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(ARTICLE)

Assessing Long-Term Groundwater Quality Trends Using Historical Water Quality Monitoring Data

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تقييم الاتجاهات طويلة الأجل لجودة المياه الجوفية باستخدام بيانات الرصد التاريخية لجودة المياه

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Abstract:

Groundwater is an important source of public drinking water. Its quality may change gradually as water continues to pass through reservoirs for many years. The study assessed long-term groundwater quality trends. Historical observational data from USGS's GAMA Prioritization Basin Project, California were used. The Google Collab experiment that was implemented used public data releases by the U.S. Geological Survey from 2004 to 2023. The dataset included 444 study sites and 145 components. It also included 21,461 double comparison records for the tenth. The analysis cleaned up the tables and converted the reported values to numbers. Handle the blocked values on the left with a simple half-term rule. Then compare the previous and subsequent results of the same wells. That's why Wilcoxon's double-sign rating tests were used. The Spearman relationship was used to examine the relationships between different species. The calculated results showed strong reductions in several ingredients. It included methyl tart-butyl ether, 1,2-dichlorobrane, 1,2,3-trichloropropene, fluoride, perchlorate, and tritium. The results also showed an increase in the amount of silver, ethrazine, strontium, calcium, magnesium, alkalinate, chloride, sulfate, manganese and uranium. This pattern points to a combination of natural and human control over groundwater quality. The use of agricultural land, urban inputs, old chemicals, and water bodies can influence trends. Studies show that public observational records can help in a clearer assessment of trends when the data is processed carefully.

Keywords: Groundwater Quality; Long-Term Trends; Historical Monitoring Data; USGS GAMA; Wilcoxon Register of Classification Locations; Public Drinking Water.

الملخص

تُعدّ المياه الجوفية مصدرًا مهمًا لمياه الشرب العامة، وقد تتغير نوعيتها تدريجيًا نتيجة استمرار حركة المياه وتفاعلها مع مكونات الطبقات والخزانات الجوفية على مدى سنوات طويلة. هدفت هذه الدراسة إلى تقييم الاتجاهات طويلة الأجل في جودة المياه الجوفية، بالاعتماد على بيانات رصد تاريخية مستمدة من مشروع أحواض تحديد الأولويات التابع لبرنامج تقييم ومراقبة جودة المياه الجوفيةGAMA ، الذي تنفذه هيئة المسح الجيولوجي الأمريكية USGS في ولاية كاليفورنيا.

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أُجري التحليل باستخدام منصةGoogle Colab ، واستند إلى مجموعات البيانات العامة التي أصدرتها هيئة المسح الجيولوجي الأمريكية خلال الفترة من عام 2004 إلى عام 2023. وشملت مجموعة البيانات 444 موقعًا للدراسة و145 مكوّنًا كيميائيًا، بالإضافة إلى 21,461 سجلًا للمقارنات الزوجية.
تضمنت عملية التحليل تنقية الجداول، وتحويل القيم المبلغ عنها إلى صيغ رقمية قابلة للتحليل. كما جرى التعامل مع القيم الخاضعة للرقابة اليساريةLeft-censored values ، أي القيم الواقعة دون حدود الكشف المختبري، باستخدام قاعدة مبسطة تعتمد على استبدالها بنصف حد الكشف أو الإبلاغ. وبعد ذلك، قورنت نتائج القياسات السابقة واللاحقة المأخوذة من الآبار نفسها.
استُخدم اختبار ويلكوكسون للرتب الموقعة للعينات المترابطة Wilcoxon Signed-Rank Test للكشف عن الفروق والاتجاهات الزمنية بين القياسات المتعاقبة، كما استُخدم معامل ارتباط سبيرمان Spearman’s Rank Correlation لفحص العلاقات بين المكونات الكيميائية المختلفة.
أظهرت النتائج المحسوبة انخفاضات ملحوظة في تراكيز عدد من المكونات، من بينها ميثيل ثالثي بيوتيل الإيثر Methyl tert-Butyl Ether (MTBE)، و1،2-ثنائي كلورو البروبان، و1،2،3-ثلاثي كلورو البروبان، والفلوريد، والبيركلورات، والتريتيوم. وفي المقابل، أظهرت النتائج ارتفاعًا في تراكيز الفضة، والأترازين، والسترونشيوم، والكالسيوم، والمغنيسيوم، والقلوية، والكلوريد، والكبريتات، والمنغنيز، واليورانيوم.
تشير هذه الأنماط إلى وجود تداخل بين العوامل الطبيعية والأنشطة البشرية المؤثرة في جودة المياه الجوفية. وقد تسهم استخدامات الأراضي الزراعية، والمدخلات الحضرية، وبقايا المواد الكيميائية القديمة، والتفاعلات بين المياه والصخور في تشكيل هذه الاتجاهات. وتوضح الدراسة أن سجلات الرصد العامة يمكن أن تُستخدم بفاعلية لتقييم اتجاهات جودة المياه الجوفية بصورة أكثر وضوحًا ودقة، شريطة معالجة البيانات وتنقيحها باستخدام أساليب مناسبة ومنهجية.

الكلمات المفتاحية: جودة المياه الجوفية؛ الاتجاهات طويلة الأجل؛ بيانات الرصد التاريخية؛ برنامج USGS GAMA لتقييم ومراقبة المياه الجوفية؛ اختبار ويلكوكسون للرتب الموقعة؛ مواقع التصنيف؛ مياه الشرب العامة.

