Machine learning for selecting time series models for drinking water pollutants in Meoqui, Chihuahua, Mexico

Aprendizaje automático para seleccionar modelos de series temporales para contaminantes en agua potable en México

Martín Alfredo Legarreta-González[1], Martha Lilia Ramírez-De la Fuente[2,3], Rafael Rodríguez-Venegas[4], Aracely Zuñiga-Serrano[5], Francisco Gerardo Véliz-Deras[4]*, Rafael Rodríguez-Martínez[4]

[1]Tecnológico de Monterrey, Escuela de Ingeniería y Ciencias, Ave. Eugenio Garza 2501 Sur, Col. Tecnológico, CP. 64700. Monterrey, Nuevo León, México.
[2]Programa de Maestría en Ciencias en Producción Agropecuaria, Universidad Autónoma Agraria Antonio Narro, Unidad Laguna, Periférico y Carretera a Santa Fe S/N, Col. Valle Verde, CP 27054. Torreón, Coahuila, México.
[3]Red de Divulgación Científica del Norte de México A.C. Circuito brillante No. 124 fraccionamiento villas diamante CP. 27086. Torreón, Coahuila, México.
[4]Departamento de Ciencias Médico Veterinarias, Universidad Autónoma Agraria Antonio Narro, Unidad Laguna, Periférico y Carretera a Santa Fe S/N, Col. Valle Verde, CP 27054. Torreón, Coahuila, México.
[5]Departamento de Salubridad e Higiene, Universidad Autónoma Agraria Antonio Narro, Unidad Laguna, Periférico y Carretera a Santa Fe S/N, Col. Valle Verde, CP. 27054. Torreón, Coahuila, México.
*Corresponding author: velizderas@gmail.com

Scientific article

Received: March 12, 2026
Accepted: August 05, 2026

ABSTRACT. The objectives were to ascertain potential variations in the levels of As, Pb and F in drinking water in Chihuahua, Mexico, across years, to evaluate time series models to forecast patterns, and to determine whether these levels comply with the Mexican Official Standard (NOM). The models implemented were: ARIMA, Facebook Prophet, GLMNET, and a hybrid model combining Facebook Prophet and an Extreme Gradient Boosting (XGBoost) model. In the context of the ARIMA and Facebook Prophet models, the 'hold-out (data)' method was employed. Conversely, for the GLMNET and hybrid models, a cross-validation procedure with five folds was utilised. Data (from the Junta Municipal de Aguas y Saneamiento – JMAS-) from Meoqui, Chihuahua, Mexico were collated from January 2010 to December 2023. The maximum levels of As stipulated by NOM have been adhered to since 2021. Since 2019, the maximum permissible levels of fluoride (F) have consistently been adhered to and the maximum levels of lead (Pb) have not been exceeded during the period under analysis. Levels of As and F have decreased in recent years, potentially due to corrective measures implemented by the relevant authorities. Projections suggest that the levels of As, Pb and F will remain below the maximum thresholds established by NOM. Facebook Prophet provides the most accurate predictions of the concentrations of As, Pb and F. These findings will provide the competent authorities with the necessary evidence to implement sustainable water resource management practices and guarantee the quality of water consumed by the population.
Keywords: Forecasting, ARIMA, facebook prophet, GLMNET, hybrid prophet w/ XGBoost.

RESUMEN. Los objetivos fueron determinar variaciones a lo largo de los años en los niveles de As, plomo Pb y F en el agua potable de Chihuahua, México, evaluar cuatro modelos de series de tiempo para pronosticar su comportamiento y determinar si los niveles de estos elementos cumplen con la Norma Oficial Mexicana (NOM). Los modelos implementados fueron: ARIMA, Facebook Prophet, Modelos Lineales Generalizados Regularizados GLMNET, y XGBoost. En los modelos ARIMA y Facebook Prophet se implementó el método «hold-out (datos)» para la extracción de datos y para los modelos GLMNET e híbridos se implementó un procedimiento de validación cruzada con cinco pliegues (folds). Los datos abarcan de enero de 2010 a diciembre de 2023. Los niveles máximos de As registrados en los pozos estudiados y en todas las observaciones han rebasado los niveles permitidos por la NOM, los de F se han cumplido de manera constante; los niveles máximos de Pb no han superado el límite normado durante el periodo analizado. Los niveles de As y F han disminuido en los últimos años, lo que podría coincidir con medidas correctivas implementadas por las autoridades. Las proyecciones sugieren que los niveles de As, Pb y F se mantendrán por debajo de lo establecido por la NOM. El modelo con mayor precisión en la predicción de las concentraciones de los elementos en el agua subterránea de Meoqui fue Facebook Prophet. Estos hallazgos brindarán a las autoridades la evidencia para establecer prácticas sostenibles de gestión de los recursos hídricos y garantizar la calidad del agua consumida por la población.
Palabras clave: Pronóstico, ARIMA, facebook prophet, GLMNET, hybrid prophet w/ XGBoost.

