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UNIVERSITY OF CALIFORNIA, MERCED

Seasonal Contamination by 1,2,3 – Trichloropropane in California's San Joquin Valley

Thesis for the Degree
Master of Science

in

Environmental Systems

by

Angela A. Rosales

Thesis Committee:
Professor Peggy O'Day
Professor Andrea Joyce
Professor Colleen C Naughton

2026

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Thesis of Angela A. Rosales is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

Professor Peggy O'Day, Chair

Professor Andrea Joyce

Professor Colleen C. Naughton, Advisor

University of California, Merced
2026

Dedication

For the San Joaquin Valley.

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List of Abbreviations

Abbreviation	Definition
GAMA GIS	Groundwater Ambient Monitoring Assessment Groundwater Information System
MCL	Maximum contaminant level
SJV	San Joaquin Valley
TCP	1,2,3 – trichloropropane
WSRT	Wilcoxon Signed Rank Test

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Thank you to my family and especially my parents to whom I am eternally grateful for. You've given me everything and more. I love you.

Thank you to the Food Energy Water Systems for the Underserved for welcoming me as an undergraduate and for their support and friendship. I will miss our field days.

Thank you to Hope Hauptman who mentored me as undergraduate through lab research and continued to offer support and guidance during my graduate research. Your help is greatly appreciated, and I feel very fortunate to have been able to work directly alongside you.

Thank you to Colleen for believing in me as a candidate for FACTS Summer Bridge program as an incoming undergraduate to UC Merced, if it were not for us meeting then I may have never pursued education beyond my bachelor's degree. I am very fortunate to have had the opportunity to conduct research in your lab, your expertise and experience offered valuable guidance toward my research. Thank you to the University of California Climate Action Grant for funding this research.

Curriculum Vitae

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Education

Master of Science (M.S.) Environmental Systems

University of California, Merced, 2026

Thesis: Seasonal Groundwater Contamination in California's San Joaquin Valley

Bachelor of Science (B.S.) Environmental Engineering

University of California, Merced, 2023

Associate of Science (A.S.) Natural Science

Napa Valley College, 2021

Associate of Science (A.S.) Natural Science and Mathematics

Napa Valley College, 2021

Relevant Experience

Graduate Student Researcher - Environmental Systems University of California, Merced
Merced, CA · August 2024-Present

- Conducted analysis of reduced water flow on wastewater collection systems in the City of Sacramento
- Updated existing wastewater collection systems model using Microsoft Excel
- Led research assessing seasonal impacts of groundwater contamination from 1,2,3 – trichloropropane
- Created geospatial maps using ArcGIS Pro v. 3.6.1 to assess hotspots of contamination and under multiple land use types
- Wrote code in R Studio v. 4.5.0 to compute statistical analysis and create figures and tables summarizing results
- Collaborated with research labs do conduct laboratory experiments using gas chromatography
- Created laboratory experiment to be shared with K-12 grade students demonstrating a simplified model of electrochemical water treatment to be shared at internal university workshops and community organizations
- Coordinated and led workshops at internal university events and at outside community workshops and organizations for grade school age students and the public to electrochemical water treatment and drinking water resources
- Mentored two undergraduate students and provided them opportunities to gain technical lab skills

Science and Engineering of Environmental Sensors Research Incubator, University of California, Merced, CA · January 2025 – June 2025

- Participated in a collaborative team to learn about and develop nanomaterials for environmental sensing applications
- Communicated effectively across multiple scientific and engineering based disciplines to bridge materials science and environmental monitoring
- Showcased final project at internal internship presentation to other participating students and faculty

Sustainable Agriculture from Farm to Lab, University of California, Merced
Merced, CA · February 2025

- Participated in a month-long program to perform analyses to learn field and laboratory research techniques
- Attended field visits of UC Merced Vernal Pools to collect soil samples in a team
- Used highly sensitive laboratory equipment to analyze soil samples to determine physical and chemical properties

Tutor, Sylvan Learning Center
Fairfield, CA · February 2024 – August 2024

- Provide k-12 grade students with support in reading, writing mathematics and science
- Communicated with student parent/guardians regarding progress and session updates
- Implemented daily lesson plans to build on existing knowledge
- Adapted instructional support to accommodate students with varying learning abilities
- Used reward systems to keep focus and motivation during each session

Facilitating Agriculture Related Mentoring for Emerging Scholars, University of California, Merced
Merced, CA · April 20203 – May 2023

- Collaborated in pairs to create and deliver lesson plans for elementary-aged students concerning food production
- Delivered presentations weekly to local elementary school students to engage students with relevant material
- Met with other program participants biweekly to share updates and give and receive helpful advice on developing lesson plan and student engagement with material

Undergraduate Researcher - Food Energy Water for Underserved Research Lab,
University of California, Merced
Merced, CA · September 2022 – December 2023

- Assisted with graduate level research by performing experiments in a professional laboratory setting under supervision of graduate student
- Operated radiation producing machine to observe electron microscopy
- Conducted imagery analysis of almond biochar using Image J

- Created and translated informational documents containing drinking water information and resources to be shared with the public

Larson Park Project - El Capitan Hotel, University of California, Merced
Merced, CA · March 2022 – April 2022

- Collaborated with a multidisciplinary team of students to create a conceptual design for an urban park in downtown Merced, CA
- Met with a team weekly to collaborate and share ideas for a proposed space that: creates energy and sense of community, promotes outdoor engagement, provides art and visual interest within neighborhood and is available for day and nighttime use
- Presented final design model to El Capitan Hotel staff

Food and Agriculture Cyberinformatics Tools and Science Research, University of California, Merced
Merced, CA July 2021 – August 2021

- Attended weekly field visits to outside laboratories and farms to learn about agricultural automation
- Attended weekly workshops and presentations from UC Merced faculty and industry professionals regarding agriculture based research
- Contributed to graduate level research as an undergraduate by helping build “CO2bies” to be used for the monitoring of greenhouse gas emissions from soil
- Presented final research in collaboration with a team at internal conference

Presentations

Seasonal Groundwater Contamination in California by 1,2,3 – Trichloropropane [Oral].
University of California, Riverside · Latinxs and the Environment Conference
October 2025

Seasonal Groundwater Contamination in California by 1,2,3 – Trichloropropane
[Poster].
Duke University · Association of Environmental Engineering and Science Professors
May 2025

Could Containerized Reverse Osmosis Systems be Run Entirely on Solar Energy for Rural Communities? [Poster]. University of California, Merced · Energize Merced
April 2025