Introduction

Groundwater is stored in holes and holes below the surface of the earth. It supplies households, farms, industries and public water systems. Its value is high as reservoirs can store water during drought. However, a single reservoir can hide water quality issues for many years. (Lamma, 2021)
Groundwater quality often changes slowly compared to surface water quality. It can take years to regain energy to reach the well. Interactions within soil and water bodies can also delay change. For this reason, one model is not enough for long-term planning. (Mohammad et al., 2015)
Historical monitoring data can show whether the water is improving or deteriorating. Such data can also show which ingredients need more attention. General data sets are useful because they are large, open, and repetitive. This research allows other researchers to evaluate this work. (Lamma, 2021)
This dataset is powerful for trends work because it makes pairwise comparisons. Each duplicate record compares a baseline sample to a subsequent sample from the same observation location. This design reduces errors due to differentiation between wells. (Lamma & Swamy, 2018; Lamma et al., 2018)
The purpose of this paper is to evaluate long-term groundwater quality trends from public data. The second goal is to show a clear experience that can be replicated in Google Collab. The paper uses simple language, but maintains the clarity of the scientific method. The study focuses on trend trends, statistical evidence, and environmental significance. It does not claim that it can replace regulatory compliance testing. Careful sampling rules, modules, and regulatory review are essential for compliance work. (Zhmool et al., 2026)

Background and Literature Review

The chemistry of groundwater controls both natural and human factors. Natural controls include rock type, recharge life, oxidation state, pH, and melting of the metal. Human control includes irrigation, fertilizers, sewerage systems, solvents, fuel additives, and urban flows.
California is a useful area of study for this subject. It includes large agricultural valleys, dense cities, masts, mountains and coastal basins. These environments create different reservoir conditions and different water quality pressures.
The USGS program is designed to assess ground water quality across the state. The program sampled public and domestic supply wells across California. They also made many of the findings available through public tools and data releases (Shelton et al., 2024; U.S. Geological Survey, 2026; Alshebgo et al., 2026).

The study of long-term trends requires consistent field and laboratory methods. The USGS National Field Guide provides protocols for water quality sampling, field measurements, sample handling, and treatment (USGS, n.d.). These protocols help make old and new results more comparable. (Alfarjani et al., 2026)
Public databases also help in the study of trends. The Water Quality Portal brings together separate water quality registries from the U.S. Geological Survey, the Environmental Protection Agency, and several partner organizations (National Water Quality Control Board etc., 2021). It allows researchers to search for data without having direct access to agency databases. (Ibrahim et al., 2026)
An important problem in analyzing groundwater trends is controlled data. Blocked results occur when a value below detection or report threshold is reported. Environmental statistics texts warn that simple change can be biased, especially when many outcomes are censored (Hillel, 2012; Belanović Simić et al. 2014).
Non-vector tests are often used in water quality studies. These are useful because water quality data are often biased. They also reduce the impact of maximum values. Wilcoxon's signature rank test is useful for replicated specimens (Wilcoxon, 1945).
The man-candle test is also common in hydrology. One-sided changes are felt over time (Main, 1945; The optional notebook section included the Main-Candle Water Quality Gate workflow for the time series. WQP records were not downloaded in the executive round.
Drinking water quality provides useful context. EPA's core standards are legally applicable for public water systems (U.S. Environmental Protection Agency, 2026). The WHO guidelines also provide public health guidelines for drinking water quality (WHO, 2026). This paper uses criteria only as context.

Materials and Methods

Secondary data design was used in this study. No new wells were drilled. No new field samples were collected. The hands-on experience in Google Collab is complemented by public data and open-source Python packages.
The primary source of data was the USGS data release titled 'Data to Analysis in Groundwater Quality Used in Public Drinking Water Supply, 2004-2023'. The version includes DOI 10.5066/P137ZTJE (Levy & Soldafini, 2026a).
Twelve tab-specific tables were downloaded from items from the U.S. Geological Survey Science Base in the running notebook. These tables include site data, component data, organic analysis, iteration information, nodal double benchmark samples, trend summaries, and correlation inputs. The notebook output shows 444 study sites and 145 components. It also displays 21,461 comparison rows. These numbers were taken from the prepared notebook inventory table.
The first step of the cleanup was to clean up the columns. The second step was to convert the reported numerical values into numbers. Values with markers below the number were considered to be half of the reported range. Blank and non-numeric entries were considered missing values.
Raw and decimal results were used in the central comparison. For each double row, the notebook calculates the decimal difference. The percentage change was calculated even when the initial value is greater than zero. The main statistical test was the Wilcoxon site test. Compare the initial and nodal values of each component. The test used bifacial p-value and a significant level of 0.05.
When the p-value was less than 0.05 and the median difference was positive, the component was marked as an increase. When the p-value was less than 0.05 and the median difference was negative, it was marked as a decrease. The other results were not reported as any significant change or any apparent change. The notebook also created the Spearman correlation matrix. This matrix used nodal differentials where there was sufficient data. Relationships were used to explore the relative changes between the components.
A quality control note is required. An optional drinking water inspection chart was prepared in the notebook. This output module did not pass conversion correctly because the double table did not provide a field for the inspection cell. Therefore, this scan chart was not used as an organizational result in this paper.

Table 1 Workflow of repeatable experiments.