How to cite: Legarreta-González MA, Ramírez-De la Fuente ML, Rodríguez-Venegas R, Zuñiga-Serrano A, Véliz-Deras, FG, Rodríguez-Martínez R (2026) Machine learning for selecting time series models for drinking water pollutants in Meoqui, Chihuahua, Mexico. Ecosistemas y Recursos Agropecuarios Núm. Esp. VI: e5240. DOI: 10.19136/era.a13nVI.5240.

Ecosist. Recur. Agropec. Núm. Esp. VI: e5240, 2026
https://doi.org/10.19136/era.a13nVI.5240

INTRODUCTION

Water scarcity and sanitation are recognised as significant challenges to contemporary society on a global scale. In response, the 2015 United Nations Sustainable Development Summit identified access to clean water and sanitation as a key component of the 17 Global Sustainable Development Goals for the year (UN 2015). In addition to the overarching objective of ensuring universal access to clean water and sanitation, these goals include specific targets such as the enhancement of water quality through the reduction of water pollutants (UN 2023). Heavy metals are recognised as a primary concern for public health (Jomova *et al* 2025). These authors argue that arsenic (As) and lead (Pb) are regarded as the most noxious pollutants, due to their presence in water sources designated for human consumption. Another significant contaminant in drinking water is fluoride (F), which has been detected in a number of community water systems as a natural occurrence and, in several countries, it has been integrated into public drinking water systems or salt, with the aim of preventing dental caries (Taylor *et al.* 2025).

The toxic effects of As, Pb and F are widely recognised. An association between chronic arsenic poisoning and an elevated risk of developing skin, lung and bladder cancer, as well as gastrointestinal and liver disorders condition to affect multiple organ systems and can lead to various cardiovascular disorders, neurological effects, respiratory problems and kidney disease (Taylor *et al.* 2025). One of the approaches used by the scientific community to identify potential risks associated with contaminant levels in drinking water is mathematical modelling, as noted by Hartmann *et al.* (2021), who constructed an assessment hierarchy for the integrated evaluation of the potential risks from emerging chemical and microbial contaminants in drinking water, and as observed in the review by Izah and Ogwu (2025), regarding the use of these methods in relation to drinking water contaminants.

Meoqui city (28° 5′ 06″ N, 105° 17′ 56″ W) is located in the ecological region of the Chihuahuan Desert which extends from central Mexico to the southeastern United States of America, is grappling with the repercussions of extreme drought conditions and substantial freshwater withdrawals, necessitated by the demand for water to meet the needs of a growing population and to facilitate the transition of land use from natural ecosystems to irrigated landscapes. In the context of the region's agricultural industry, the judicious utilisation of water resources for crop irrigation purposes assumes considerable significance. As demonstrated in the relevant literature, these conditions have been shown to exert a significant impact on the seasonality of well levels (Legarreta-González *et al.* 2024a, Legarreta-González *et al.* 2024b). In this region, some studies have been conducted on the quality of drinking water, including one by Barrera-Prieto *et al.* (2020), regarding nitrates, and two other studies: Gutiérrez *et al.* (2008) and Bencomo-Calderón *et al.* (2024). However, in neither of the two was modelling used for forecasting, and they were based on few observations or were cross-sectional studies. Consequently, this phenomenon can give rise to seasonal fluctuations in the levels of As, Pb and F in drinking water wells. The objectives of this research were to ascertain the presence of potential variations across years in the levels of As, Pb and F in drinking water from Meoqui, Chihuahua, Mexico and to evaluate four mathematical models in order to forecast their pattern and determine whether the levels of the three elements comply with the Mexican Official Standard NOM-127-SSA1-2021 (SS 2021).

e-ISSN: 2007-901X

MATERIALS AND METHODS

Study site

The data were collected from the city of Meoqui, Chihuahua in Mexico. The geographic coordinates of the city are 28° 5′ 06″ N, 105° 17′ 56″ W. Figure 1 illustrates the geographical position of the municipality of Meoqui. The climate is semi-arid with temperatures between -2 °C and 13 °C in Winter and a maximum between of 38 °C and 42 °C in Summer.