Society of Women Engineers [Panelist]. University of California, Merced · Expanding Your Horizons
March 2025

Affiliations

Society of Women Engineers

August 2021 – December 2023

Awards

Graduate Student Professional Development Travel Fellowship (2024)

Damian Maldonado Memorial Scholarship (2018)

Seasonal Groundwater Contamination by 1,2,3 – Trichloropropane in California's San Joaquin Valley

By Angela A. Rosales
Master of Science in Environmental Systems
University of California, Merced
Professor Colleen C. Naughton, Advisor

Abstract

The San Joaquin Valley is a rural, agricultural area in California with high rates of poverty and food and water insecurity. Applications of soil fumigants and pesticides in agriculture are widely understood to be a leading cause in groundwater contamination. From the 1940s until the mid-1980s in California, agricultural production often involved the use of pesticides, particularly those containing 1,2,3-Trichloropropane (TCP). After numerous studies found that TCP caused cancer and infertility in mice, TCP was banned from agricultural use in the 1980s. TCP, however, remains in groundwater at concentrations exceeding state regulations, especially in the San Joaquin Valley. Previous toxicology studies suggest that TCP is unsafe even at its lowest detection limit, 0.005 µg/L. One of the most assumed but understudied determining factors of contamination level is precipitation.

This study statistically analyzes Groundwater Ambient Monitoring and Assessment (GAMA) Groundwater Information Systems data from 2020-2024 to determine if TCP concentrations vary by season (wet vs. dry). Wet season is defined from October through April, and dry season is defined as May through September. Understanding potential fluctuations with seasonality may help domestic well users and municipal water system operators understand when water quality may be at its lowest or highest levels of contamination. Individual wells were averaged for each county by year and season. Results showed variation in sampling amounts by year, individual wells and well type. Three out of eight SJV counties had significant ($p < 0.05$) differences between seasonal contamination levels, where each of those counties had higher contamination during the wet season. Further research is recommended with longer term data, comparing to soil type, and more sampling at varying well depths. Additional TCP remediation needs to address needs and factors for water treatment for Central Valley residents. This should be done with a One Water approach through engagement with the local public to meet long-term community and environmental needs.

1. Introduction

In the State of California where groundwater wells are a primary water source for over 40% of the population, the risk of groundwater contamination remains high due to past and current fertilizer, pesticide and industrial applications (CAWB 2025). The San Joaquin Valley (SJV) is at risk of higher rates of groundwater contamination due to heavy applications of pesticides, especially those containing 1,2,3, trichloropropane (TCP) (Hauptman et al. 2023). TCP is found to exist as an impurity mixture previously used in soil fumigants during the manufacturing of Telone and dichloropropane-dichloropropene (DD) mix (IARC 1995). DD mix became available in 1942, and large scale use of these TCP containing fumigants began in the 1950s until they were banned in California in 1984 (Deely et al. 1991, Loague et al. 1998, Cardozo et al. 1988). Although TCP has been out of use in agricultural applications for decades, it is a chlorinated hydrocarbon, making it highly stable and persistent in the environment (Samin & Janssen 2012). In addition to agricultural applications, TCP is a main ingredient in solvents and is an extracting agent (found in paint and varnish remover, cleaning and degreasing agents, and cleaning and maintenance solvents) and is typically found at industrial and hazardous waste sites (Dombeck & Borg 2005, ATSDR 1992). TCP is denser than water and is assumed to exist at deeper groundwater depths (IARC 1995). For these reasons, TCP continues to exist in groundwater at high levels of contamination.

Animal studies have determined short term exposure of TCP to cause eye and/or throat irritation, and long-term exposure has been shown to cause liver and kidney damage and reduced body weight (USNTP 1993). In 1992, TCP was recognized as a chemical known to the State of California to cause cancer under California's Safe Drinking Water Act and Toxic Enforcement Act (Proposition 65).

After its discovery at a Southern California superfund site, Burbank Operable Unit in Los Angeles County, the California Water Boards established a notification level of 0.005 µg/L. This value is based on associated cancer risk from laboratory animal studies (CWB 2025) which is the same concentration as the analytical reporting limit. Human exposure to TCP is most likely through inhalation of ambient air and ingestion of drinking water (ATSDR 1995). TCP unfortunately, is not the only harmful chemical that exists in groundwater; however, little to none is known about concentration fluctuations between seasons. Notably, communities of color – and in the case of the SJV, Latino communities- are more likely to be served by water systems that violate state/federal limits set forth for contaminants (Balazs et al. 2012).

It is widely understood that variations in groundwater quality are primarily controlled by natural processes such as runoff, infiltration and precipitation (Trivedi et al. 2010, Machiwal & Jha 2015). Multiple studies have shown that one of the most predictable factors of TCP contamination is precipitation (Hauptman et al. 2023). Hauptman's 2023 study using a Random Forest model found precipitation as the top predictor variable where the highest concentrations of TCP were associated with the lowest rainfall levels. The highest concentrations were recorded in the Southern Central Valley of California where annual precipitation rates are relatively low. These same predictor variables were determined by Rowe et al. (2007) for volatile organic

compounds. A separate study determined similar predictor variables where concentrations of TCP were correlated with concentrations of other agricultural constituents including redox conditions and recharge rates (Burrow et al. 2019).

No previous studies in literature searches, however, have compared contamination levels between wet and dry seasons and analyzed data to determine statistical significance. Measuring contamination levels between seasons may provide helpful indicators on when contamination is higher or lower. This is especially useful information for agriculture communities that have a higher number of residents that rely predominately on groundwater from wells on their properties for domestic use. We hypothesize that contamination will be greater during the dry season due to less groundwater recharge and higher concentration. Understanding potential fluctuations with seasonality may help domestic well users and municipal water systems operators understand when water quality may be at its lowest or highest levels of contamination. This study serves as a framework for future groundwater contamination studies that aim to determine trends from other contaminants. TCP contamination is also a concern in other U.S. states (notably Hawaii and New Jersey) and other countries (e.g., the Netherlands) (Hauptman et al. 2021).