FOOT	CEREMONY	PURPOSE
Upload Data	USGS's public GAMA tables are uploaded from the Science Base.	General Repeatability
Cleaning of Pillars	I changed the name to simple small fields.	Low coding error
Numerical Analysis	The results of the text were converted to numbers.	Trend Calculation
Database Monitoring	Use a half-limit substitution for values that are less than the values.	Presentation only
Dual Analysis	I compared the initial and nodal results of the same sites.	Long-term change
Wilcoxon Test	Double difference testing was done for each component.	Trend Guides
Correlation Matrix	Use the relationship between the types of Spearman.	Joint Control
Export Sheep	Archived maps, charts, box charts, and heatmaps.	Paper Drawings

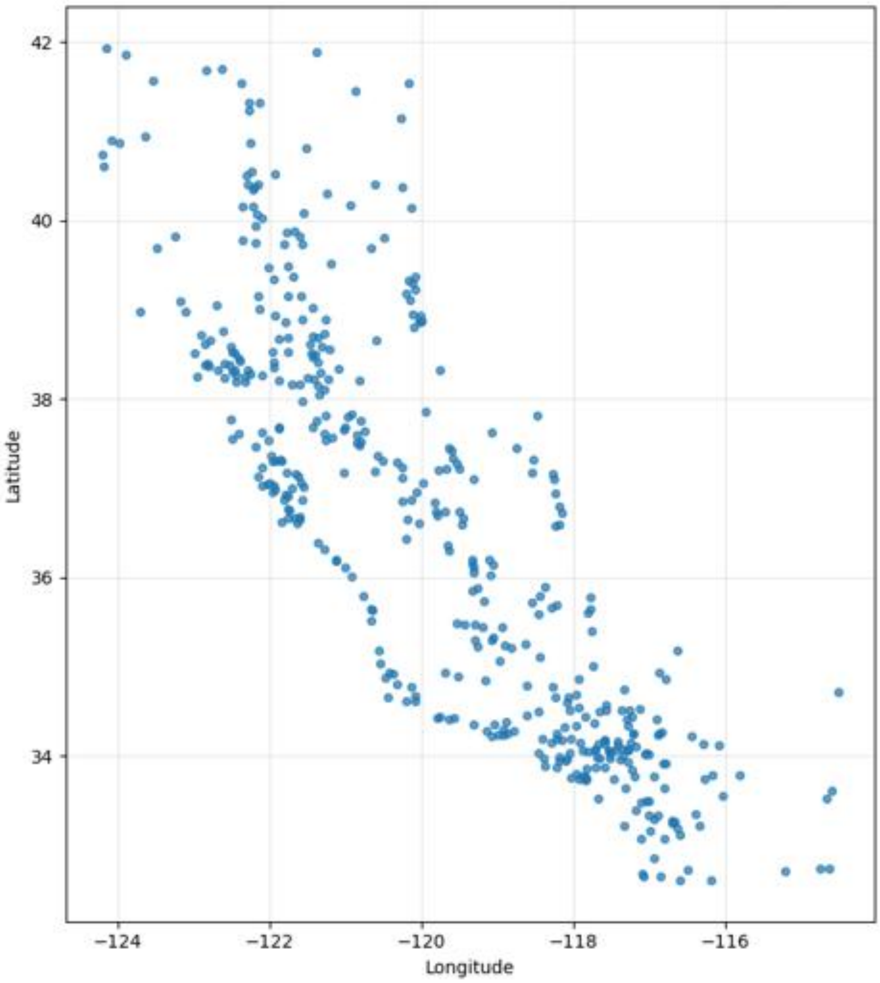

Figure 1 Study sites used to assess nodal groundwater quality.

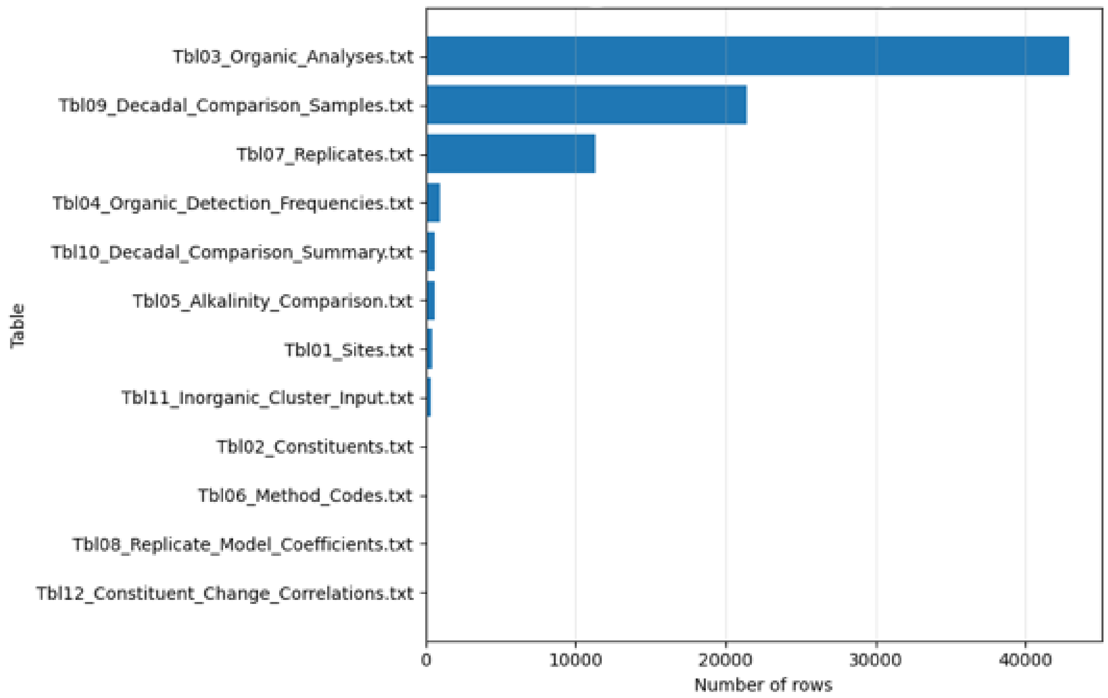

Figure 2: Dataset inventory from the Port Collab Notebook

Results

The dataset list displays a large archive that is useful for monitoring. The largest table was the organic analysis table with 42,932 rows. There were 21,461 rows in the double-nodal comparison table. There were 11,339 rows in the transcription table.