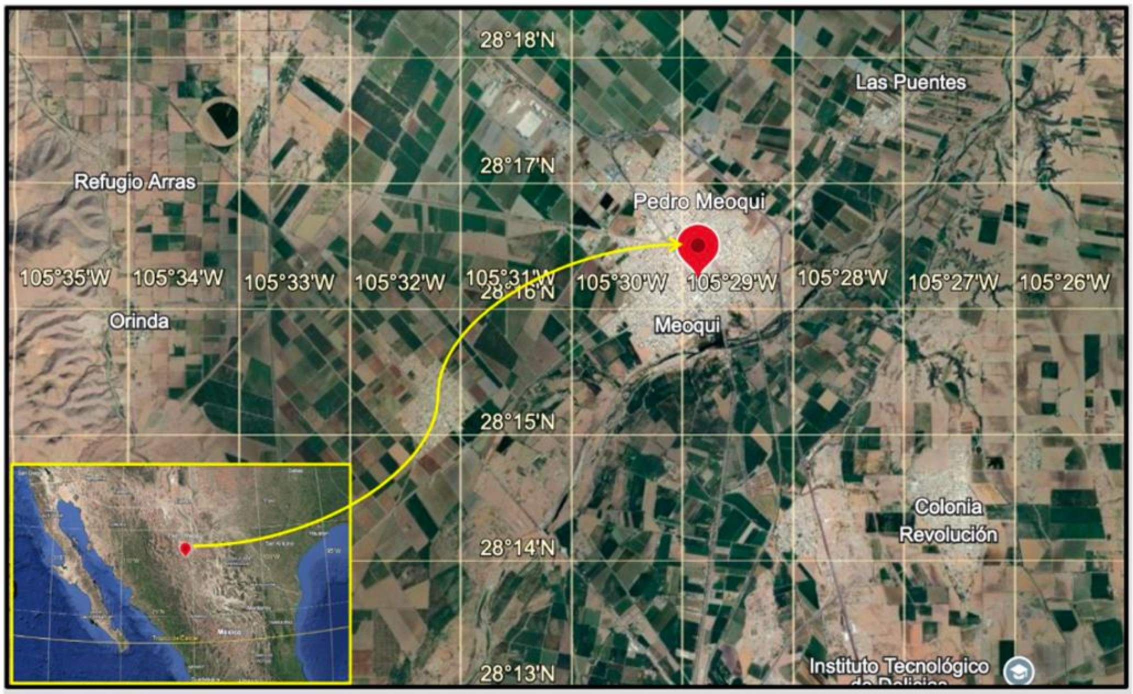

Figure 1. Geographical position of the city of Meoqui, Chihuahua, Mexico.

Data Collection

The city has 10 wells where water is extracted. Table 1 shows where the samples were taken from. Figure 2 illustrates the geographical positioning of the wells. The data were obtained from 10 wells between the years 2010 and 2023. The wells are equipped with water meters, the data from which are stored in an Excel database on a computer at the Junta Municipal de Aguas y Saneamiento (JMAS) of Meoqui, Chihuahua headquarters. The data was formally requested from JMAS by the corresponding author. The data employed in this study was that pertaining to the mean monthly extraction rate. Wells F-4, F-5 and F-6 are used to supply drinking water to the brewing industry. In addition, the wells 1, 4, 5, 6, 7, F1 and F-2 provide water to a variety of sectors, including domestic, commercial, educational, public and industrial. The water obtained from these mentioned seven wells is made potable by JMAS and subsequently distributed to the mentioned sectors via the municipal drinking water network. In accordance with Mexican regulations, water samples are to be taken at least every six months and submitted for analysis to an external, certified laboratory. In certain instances, analyses have been conducted on water mixtures from two or more wells; however, samples from individual wells have been analysed on a regular basis.

Table 1. Wells sampled, year, month and mg L^{-1} of Arsenic that showed an excess of 0.01 mg L^{-1} in drinking water in Meoqui, Chih., México.

Well(s)	Year	Month	mg L^{-1}	Well(s)	Year	Month	mg L^{-1}
1	2010	April	0.036	1	2018	7	0.033
5	2010	April	0.087	F1 and F2	2018	12	0.036
6	2010	April	0.171	7 and 2	2018	12	0.027
7 and 2	2010	April	0.029	F1	2018	12	0.075
5	2011	November	0.900	F1	2018	4	0.069
6	2011	November	0.300	7 and 2	2018	4	0.030
7 and 2	2011	November	0.036	5	2018	4	0.074
7 and 2	2011	June	0.081	1	2018	4	0.037
6	2011	June	0.178	F1	2018	4	0.069
7 and 2	2013	May	0.029	1	2019	7	0.034
6	2013	May	0.034	5	2019	7	0.070
5	2013	May	0.087	7 and 2	2019	7	0.037
1, 5 and 7	2015	July	0.056	F1	2019	7	0.067
7 and 2	2015	July	0.077	1	2021	2	0.033
5	2015	July	0.031	5	2021	2	0.069
1	2015	July	0.069	7 and 2	2021	2	0.030
6	2015	July	0.282				
5	2017	April	0.071				
F1	2017	April	0.059				
6	2017	April	0.185				
1	2017	April	0.031				
F1 and 1	2017	April	0.030				
F1 and 1	2017	April	0.030				
5 and 7	2017	April	0.044				
5 and 7	2017	April	0.070				

Statistical methods
In the present study, four different methodologies were evaluated and tested to estimate time series models for historical Arsenic, Lead and Fluorides in Meoqui, Chih., Mexico. The methodologies evaluated and tested were Auto Regressive Integrated Moving Average (ARIMA), Facebook Prophet, Lasso and Elastic-Net Regularized Generalized Linear Models (GLMNET) and a hybrid model of Facebook Prophet with Extreme Gradient Boosting model (XGBoost) where models were calibrated.