2. Methods

2.1 Data Collection and Organization

California's water year is defined as October 1st through September 30th; however, to conduct a comparison of seasonality, years were divided into a "wet season" and "dry season". Wet season was defined as October 1st through April 30th and dry season was defined as May 1st through September 30th (CDWR 2020). Groundwater data for municipal and domestic wells was downloaded from California State Water Boards Groundwater Ambient Monitoring Assessment Groundwater Information System GAMA GIS (CSWRCB 2025). Prior to download, filters were applied to include records of the most recent five years of data (2020-2024) for SJV counties: San Joaquin, Stanislaus, Merced, Madera, Fresno, Tulare, King, and Kern as defined by San Joaquin Valley Council of Governments (SJVRPC 2025). Additionally, all eight counties' data was merged to create a representative average of the entire SJV. Based on the GAMA GIS data set, Kings County has the smallest number of wells with only 55 wells and the rest of the counties' number of wells ranged from 266 to 641.

Once individual county data files were obtained, R studio v. 4.5.0 was used to clean the data set, statistically analyze the data, and to produce graphical representations comparing seasonal averages per county. Averages were determined for individual wells based on the five-year data set and county averages were determined by all sample results collected during each season and for the entire year for an overall data set. The raw data files contained multiple empty values, 0 values, and modifies ("<" or "="). Values that had a "<" modifier attached were divided by 2, all 0 values were replaced with half of the detection limit (0.0025 µg/L) to avoid incorrectly treating non-detects as zero, and rows with no recorded value were not considered in the analysis (Helsel 1990).

Once the values in the raw data set were adjusted, the next step was to account for outliers in the data. The standard deviation for wet, dry and overall data set was determined and values greater than two standard deviations from the mean were

considered outliers and removed from the data set. Finally, based on the clean data set, values for standard deviation, average, and number of samples for each season were determined and saved to a summary data table.

2.2 Data Visualization

Based on the data collected for contaminant seasonal averages across counties, a graph was created to represent seasonal averages per year and for a five-year average. A cumulative dataset for all eight counties was also included to represent an overall SJV average. The values shown in Figure 1 are cumulative averages of all well points sampled for their respective season. Error bars are used to show where outlier values fall within a county's dataset.

A secondary analysis was conducted by removing wells that were in urban areas that may be more point sources of industrial contamination than past non-point source agriculture applications that maybe more influenced by seasonality. The United States Census Bureau 2020 defines urban areas as representing densely developed territory that encompass residential, commercial and other nonresidential urban land uses where each urban area must encompass at least 2,000 housing units or at least 5,000 people. Urban wells were removed from the dataset using ArcGIS Pro v.3.4.0 by first uploading the urban layer onto each of the counties and then using the "Select by Location" function and selecting wells with the urban layer and then using "Erase" to remove wells within urban borders. Statistical analysis was repeated for this new data set and values recorded to a summary data table.

2.3 Geospatial Mapping

To visually complement the data analysis, three geospatial maps were created using ArcGIS Pro v.3.4.0 to show dry, wet and overall regional distribution. Based on the cleaned data file described in section 2.1, individual well averages for a five-year period were uploaded for each county. Data ranges for the contamination level were determined by ArcGIS Pro v.3.4.0 through Natural Breaks (Jenks) method with four classes chosen to represent the ranges in contamination. The class values were adjusted so that the first range maximum value does not exceed the MCL.

Further analysis was conducted to visualize any relationship between high contamination regions and land use type. Well points were overlaid onto layers representing farmland types and urban land use. Some of the highest levels of groundwater contamination levels in agricultural areas that have previously been observed are through fertilizer and pesticide applications which run off during precipitation events and infiltrate the aquifer (Ayobolu & Eyinla 2022). To determine the farmland type that the wells are on, the California Important Farmland Finder Farmland Mapping and Monitoring Program was applied under the well coordinates (CDC 2025). Separately, an urban regions layer developed by the United States Census Bureau was applied (USCB 2020). To note significant exceedances within urban regions, wells located within an urban border were removed from the data set for a secondary analysis determining statistical significance between seasons. These two parameters were considered most important as the SJV is an agriculturally intensive region and urban

regions are more likely to have higher rates of contamination due to higher population density and industrial activity (Arshad & Rashid 2022).

2.4 Nonparametric Test

The distribution of the well data was heavily positively skewed on a curve toward lower TCP concentrations. Since the data was nonnormally distributed, to determine statistical significance, a nonparametric test was conducted. Using R studio v. 4.5.0, a Wilcoxon Signed Rank Test (WSRT) was conducted on the overall data set for each county. The WSRT makes the following assumptions: (1) two sets of data are dependent and (2) data is nonparametric (Wilcoxon 1950). Due to the inconsistent values in datasets between seasons, only wells that were sampled in both seasons were used to conduct the WSRT. Results for each county were stored in a county summary table as a W statistic and p-value. For the secondary data set in which urban wells were removed, the overall data set was similarly analyzed using the WSRT and results stored in a separate county summary table.

2.5 Precipitation Rates

Precipitation rates were calculated from a single weather station in each county based on available National Weather Service and Weather Underground data (NWS 2026, WU 2026). Precipitation values were summed based on their respective seasonal months to determine seasonal rainfall for each year of analysis.

3. Results

3.1 Data Treatment

All preliminary data treatment and statistics recorded values for the entire five-year data set including sample size, seasonal average, seasonal standard deviation and number of removed data are included in Table 1 and visualized in Figure 1. Merced and Kern County showed the highest average contamination values for wet, dry and overall averages out of all counties. Kings County and Madera County were the only two counties to consistently average below the Maximum Contaminant Level (MCL) for both wet and dry seasons for all five years. There was not a large difference between wet and dry season for the SJV average.