There were 444 records in the study site table. The site map shows that these locations cover most of California. This wide coverage is important as the ground water status varies across the State. The component metadata table lists 145 measured components. The double comparison design made it possible to compare the before and after directly in the same place. This design is stronger than that of unconnected wells.

The output class is calculated that the components grow more than they decrease. Bar charts show that increments were the most common category. Fall was also common. Some voters didn't see much change. The strongest statistical declines included 1,2-dichloropropene, MTBE, nitrite, 1,2,3-trichloropropene, tritium, fluoride, and perchlorate. These results had very low p-values in the laptop's output.

The most statistically potent additions included 3,4-dichloronylene, silver, atrazine, cis-1,2-dichloroethylene, semazine, strontium, calcium, magnesium, sodium, manganese, alkali, sulfate, and uranium. The highest percentage reduction in average percentage was mostly associated with VOCs and some selected processed ingredients. MTBE computerized production declined by 88%. 1,2,3-Trichloroprene reduced by 95%.

Fluoride and perchlorate were also reduced in computerized analysis. This is in line with the GIM Survey Trends Summary, which indicates widespread reductions in fluoride and perchlorate in the reference ingredients (Levy & Soldafini, 2026b).

The calculated production showed an increase in uranium. The intermediate change in uranium was positive, and the p-value was very low. This is also consistent with the publication of the USGS, which identified uranium as a mass enriching component that has regulatory standards (Levy & Soldafini, 2026b). The initial depression vs. node diagram shows how the double samples compare to the selected component. The dots below a line indicate the pit. The dots above the line indicate increments. This graph is easy to understand because each point is the same comparison.

Table 2 : The results of the dual trends selected from the executing book were calculated.

Uprising	pairs	Beginner Broker	Decimal medium	Average difference.	Median %	P Value	Direction
dichloropine (1,2--1,2 (DCP	442	0.026	0.004	0.022-	84.6-	1.25e-72	Demise
Ether Methyl Turt-Butyl (MTBE)	442	0.1	0.012	0.088-	88.0-	1.17E-71	Decline
Dichlorenelin-3,4	398	0.0045	0.006	0.0015	33.3	1.73e-63	addition
Nitrate, Nitrogen	364	0.002	0.001	0.001-	50.0-	1.71e-47	Decline
silver	364	0.1	1	0.9	900.0	4.22E-41	addition
trichloroppine-1,2,3 (TCP-1,2,3)	442	0.12	0.006	0.114-	95.0-	3.58e-35	Decline
Atrazine	399	0.007	0.008	0.001	14.3	4.22e-34	addition
Tritium	403	3.29	2.36	0.83-	33.9-	4.95e-34	Decline
Fluoride	362	0.2185	0.189	0.029-	11.4-	7.56E-31	Decline
Perchlorites	410	0.5	0.128	0.104-	24.4-	1.68e-28	Decline
Cis-1,2-dichloroethylene (cis-1,2-DCE)	442	0.022	0.025	0.003	13.6	2.51E-21	addition
Simazine	399	0.006	0.008	0.001	20.0	8.23E-21	addition
Ammonia, in the form of nitrogen	364	0.02	0.01	0.01-	50.0-	6.89E-19	Decline
Beryllium	364	0.036	0.01	0.01-	50.0-	9.15e-19	Decline
Dichloroethane (1,1--1,1 (DCE	442	0.022	0.025	0.003	13.6	6.06E-18	addition
strontium	364	283	315	16.89	7.5	1.38E-16	addition
Calcium	364	34.27	37.88	1.289	5.2	1.66E-15	addition
Magnesim	364	11.21	12.66	0.462	6.0	2.24E-15	addition
Antimony	364	0.14	0.06	0.0272-	25.0-	1.51E-12	Demise
Sodium	364	31.55	33.7	0.78	4.1	9.41E-12	addition

Notes. The modules are based on configured metadata. These values must be read by the original USGS module fields. The table ranks the strongest p values from the output of Colab.