Model predictions
It is evident that certain models yield negative predictions, attributable to elevated variations. The authors elected to maintain these values, though it is imperative that they are interpreted as zero.

Time series trend
The evaluation of the slope of the time series was conducted by employing the Sen's slope statistics and Mann-Kendall Test. Model selection. In order to select the most appropriate models, the

Ecosist. Recur. Agropec. Núm. Esp. VI: e5240, 2026
https://doi.org/10.19136/era.a13nVI.5240

smaller values of the Mean Absolute Error (MAE) were chosen. In instances where values are equal, the Root Mean Square Error (RMSE) was employed as a secondary criterion, in conjunction with the maximum attainable value of coefficient of determination (R-sq or R^2) as in the works of (SS 2021, Agaj *et al.* 2024, Jaya *et al.* 2024, Legarreta-González *et al.* 2024a, Legarreta-González *et al.* 2024b). In instances where the R^2 values were unable to be estimated, the model would be disregarded. In order to circumvent the issue of overfitting, the 'hold-out (data)' method was employed in lieu of utilising the entirety of the data for training purposes. The dataset was then divided into two sets: a training set and a testing set. This finding suggests that the model exhibits effective generalisation capabilities, as evidenced by its ability to effectively predict unseen data that was not part of the training set. This approach is frequently employed when there is a sufficiently large dataset available for training, even subsequent to data splitting, as was the case with the dataset under consideration. In accordance with the established recipe, a cross-validation procedure was employed for both the GLMNET and the hybrid models. The number of folds in the cross-validation was specified as K = 5 for both models. For an in-dept explanation of these models, calibration and model selection, please read the work of Herrera-González *et al.* (2024).

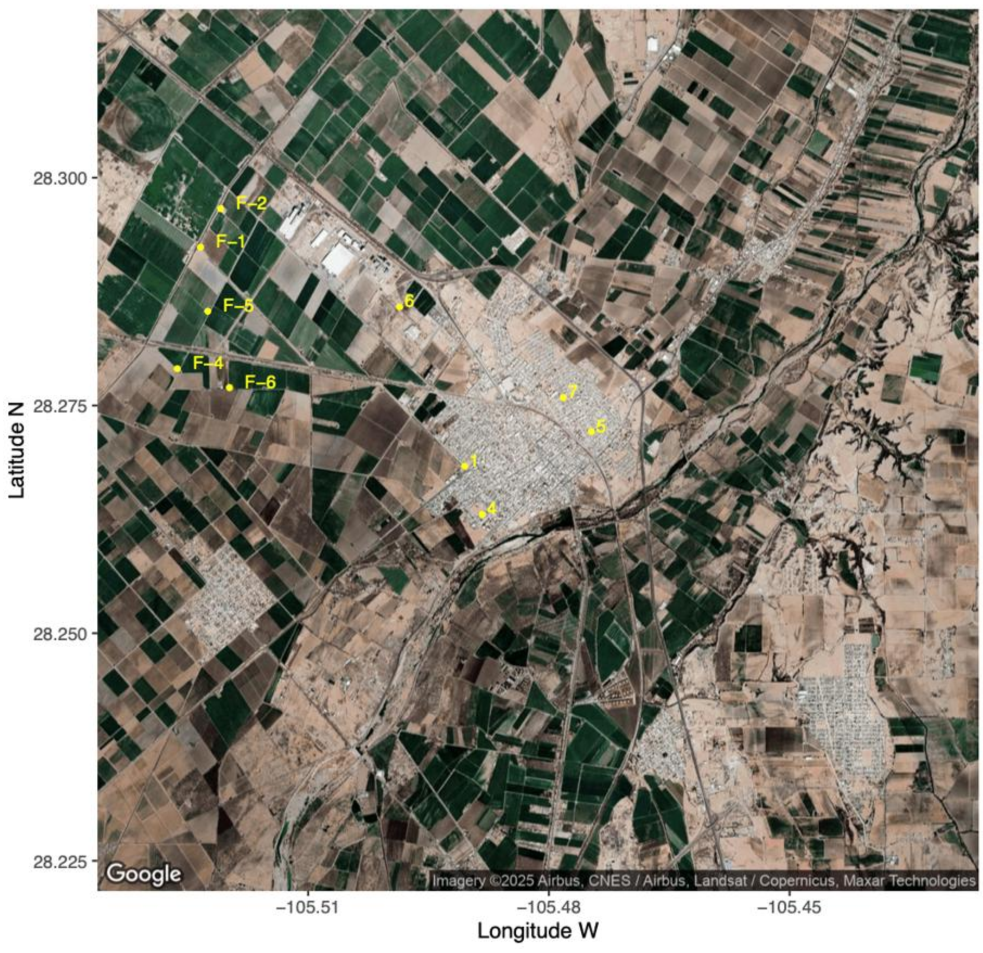

Figure 2. Satellite view of Meoqui City and location of the wells utilized for sampling Arsenic, Lead and Fluorides in drinking water.

e-ISSN: 2007-901X

Ecosist. Recur. Agropec. Núm. Esp. VI: e5240, 2026
https://doi.org/10.19136/era.a13nVI.5240

Data analysis

We used the R programming language (Version 4.5.0) (R Core Team 2025), ggplot2 (Version 3.5.1) (Wickham 2016), modeltime (Version 1.3.0) (Dancho 2026), and trend (Version 1.1.6) (Pohlert 2023).

