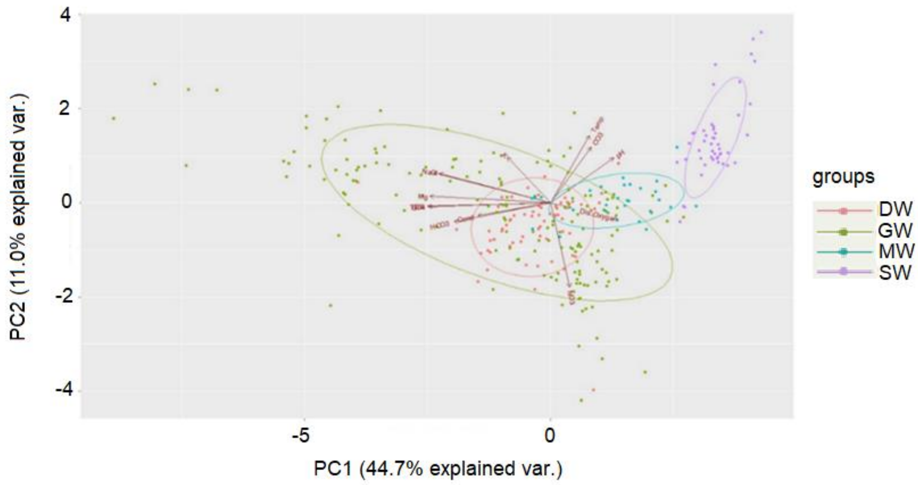

Figure (10): Plot for principal component analysis

CONCLUSIONS

Salt concentration rate is statistically analyzed over time and flow regimes in this paper. Statistical models simulate groundwater, drain-water, surface-water and mixed-water TDS transit. The model results are used to assess water reuse for irrigation purposes. This study concluded that water from different flow regimes can be used for irrigation purposes based on water-quality index and statistical analysis. Statistical models' general conclusions are:

- Results obtained from the ANCOVA model show no interaction between time and flow regime.
- Results obtained from the ANOVA model show a non-significant time (year) influence on TDS values.
- Results from Tukey adjustment pairwise model were used to compare TDS means for each year for each flow regime. The results were statistically

insignificant, proving that TDS means vary by flow regime, but not over time. However, the flow regime's principal TDS effect is significant. This shows that flow regime affects TDS results.

- Results obtained from PCA analysis showed that 58% of temporal and spatial fluctuations affect drain-, groundwater-and surface-water quality with fewer variables. The strongest connection between ion concentrations in the research region is between TDS value and SO_4.

These results provide insights into the impact of tile drains on watershed-wide salinity transport and can be used to help guide salinity management in irrigated, drained landscapes. Future studies should employ statistically-developed models to evaluate water quantity and quality on a watershed scale and apply these statistical models to different study regions and time ranges to analyze study implications and uncertainties. In general, statistical models can be a useful tool in simulating salinity transport in tile-drained watersheds and investigating salinity best management practices. The present study is based on statistical analysis of water samples for a limited period of time and for a specific study area.

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