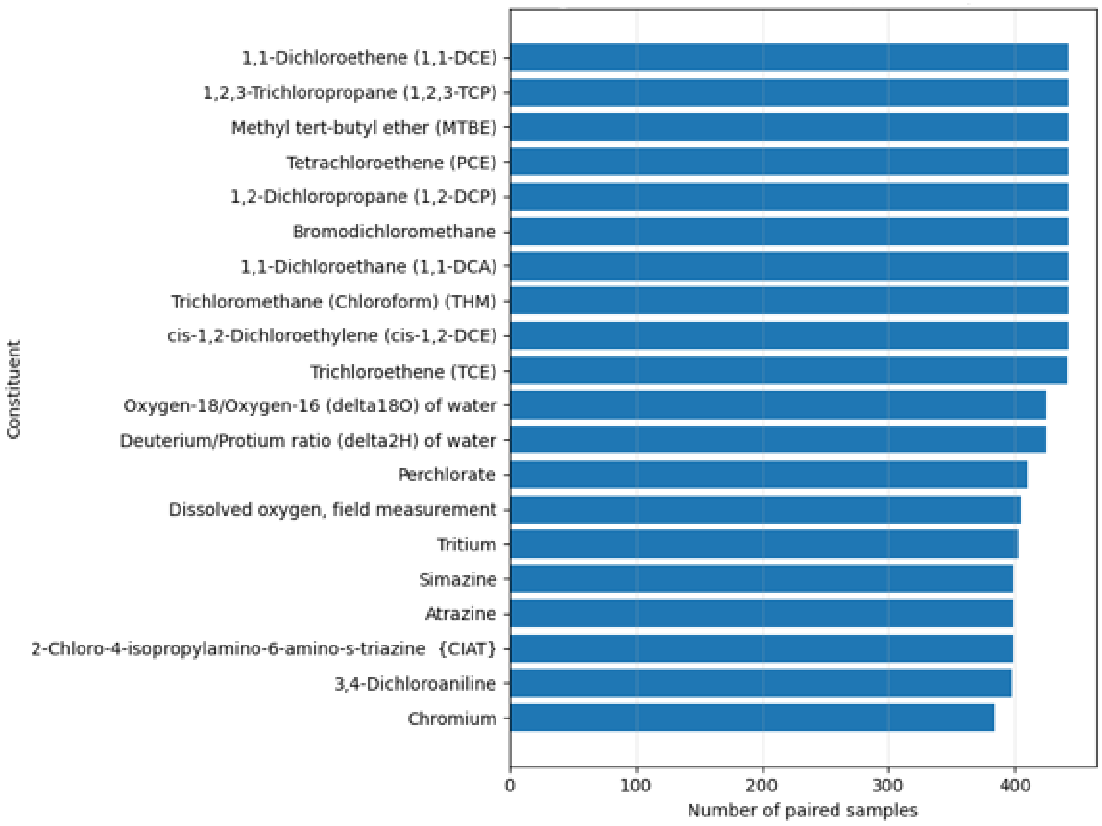

Figure 33

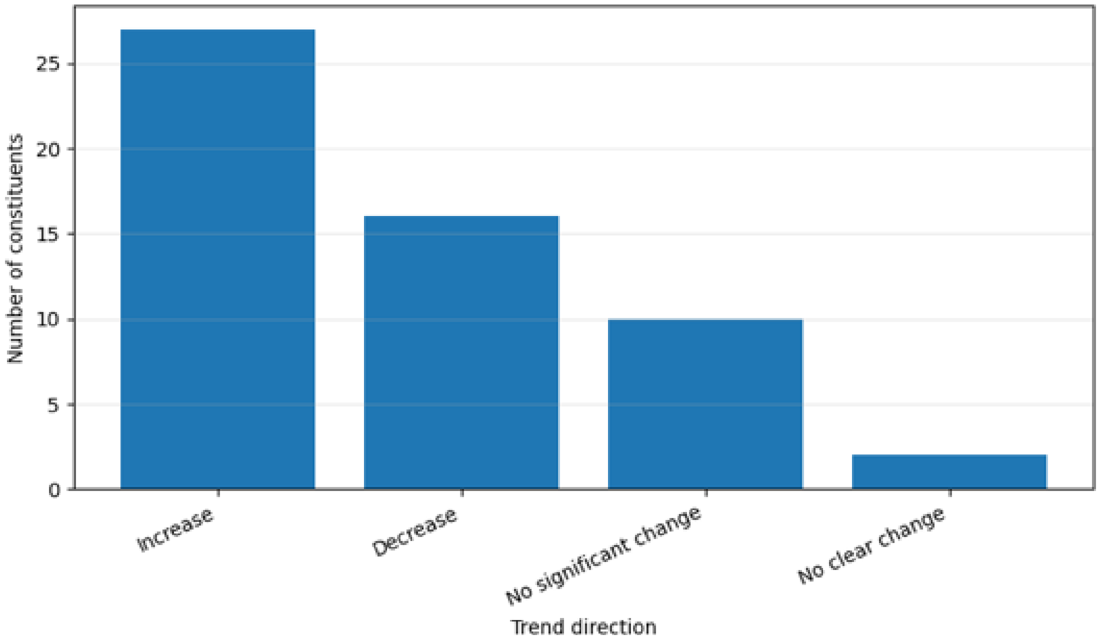

Figure 4: Counting the trend direction from Wilcoxon's pairwise tests.

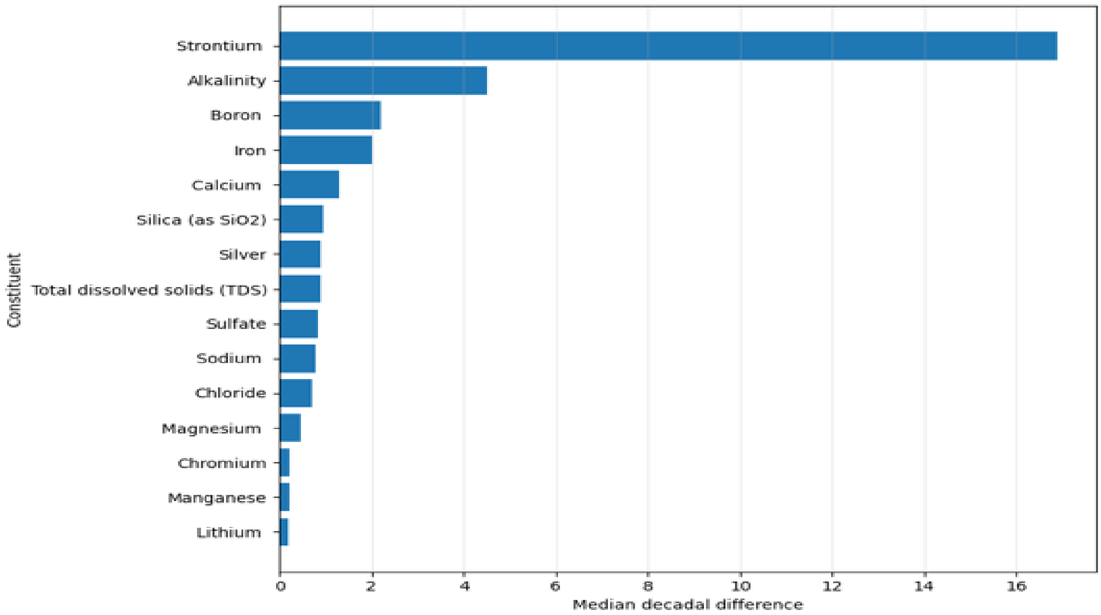

Figure 5: The highest median increase in laptop output.