RESULTS

Descriptive statistics

Arsenic

During the analysed period, the mean, standard deviation and maximum values for As were 0.06 ± 0.12 and 0.9 mg L^{-1}, respectively. In accordance with the stipulations set out in NOM, for the provision of water for human use and consumption, Table 1 details the dates, wells and As mg L^{-1} on which permissible limits for water quality were exceeded. The maximum permitted level of As is 0.01 mg L^{-1}.

Lead

The mean, standard deviation and maximum values for Pb were 0.001 ± 0.002 and 0.01 mg L^{-1}, respectively. All of the observed Pb mg L^{-1} values were in accordance with the stipulations set out in the NOM, for the provision of water for human use and consumption.

Fluoride

The mean, standard deviation and maximum values for F were 2.07 ± 1.26 and 5.1 mg L^{-1}, respectively. In accordance with the stipulations set out in the NOM, for the provision of water for human use and consumption, Table 2 details the dates, wells and F mg L^{-1} on which permissible limits for water quality were exceeded. The maximum permitted level of F is 1.5 mg L^{-1}.

Table 2. Wells sampled, year, month and mg L^{-1} of Fluoride that showed an excess of 1.5 mg L^{-1} in drinking water in Meoqui, Chih., México.

Wells	Year	Month	mg L^{-1}	Wells	Year	Month	mg L^{-1}
5	2010	4	4.73	1, 5 and 7	2015	7	2.76
6	2010	4	2.52	5	2015	7	4.45
7 and 2	2010	4	1.85	6	2015	7	3.00
5	2011	11	4.65	5	2017	4	3.22
6	2011	11	1.79	F1	2017	4	1.64
7 and 2	2011	11	3.13	6	2017	4	3.17
F2	2011	11	2.33	1	2017	4	1.62
6	2011	5	2.73	F1-1	2017	4	1.77
6	2012	3	2.48	F1-1	2017	4	1.78
5	2012	3	4.75	5 and 7	2017	4	3.18
5	2012	11	4.64	7 and 2	2017	4	2.43
6	2012	11	2.30	5 and 7	2017	4	3.44
7 and 2	2013	5	1.94	1	2019	7	1.60
6	2013	5	1.73	5	2019	7	5.10
5	2013	5	4.90	7 and 2	2019	7	2.10
F2	2014	8	1.54				

Model selection

As demonstrated in Table 3, the parameters required to select the optimal model for As, Pb and F are presented. In all instances, the most suitable model was the Prophet. The values for MAE and R^2 (parameters employed for selection) were, respectively, a) 0.03 and 0.06 for As; b) 0.13 and 0.12 for Pb. In this particular instance, the values were identical for the hybrid model; however, the Prophet model was selected due to its significantly more straightforward nature; and c) 1.04 and 0.04 for F. In this case, the estimate of the forecast were constant and with non-standard deviation, then r-sq can not be estimated, thus, the ARIMA model was discarded, selecting the Prophet model.

Table 3. Model selection parameters for Arsenic, Lead and Fluoride in drinking water in Meoqui, Chih., México.

	Arsenic			**Lead**			**Fluoride**		
	MAE	**RMSE**	**R-sq**	**MAE**	**RMSE**	**R-sq**	**MAE**	**RMSE**	**R-sq**
ARIMA	0.04	0.04	NA	0.14	0.15	NA	0.95	0.95	NA
Prophet	0.03	0.05	0.06	0.13	0.14	0.12	1.04	1.45	0.04
GLMNET	0.04	0.06	0.05	0.13	0.17	NA	4.43	4.72	0.06
Hybrid	0.04	0.06	0.02	0.13	0.17	0.12	1.91	2.54	0.01

Arsenic

Table 4 presents 12 months prediction of As mg L^{-1} and its 95 % Confidence Intervals (CI), Inferior (ICI) and Upper (UCI) in drinking water. Figure 3 (left) shows the time series plot and (right) the forecast plot. Sen's Slope = 0.00, Mann-Kendall Test, S = −4.58 × 102 , $p < 0.2875$ which indicates there is no statistical significant slope. Furthermore, it is anticipated that there will be instances where the As concentration will exceed the permissible limits stipulated by the NOM.

Table 4. One year monthly prediction of Arsenic mg L^{-1} and its 95% Confidence Intervals in drinking water in Meoqui, Chih., México.