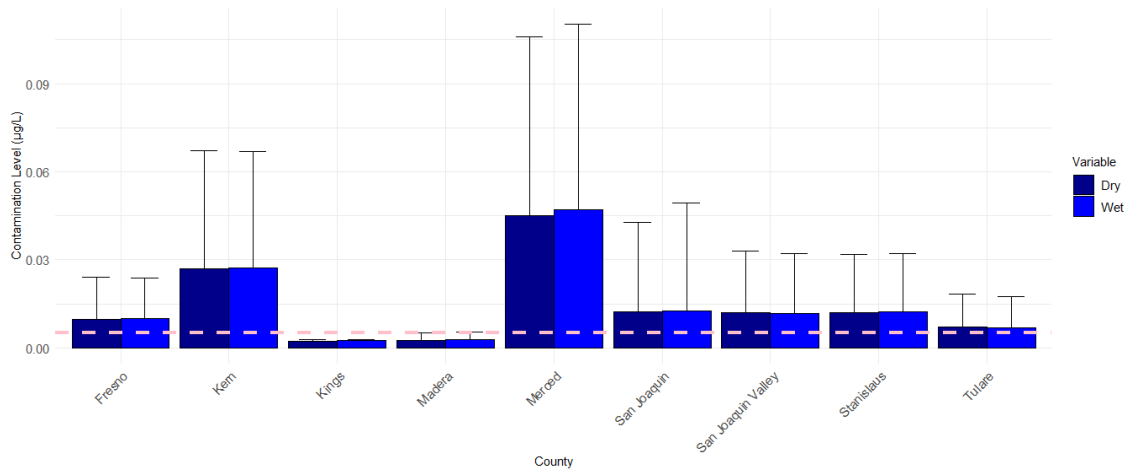


Figure 1 Five-year county averages of TCP well concentrations compared between dry and wet season (GAMA GIS 2025) and the standard deviation shown by the bars. The dashed pink line is the Maximum Contaminant Level; dark blue is dry season (May 1st through September 30th) and blue is wet season (October 1st through April 30th).

Across all counties, the number of samples tested during wet season exceeded the number of samples taken in the dry season. Statistical analysis conducted using the WSRT showed that Fresno, Madera and San Joaquin County all had significant ($p < 0.05$) differences between seasonal contamination levels. The dry season had slightly lower TCP concentrations than the wet season.

Table 1 County summary data table for combined five-year data (2020-2024).

County	Yearly Average (µg/L)	Standard Deviation	Sample Size	Wet Average (µg/L)	No. Wet Samples	Wet Standard Deviation	Dry Average	No. Dry Samples	Dry Standard Deviation	W Statistic	p-value
Merced	0.046	0.062	1584	0.0471	972	0.063	0.0449	612	0.061	308621.5	0.203
Fresno	0.010	0.014	2912	0.00984	1741	0.014	0.00979	1171	0.014	1084648.5	0.003
Stanislaus	0.012	0.020	1999	0.0122	1211	0.020	0.0120	788	0.020	490734.5	0.275
Madera	0.003	0.003	734	0.0029	452	0.003	0.0026	282	0.003	71944.5	0.001
San Joaquin	0.012	0.012	1198	0.0125	757	0.037	0.0123	473	0.031	190200	0.046
Kings	0.003	0.000	87	0.0024	69	0.000	0.0022	31	0.001	1172	0.193
Tulare	0.007	0.011	3075	0.0068	1885	0.011	0.0070	1190	0.011	1156488	0.144
Kern	0.027	0.040	4244	0.0273	2606	0.040	0.0269	1638	0.040	2145606	0.769
San Joaquin Valley	0.012	0.021	11174	0.0116	6979	0.021	0.0118	4195	0.021	14983318	0.034

Further analysis based on single year data showed more notable differences between wet and dry seasons for all five years of data. Figure 2 – Figure 6 shows individual year averages from 2020 through 2024. The largest observed difference in seasonal contamination average occurred in Kern County in 2020 shown in Figure 2 in which the dry average is notably higher than the wet average.

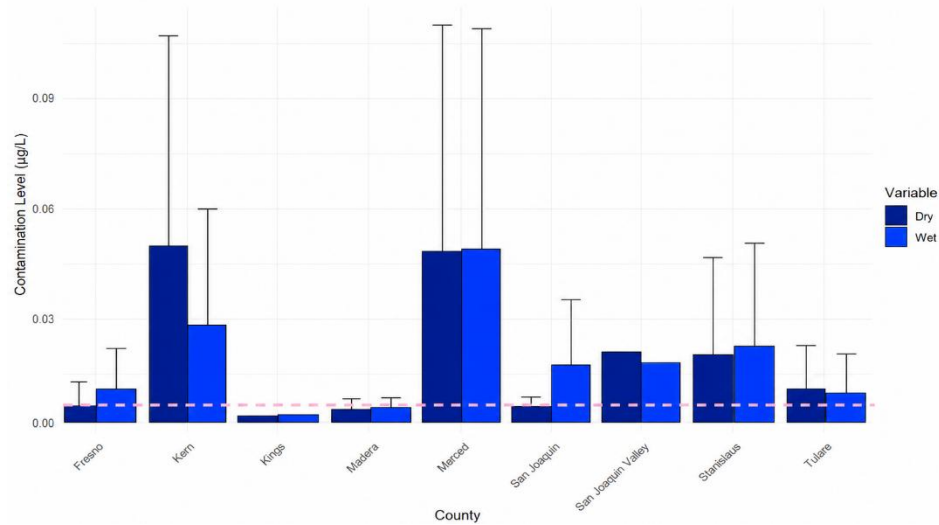


Figure 2 County averages of TCP well concentrations in 2020 compared between dry and wet season with standard deviation shown by the bars. The dashed pink line in the Maximum Contaminant Level (MCL) for TCP, dark blue is dry season (May 1st through September 30th) and blue is wet season (October 1st through April 30th).

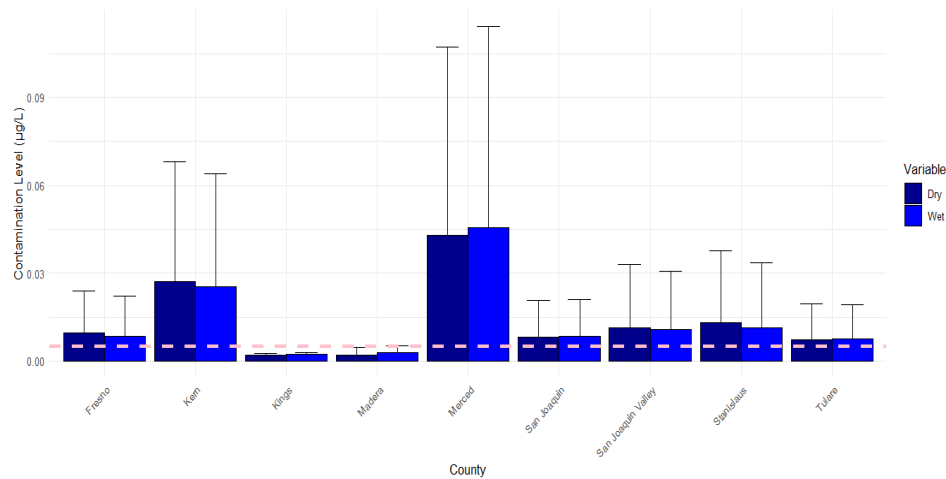


Figure 3 County averages of TCP well concentrations in 2021 compared between dry and wet season with standard deviation shown by the bars. The dashed pink line in the Maximum Contaminant Level (MCL) for TCP, dark blue is dry season (May 1st through September 30th) and blue is wet season (October 1st through April 30th).