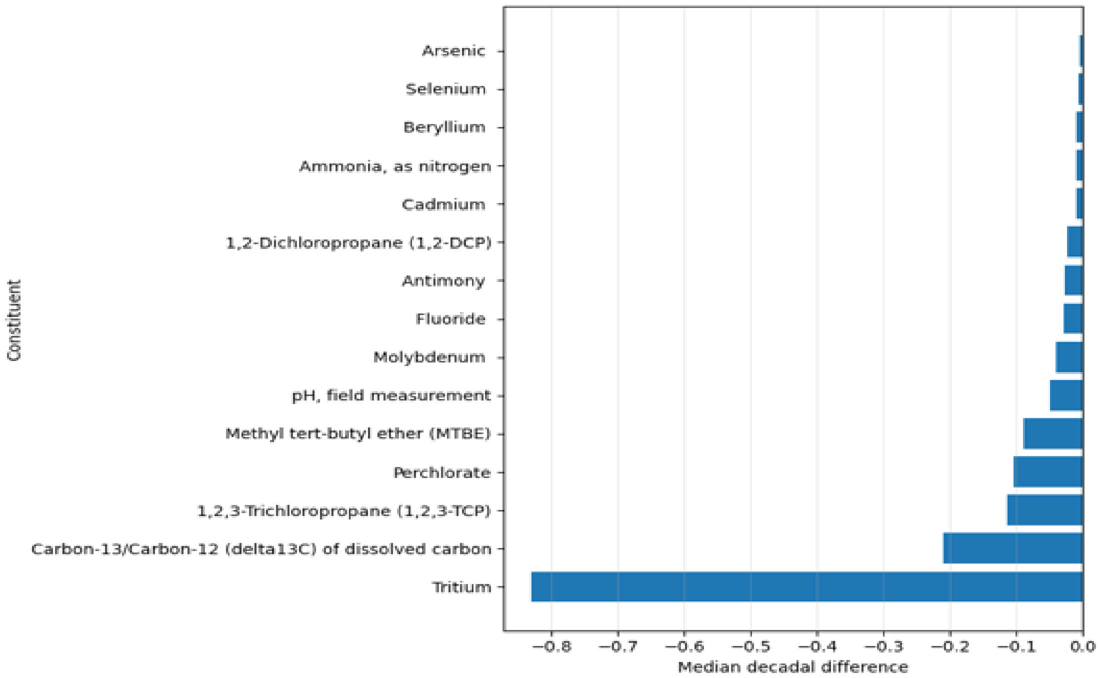

Figure 6: Largest Average Decline in Laptop Production

The fund chart of the nodal differences shows that several components have seen narrow core changes. However, the growth of some voters was wider. The wide range means that some wells have changed more intensely than others.

A correlation thermal map provides a second view of the data. This does not prove cause and cause. It shows whether the changes move together in different locations. These patterns may point to geochemical controls or general land use.

The effect size and significance chart shows that p values alone are not enough. When the sample is large, there can be a very small p-value. The median change in percentage helps to show whether the change is big enough for them.

The results also show the value of the paired sample. Large state datasets can hide local differences. Dual-well level data shows whether the same groundwater source has changed over time.

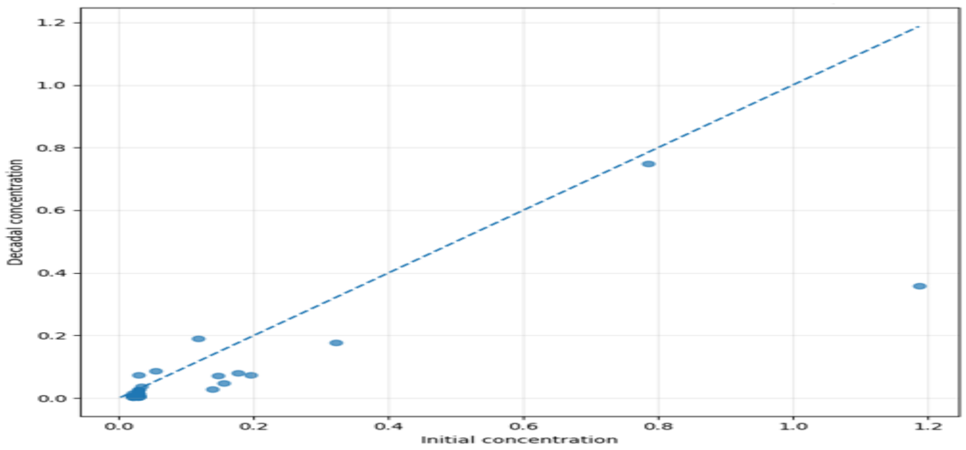

Figure 7: Initial vs. decimal values of the auto-selected high-sample component.