Month	**ICI**	**Prediction**	**UCI**
January	-0.130	-0.025	0.080
February	-0.118	-0.013	0.092
March	-0.130	-0.025	0.080
April	-0.031	0.074	0.179
May	-0.118	-0.013	0.092
June	-0.105	0.001	0.106
July	-0.065	0.040	0.145
August	-0.125	-0.020	0.085
September	-0.131	-0.026	0.079
October	-0.132	-0.027	0.078
November	-0.024	0.081	0.186
December	-0.115	-0.009	0.096

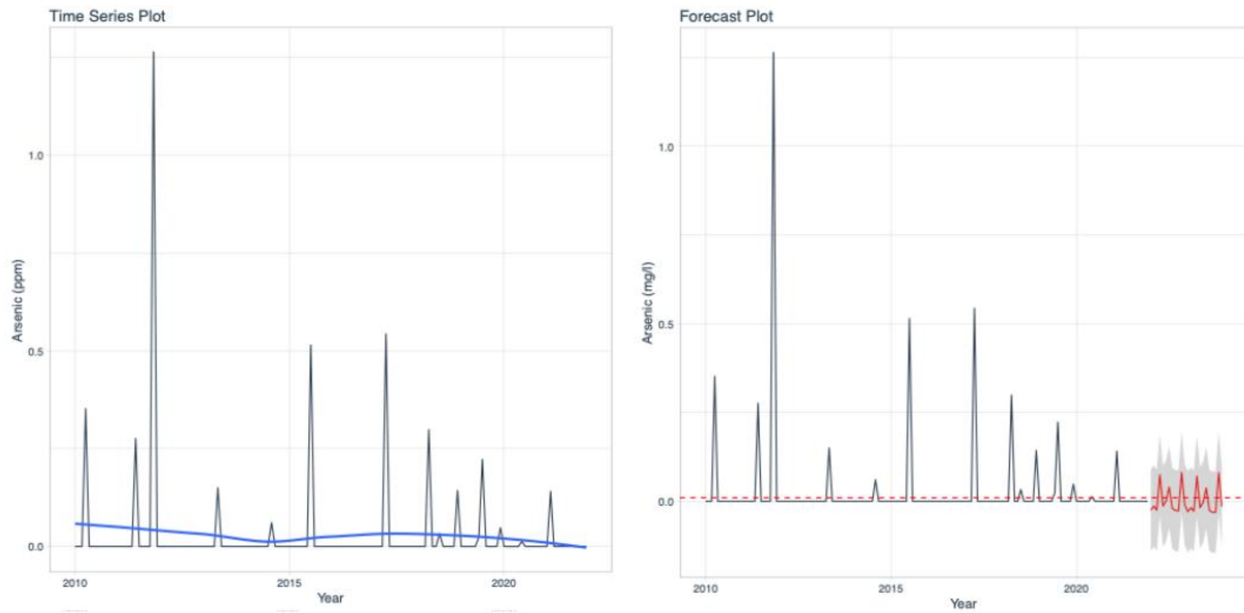

Figure 3. Arsenic level in mg L-1 in water in Meoqui, Chih., México from January 2010 to December 2023. Left Time series plot. Right, Forecast plot where dotted red line indicates the maximum permitted level of 0.01 mg L-1.

Lead

Table 5 presents 12 months prediction and it 95% CI of Pb mg L-1 in drinking water. Figure 4 (left) shows the time series plot and (right) the forecast plot. Sen's Slope = 0.00, Mann-Kendall Test, S = −2.75 × 102, $p < 0.4785$ which indicates there is no statistical significant slope. Furthermore, it was observed that the Pb model does not predict levels that exceed the permissible limits stipulated by the NOM.

Table 5. One-year monthly prediction of Lead mg L-1 and its 95% Confidence Intervals in drinking water in Meoqui, Chih., México.

Month	ICI	Prediction	UCI
January	-0.001	0.000	0.001
February	-0.001	0.000	0.001
March	-0.001	0.000	0.001
April	0.000	0.000	0.001
May	0.000	0.000	0.001
June	-0.001	0.000	0.000
July	0.001	0.003	0.004
August	-0.001	0.000	0.000
September	-0.001	0.000	0.000
October	-0.001	0.000	0.001
November	-0.001	0.000	0.001
December	-0.001	0.000	0.001