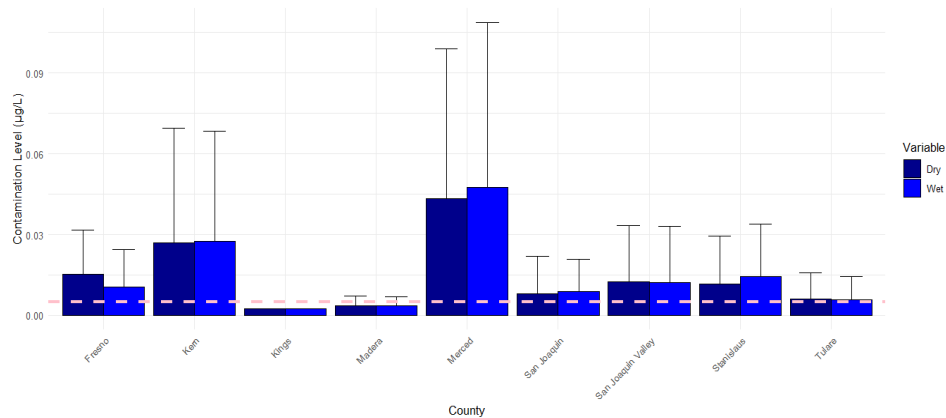


Figure 4 County averages of TCP well concentrations in 2022 compared between dry and wet season with standard deviation shown by the bars. The dashed pink line in the Maximum Contaminant Level (MCL) for TCP, dark blue is dry season (May 1st through September 30th) and blue is wet season (October 1st through April 30th).

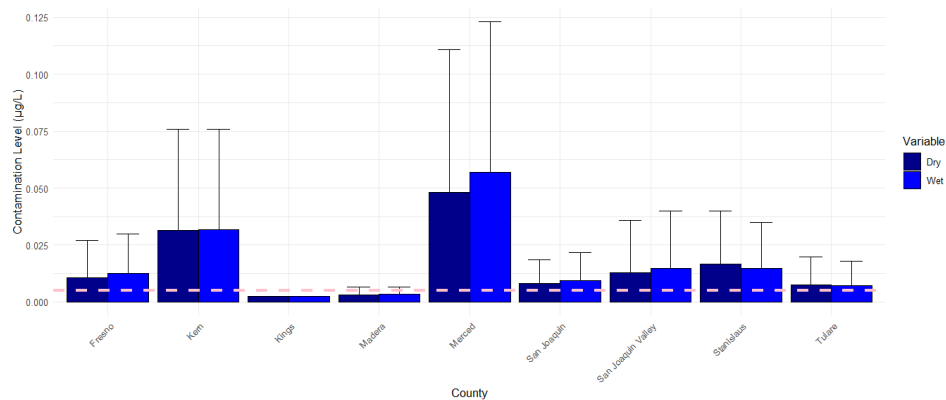


Figure 5 County averages of TCP well concentrations in 2023 compared between dry and wet season with standard deviation shown by the bars. The dashed pink line in the Maximum Contaminant Level (MCL) for TCP, dark blue is dry season (May 1st through September 30th) and blue is wet season (October 1st through April 30th).

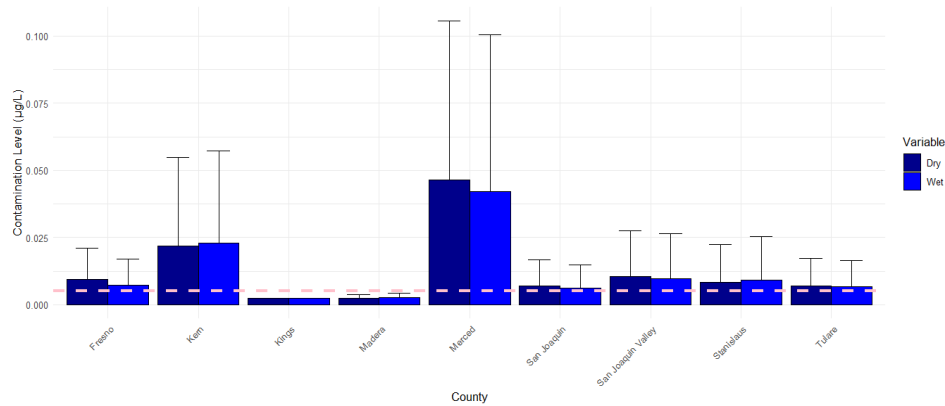


Figure 6 County averages of TCP well concentrations in 2024 compared between dry and wet season with standard deviation shown by the bars. The dashed pink line in the Maximum Contaminant Level (MCL) for TCP, dark blue is dry season (May 1st through September 30th) and blue is wet season (October 1st through April 30th).

3.2 Farmland Type

The top types of farmland type in the SJV were: (1) Prime Farmland, (2) Farmland of Statewide Importance, and (3) Urban and Built-Up Land. Figures 7 and 8, show the well points overlaid onto farmland types.