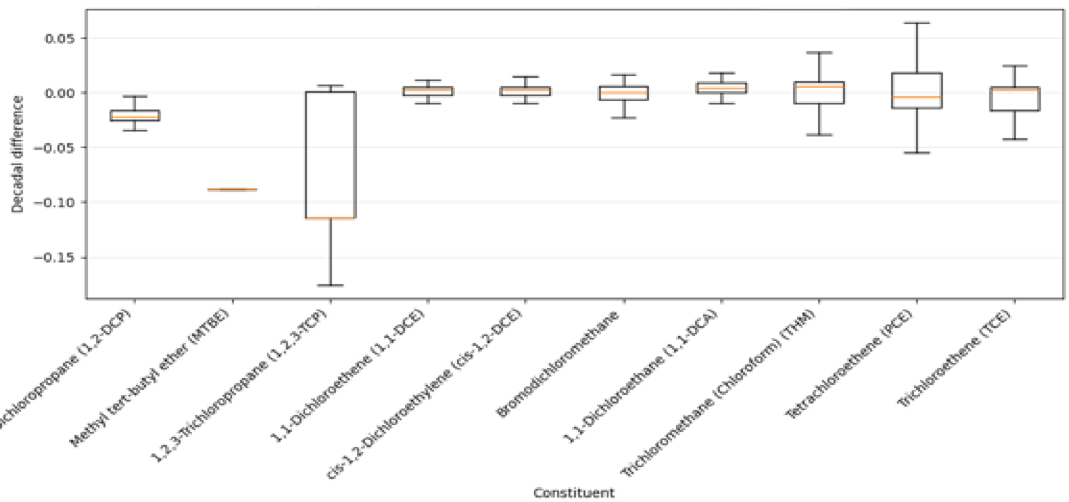

Figure 8 : Distribution of nodal differences for the most sampled components.

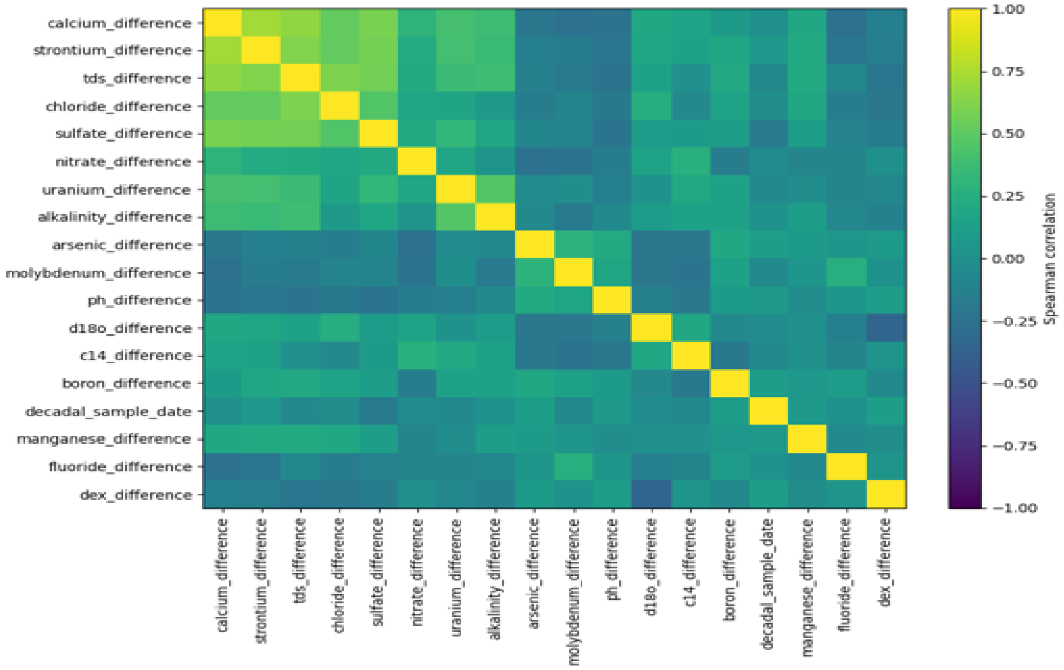

Figure 9: Heatmap of the relationship between Spearman's nodal groundwater quality changes.

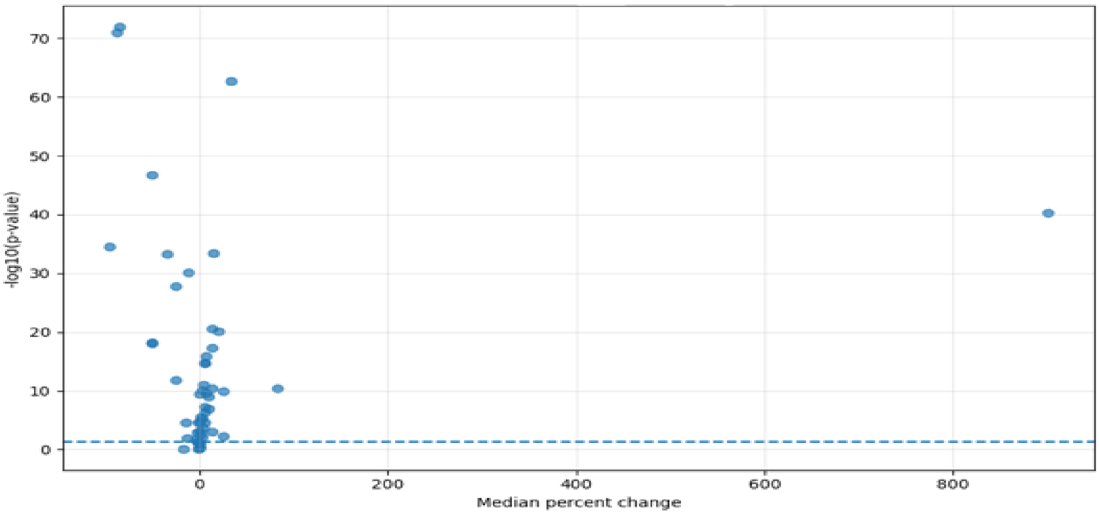

Figure 10 : Impact size and statistical significance.