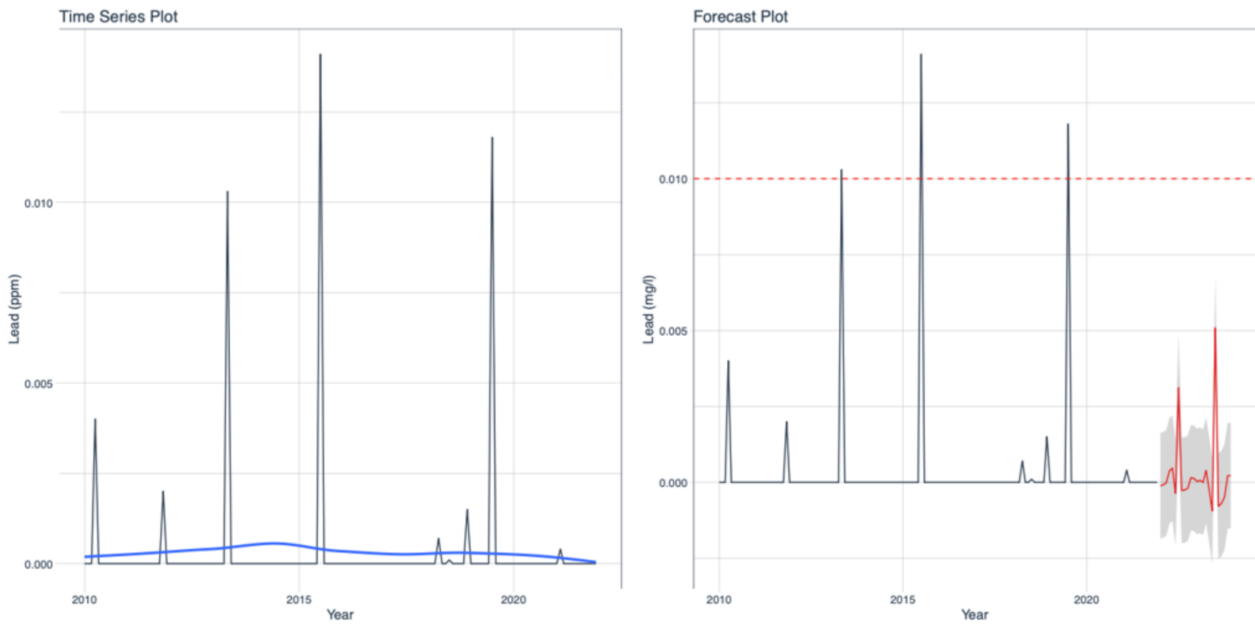

Figure 4. Lead level in mg L^{-1} in water in Meoqui, Chih., México from January 2010 to December 2023. Left, Time series plot. Right, Forecast plot.

Fluoride

Table 6 presents 12 months prediction and it 95 % CI of fluoride mg L^{-1} in drinking water. Figure 5 presents (left) the time series plot and (right) the forecast plot. Sen's Slope = 0.00, Mann-Kendall Test, $S = -2.33 \times 102$, $p < 0.5432$ which indicates there is no statistical significant slope. As with the element under discussion, and also with arsenic, the model predicts periods in which the level of the substance will exceed the limits set out in the NOM.

Table 6. One year monthly prediction of Fluoride mg L^{-1} and its 95% Confidence Intervals in drinking water in Meoqui, Chih., México.

Month	ICI	Prediction	UCI
January	-3.306	-0.396	2.514
February	-3.308	-0.398	2.512
March	-2.481	0.429	3.339
April	-0.187	2.723	5.633
May	-2.153	0.757	3.668
June	-2.938	-0.028	2.882
July	-1.064	1.847	4.757
August	-2.788	0.122	3.032
September	-3.326	-0.416	2.494
October	-3.359	-0.449	2.461
November	-1.359	1.550	4.461
December	-2.996	-0.086	2.825