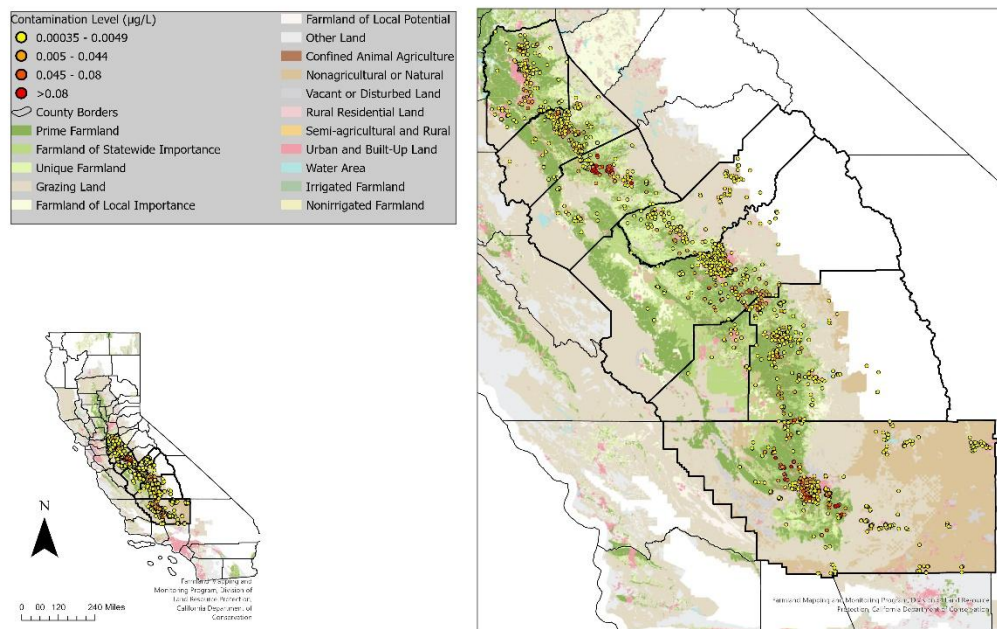


Figure 7 Concentration of 1,2,3 – TCP in domestic and municipal wells for all samples collected in the dry season (May 1st through September 30th, 2020-2024) (GAMA GIS 2025) overlaid onto farmland type (CDC 2025). San Joaquin Valley counties are outlined in bold. From top to bottom, left outright are San Joaquin, Stanislaus, Merced, Fresno, Madera, Kings, Tulare, and Kern counties.

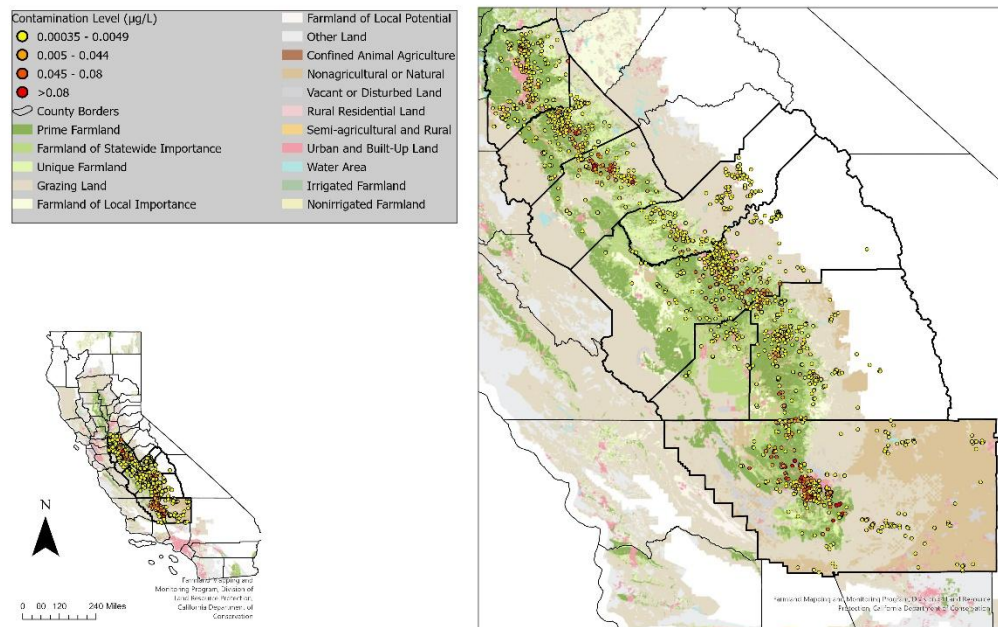


Figure 8 Concentration of 1,2,3 – TCP in domestic and municipal wells for all samples collected in the wet season (October 1st through April 30th, 2020-2024) (GAMA GIS 2025) overlaid onto farmland type (CDC 2025). San Joaquin Valley counties are outlined in bold. From top to bottom, left to right are San Joaquin, Stanislaus, Merced, Fresno, Madera, Kings, Tulare, and Kern counties.

3.3 Urban Regions

The removal of urban wells led to a decrease in the five-year average TCP concentrations seen noted in Figure 11 and Table 2. Most notably were the decrease in wet and dry averages in Merced and Kern Counties from 0.047 µg/L to 0.020 µg/L in the wet season, from 0.045 µg/L to 0.025 µg/L in the dry season and from 0.027 µg/L to 0.013 µg/L in the wet season and from 0.027 µg/L to 0.012 µg/L in the dry season respectively. Additionally, Figures 9 and 10 demonstrate the sample size differences between seasons. Prior to removal of urban wells, each of the counties except for Merced and Kern, showed about equal contamination level for both wet and dry season and after removal of urban wells, the wet season contamination decreased across counties. The only two counties that remained constant during both data treatment methods were Kings and Madera counties.

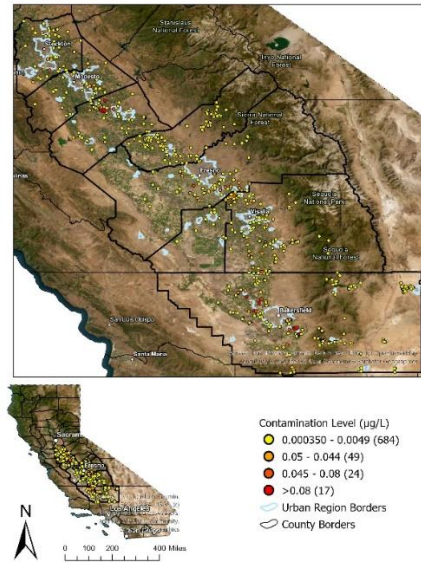


Figure 9 Concentration of 1,2,3 – TCP in domestic and municipal wells for all samples collected in the dry season (May 1st through September 30th, 2020-2024) (GAMA GIS 2025) after the removal of urban wells (USCB 2020). San Joaquin Valley is outlined in bold. From top to bottom, left to right are San Joaquin, Stanislaus, Merced, Fresno, Madera, Kings, Tulare and Kern counties.

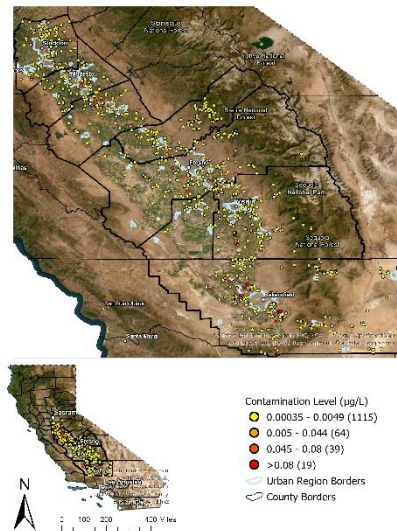


Figure 10 Concentration of 1,2,3 – TCP in domestic and municipal wells for all samples collected in the wet season (April 1st through October 31st, 2020-2024) (GAMA GIS 2025) after the removal of urban wells (USCB 2020). San Joaquin Valley is outlined in bold. From top to bottom, left to right are San Joaquin, Stanislaus, Merced, Fresno, Madera, Kings, Tulare, and Kern counties.