Discussion

The results show that groundwater quality has not gone in just one direction. The number of ingredients increased, and some decreased. This mixed pattern is expected in large groundwater systems.

Reductions in MTBE and some VOCs may reflect source control and natural vulnerability. MTBE was widely used as an oxygenated fuel. Lower inputs can lead to lower volumes over time as groundwater flow and deformation allow it.

Perchlorate deficiency may also reflect changes in source inputs and aquifer processes. USGS preprints showed that perchlorate reductions were very high in Southern California (Levy & Soldavini, 2026b). This corresponds to the drop found in the device's output.

The calculated results showed a reduction in fluoride. The USGS study linked fluoride deficiency to an increase in calcium. This relationship is chemically possible because calcium can affect the solubility of fluoride in groundwater (Levy & Soldafini, 2026b).

Uranium production increased accountable. The USGS study reported widespread increases in uranium, particularly in agricultural and urban environments. They also linked the increase in alkalinity to the increase in uranium (Levy and Soldafini, 2026b).

Increases in calcium, magnesium, sodium, chloride, sulfate, and alkalinity indicate a broader signal of interactions with salts and water rocks. Irrigation can concentrate salts in soil water. Recharging can then transfer these dissolved ions into groundwater.

Agricultural pumping and irrigation can also change the chemistry of groundwater. Deep pumping can mix water of different ages. Return irrigation flow can add dissolved salt, nitrates, and carbonate alkalinity. These changes may be gradual but continuous.

Urban land use can affect groundwater through infrastructure leaks, industrial sites, fuel spills and rainwater harvesting. Some of the organic compounds in the results are linked to urban or industrial sources. There may be a decrease in input in their dips or a gradual cleaning.

It is important to read the results of atrazine and semazine carefully. These compounds are herbicides. Small changes in the median can be statistically significant in large double data sets. Results should be checked with the frequency of discovery and report changes in ranges. The same precaution applies to silver and some trace elements. Changes in laboratory practices or reporting limitations may affect the trends shown. The USGS data release includes information on the procedure and frequency of this cause.

Controlled values are an important constraint. Use a half-limit replacement notebook. This may be acceptable for the first check-up. It can be weak when detection limits change over time. Lucky data methods have more sophisticated monitoring than future work (Hillel, 2012).

The USGS's official summary provides important context. Note that arsenic and nitrate often did not show significant changes in directions, but significant changes did occur in both directions (Levy & Soldavini, 2026b). This means that health-related voter monitoring is still essential.
An important lesson is that trend direction and public health risks are different ideas. The decreasing component may be higher. The growing item may be below the standard. Standards should be reviewed through sound units and organizational procedures. The Executive Notebook prepared a benchmark check bench, but the unit field was not delivered to this cell. This led to unrealistic overdensity rates for several trace elements. Therefore, the final explanation avoids these prices. This is an important decision for quality control. The study also shows that open data can support transparent science. Anyone can run a notebook by uploading the same data version. This method is useful for students, water administrators and researchers.

Table 3: Drinking Water Standards Used as Background Only

Component Matching	Value in Mg/L	Criteria of Context
Arsenic	0.0100	EPA MCL Throw for Arsenic
Nitrates	10.00	EPA MCL as N for nitrate
Nitrate	1.00	EPAMCL Bonds for Nitrate as N
Fluoride	4.00	EPA Fluoride Micro Electric Microphone
Selenium	0.0500	EPA MCL for Selenium
Uranium	0.0300	UAE AMCL Material for Uranium
bullet	0.0150	EPA's Lead Working Level
Chrome	0.1000	EPA MCL for Total Chromium

Border

General secondary data were used in this study. They had no authority over the actual sampling dates, field methods or limitations of laboratory reports. The U.S. Geological Survey data release mitigates this problem by providing harmonized comparison tables. The analysis used a simple half-threshold method of monitored data. This method can be easily repeated. Average and percentage changes can be biased when oversight is common or when reporting limits change.
The calculated trend table did not include units in the final test output. It does not affect the duality of any one component. This affects the comparison with the quality of drinking water. That's why you didn't use override rates.
Wilcoxon's test shows a similar difference. The reason for the change was not explained. The reasons require hydrogeological description, land use data, pumping records, and geochemical modeling. The results are the results of a state-level examination. Local wells can behave differently. Local administrations have to use local monitoring data and information from local water bodies.
Optional WQP analysis was not triggered in the provided Colab outputs. Therefore, this paper does not claim the results of the annual trend of the WQP. Only the USGS's decimal GAMA outputs and executive book report results.

Conclusion

The study assessed long-term groundwater quality trends using general historical monitoring data. The Colab experiment which used USGS California GAMA data from 2004 to 2023 was implemented. This dataset was powerful for analyzing trends. It covered 444 locations, 145 components, and 21,461 double-digit records for nodal comparison. The dual design made direct comparison possible over time.

The calculated results showed both increases and decreases. Deficiencies in MTBE, 1,2-dichlorobrane, 1,2,3-trichloroprene, fluoride, perchlorate, and tritium were evident. This increase was evident for many large ions such as alkali, manganese, and uranium.

The results show that the change in groundwater quality is complex. Some of the improvements may reflect a reduction in pollution. Some of these additions may reflect irrigation, urban impacts, mineral erosion, and changing geochemical conditions. The sheet also shows the value of open data. Public datasets and repeatable ledgers can make groundwater science more transparent. It also helps students and water administrators to check the results themselves.

Future research will improve controlled data processing. It will also load the unit fields during each evaluation stage. The raw annual WQP data can be used to test detailed time trends in selected water bodies.

This study supports continued surveillance. Groundwater quality may be good for some components and bad for others. Long-term public surveillance is essential for safeguarding drinking water supply.

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