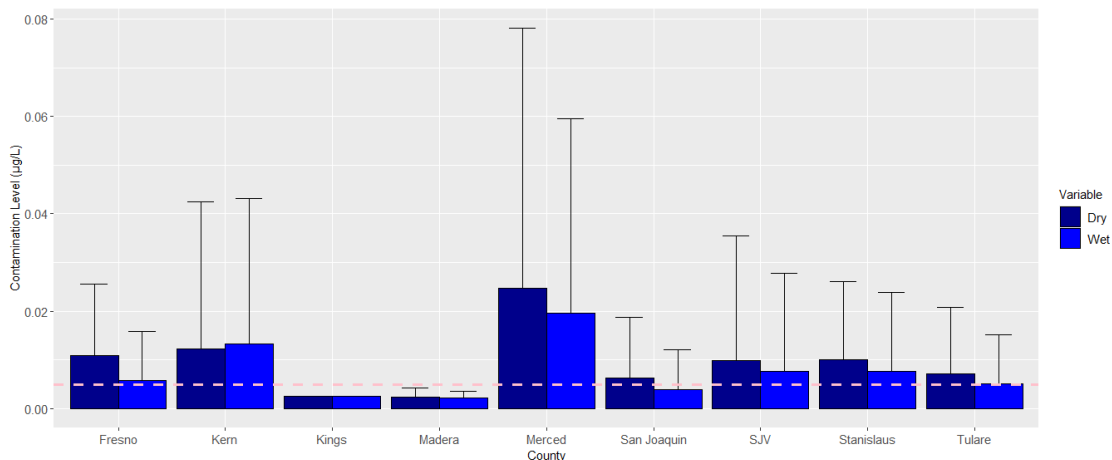


Figure 11 Five-year county averages of TCP wells concentrations compared between dry and wet season after removal of urban wells and the standard deviation shown by the bars. The dashed pink line is the Maximum Contaminant Level (MCL) for TCP, dark blue is dry season (May 1st through September 30th) and blue is wet season (October 1st through April 30th).

The removal of urban wells also caused a decrease in sample size across all counties by hundreds. Statistical analysis was again run using the WSRT determined fewer counties as having statistically significant differences in contamination level between seasons. Fresno had the only statistically significant difference between seasons where TCP concentrations were higher in the dry season (0.011 µg/L) compared to the wet season (0.006 µg/L). Values recorded for Kings County remain constant across seasons and saw no difference between seasonal average or standard deviation so there was not a p-value.

Table 2 County summary data table for combined five-year data after removal of urban wells (2020-2024).

Couty	Yearly Average (µg/L)	Standard Deviation	Sample Size	Wet Average (µg/L)	No. Wet Samples	Wet Standard Deviation	Dry Average (µg/L)	No. Dry Samples	Dry Standard Deviation	W Statistic	p value
Merced	0.022	0.046	172	0.020	98	0.040	0.025	74	0.053	3981.5	0.262
Fresno	0.007	0.012	275	0.006	193	0.010	0.011	82	0.015	6250.5	0.002
Stanislaus	0.008	0.016	133	0.008	94	0.016	0.010	39	0.016	2069	0.215
Madera	0.002	0.002	326	0.0022	191	0.001	0.0023	135	0.002	12364	0.500
San Joaquin	0.005	0.010	210	0.004	148	0.008	0.006	62	0.013	4422.5	0.585
Kings	0.003	0.000	52	0.003	32	0.000	0.003	20	0.000	320	N/A
Tulare	0.006	0.012	336	0.005	206	0.010	0.007	130	0.014	12782.5	0.456
Kern	0.013	0.030	505	0.013	269	0.030	0.012	236	0.030	32365.5	0.689
SJV	0.009	0.022	2009	0.008	1231	0.020	0.010	778	0.026	473121.5	0.625

3.4 Geospatial Mapping

The seasonal maps (Figures 12-14) demonstrate more notable differences including sample size and geographic distribution. The wet map (Figure 13) represents a larger data set of 2240 points compared to the dry map with 1724 and both maps show a clear geographic pattern in which the clusters run down the center of the SJV. The maps shown in Figure 12 through Figure 14 show the highest cluster of wells testing above the MCL with the same counties that show the highest contamination levels on the graph (i.e., Merced and Kern counties). The wet map (Figure 13) is representative of far more samples than the dry map (Figure 12) making for unevenness in data collection. This difference in sample size was notable in the geospatial maps with 1724 points on the dry map compared to 2240 points on the wet map.

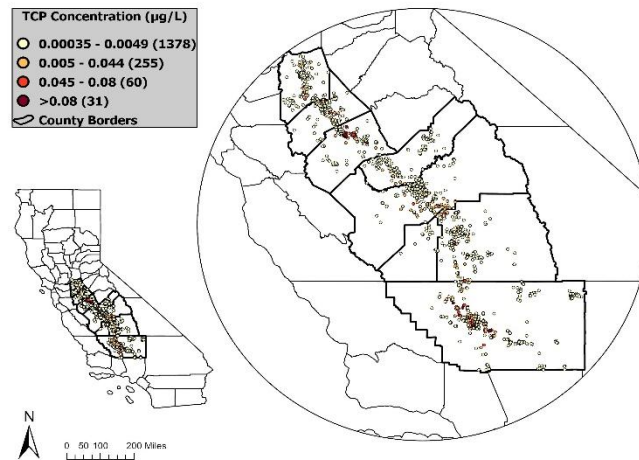


Figure 12 Concentration of 1,2,3 – TCP in domestic and municipal wells for all samples collected in the dry season (May 1st through September 30th, 2020-2024) (GAMA GIS 2025). San Joaquin Valley counties are outlined in bold. From top to bottom, left to right are San Joaquin, Stanislaus, Merced, Fresno, Madera, Kings, Tulare, and Kern counties (CDT 2024).

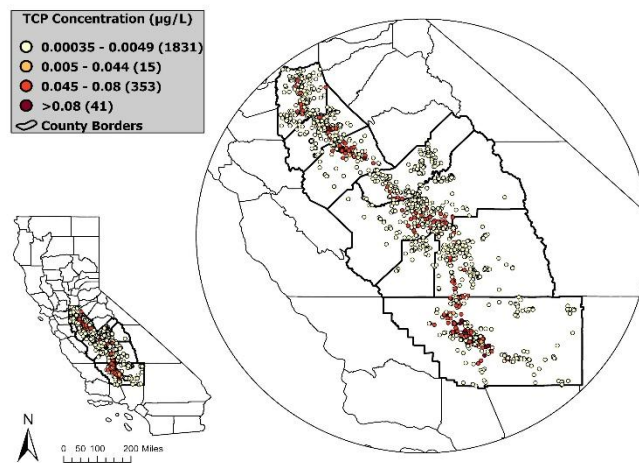


Figure 13 Concentration of 1,2,3 – TCP in domestic and municipal wells for all samples collected in the wet season (October 1st through April 30th, 2020-2024) (GAMA GIS 2025). San Joaquin Valley counties are outlined in bold. From top to bottom, left to right are San Joaquin, Stanislaus, Merced, Fresno, Madera, Kings, Tulare, and Kern counties (CDT 2024).

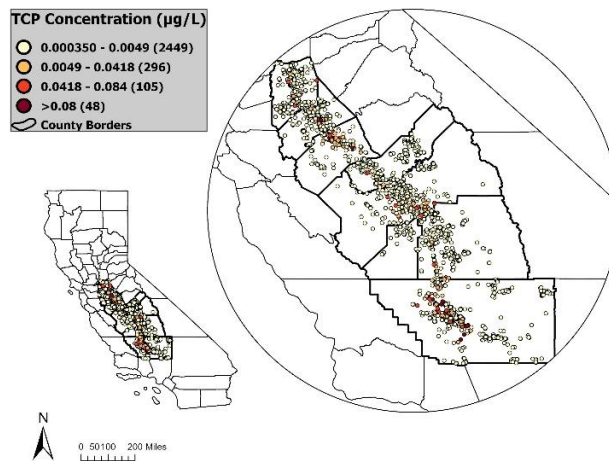


Figure 14 Concentration of 1,2,3 – TCP in domestic and municipal wells for all samples collected from 2020–2024 (GAMA GIS 2025). San Joaquin Valley counties are outlined in bold. From top to bottom, left to right are San Joaquin, Stanislaus, Merced, Fresno, Madera, Kings, Tulare, and Kern counties (CDT 2024).

3.5 Precipitation

Each county had greater amount of rainfall recorded during the wet season as noted in Table 3. Although precipitation was always greater during the wet season, contamination levels showed inconsistent patterns between seasons. This may be an indicator that precipitation alone does not determine where in the year contamination is greater.

Table 3 Precipitation rates for each San Joaquin Valley county.

County	2020 (inches)		2021 (inches)		2022 (inches)		2023 (inches)		2024 (inches)	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Fresno	0.12	5.83	0	10.61	0.06	6.33	0.54	13.3	0.44	10.63
Kern	0.18	5.17	0	5.73	0.01	4.2	1.6	8.4	0.1	7.4
Kings	0.11	9.87	0	8.22	0.04	5.39	0.5	11.28	0.02	10.01
Madera	0.2	5.6	0.03	4.34	0.65	6.77*	0.79*	16.84	0.43	10.79
Merced	0.2	7.15	0	10.84	0.2	7.86	0.86	7.37	0.56	15.27
San Joaquin	0.12	6.75	0.08	15.44	0.16	7.25	0.11*	16.13	0.56*	15.92
Stanislaus	0.07	5.01	0.03	12.89	0.09	5.85	0.43	14.89	0.77	14.85
Tulare	0.36	5.32	0.02	8.97	0.15	5.58	0.11	10.6	0.4	11.46

*Calculated with missing values

4. Discussion

Land use is likely an additional determining factor to precipitation in predicting contamination levels. The removal of urban wells saw similar trends across four of the eight counties in which the wet season TCP concentration averages were lower based on a five-year data set. Kings and Madera County expectedly saw minimal, or no change based on yearly analysis due to consistent detection levels. Seasonal contamination averages showed irregular patterns for all counties for all years. The difference in sample amounts by season may cause the data to skew in favor of higher wet averages due to the higher number of recorded values in the wet season.

Although Merced and Kern County are largely agriculturally dominated, their commodities differ. For the past five years, the Merced County Agricultural Commissioner's office reported that the top commodities by value have been milk, almonds and fluctuations between cattle and calves, sweet potatoes and chickens as top third (MCDA 2024). Kern County reported their top commodities to be grapes, citrus and fluctuations between carrots, pistachios, milk and almonds as top third, though prior studies found no correlation between TCP and crop type (Hauptman et al. 2023, Burow et al. 2019).

Precipitation rates overall and not by season are more likely the determining predictor variable as these observations support previous findings from Hauptman et al. (2023). Hauptman et al. (2023) determined through their Random Forest model that precipitation is the top predictor variable in which the highest concentrations of TCP are associated with the lowest rainfall levels. Land use, frequency of pesticide application and soil type are also factors expected to contribute to higher rates of contamination.

Largely missing from the GAMA data download were associated well depths. Due to insufficient data, we could not complete this analysis. Graphing concentrations against well depths may be a notable indicator of seasonal patterns. This factor, if included, could support Hauptman et al. (2023)'s claim that higher rainfall may dilute TCP contaminated wells and that higher TCP levels should be expected in wells with lower recharge rates (IARC 1995). We also recommend expansion of our analysis with more years of data.

5. Conclusion

Water contamination is a pressing concern in California that is exacerbated by climate change and water scarcity. Although the overall analysis did not show a definitive difference in TCP contamination level between seasons, future analysis should expand the timeframe and consider drought years and non-drought years. Future well testing should aim for even amounts of sampling between seasons and should measure respective well depth. For many rural, especially agricultural communities, residents are faced with the issue of accessibility to water that meets state regulatory standards. Private well owners should take proactive measures to mitigate exposure to water contaminants by conducting at least annual testing on their water. Research such as this provides a useful information for these communities so that they may better understand water contamination patterns.

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Appendix

Table 1A Number of wells by county (municipal and domestic).

County	Number of Wells
Fresno	608
Kern	641
Kings	55
Madera	346
Merced	266
San Joaquin	360
Stanislaus	405
Tulare	440