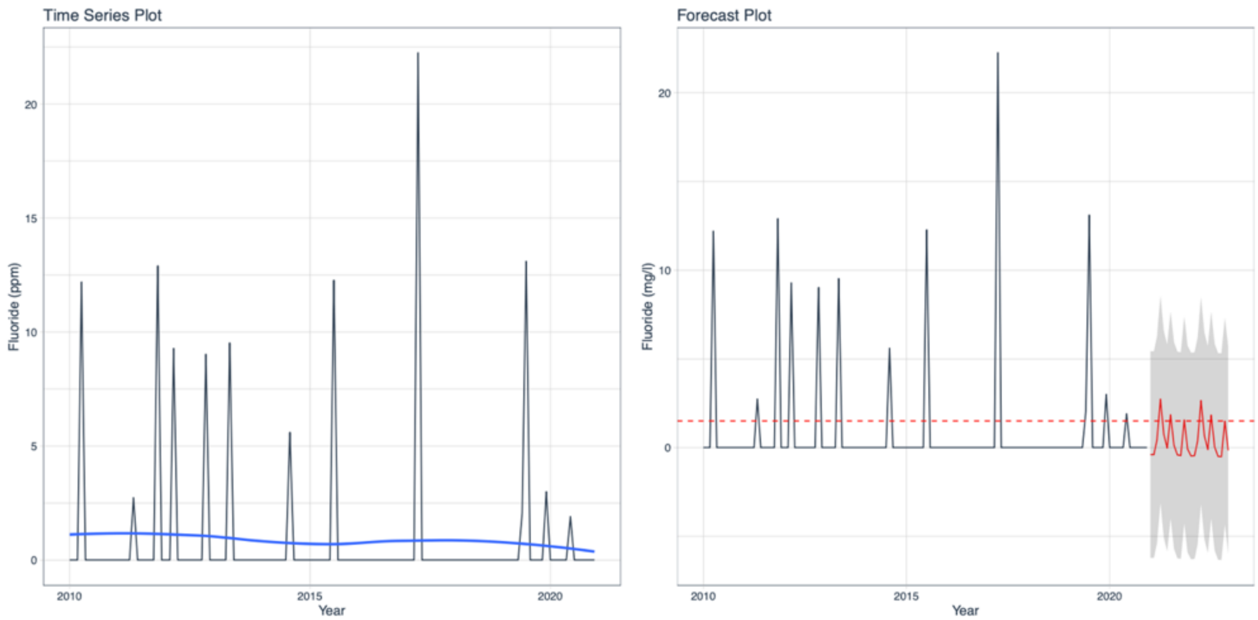

Figure 5. Fluoride level in mg L^{-1} in water in Meoqui, Chih., México from January 2010 to December 2023. Left, Time series plot. Right, Forecast plot.

DISCUSSION

The objective of this study was to assess whether there is variability in the wells supplying drinking water to Meoqui, Chihuahua, in three of the most recurrent contaminants in drinking water. The study established that such variability does indeed exist and that, in certain instances, they pose a genuine threat to public health.

As, Pb and F levels

The mean concentrations of As, Pb and F were analysed during the specified period, with the results indicating 0.06 mg L^{-1} for As, 0.001 mg L^{-1} for Pb and 2.07 mg L^{-1} for F. According to NOM, the maximum permitted values are 0.01 mg L^{-1}, 0.01 mg L^{-1} and 1.5 mg L^{-1}, respectively. With regard to the mean, As and F demonstrated levels that exceeded the established norm. However, the maximum values recorded were 0.9 mg L^{-1}, 0.01 mg L^{-1} and 5.1 mg L^{-1} for As, Pb and F, respectively. This finding probes that the values obtained for As and F exceed the permissible limits, while for Pb, the maximum value is marginally below the upper limit. These results suggest a potential toxic effect of drinking water due to the levels of As and F, which have been demonstrated to cause severe damage to health. Furthermore, it is important to acknowledge that the models obtained for both As and F enable the anticipation of transient occurrences in which both elements exceed the NOM parameters established for drinking water. In the context of groundwater, the presence of As constitutes a global public health concern. This is due to the fact that groundwater represents a principal source of drinking water and remains a significant water resource. As Thakur and Devi (2024) demonstrate, a significant proportion of drinking water sources in developing countries are derived from groundwater and their the data indicates that more than two thirds of drinking water sources in developing countries are derived from groundwater.

Furthermore, F is also more frequently found in groundwater and has become one of the most important toxicological environmental hazards worldwide. Its presence in groundwater is attributable to the weathering and leaching of fluoride minerals from rocks and sediments, as previously documented by Burgstahler (1966) and Thakur and Gupta (2025). Consequently, F from natural sources is present in certain community water systems, as evidenced by Taylor *et al.* (2025).

Wells and As, Pb and F levels

With regard to the correlation between the wells' pattern and their As levels, it is noteworthy that, with the exception of Wells F-4, F-5 and F-6, all the wells in the system exhibited levels above the standard at some point. These wells are the primary suppliers of water to the regional brewing industry. It is also noteworthy that there are no reports of levels above the standard in the years 2010 to 2016 and in the years 2020, 2022 and 2023, as well as the fact that wells 6, 5 and 7, F1 and F1 and F2 only showed levels above the standard in one of the years of the study. Finally, a yearly decrease in arsenic levels in drinking water was also observed. For the years 2017, 2018, 2019 and 2021, the average out-of-norm levels were recorded as 0.065, 0.050, 0.052 and 0.044 mg L^{-1}, respectively.

With respect to F, as in the case of As levels in the well water, all wells, with the exception of F-4, F-5 and F-6, showed levels above the standard at some point in time. It is imperative to reiterate the fact that the wells designated F-4, F-5 and F-6 supply water to the brewery industry in the region. During the specified time period (2016 to 2023), no reports were identified that exceeded the established normal parameters. In contrast to As, for F, no trend towards decreasing levels was evident during the years with off-normal data. Indeed, two peaks were observed: one in 2011 and 2012, and another in 2015 and 2017.

According with the above, a latent threat to the physical integrity of individuals is evident, attributed to the periods in which the concentrations of As and F exceed the thresholds established by the Mexican NOM. It is important to emphasise that both contaminants exhibit high toxicity, particularly when ingested over prolonged periods. Thakur and Gupta (Thakur and Gupta 2025) point that It has been demonstrated that the ingestion of water containing elevated levels of arsenic over an extended period can result in the development of gangrene and skin lesions or worst, an emerging corpus of evidence suggests a potential link between this practice and an elevated risk of developing long-term uterine and liver cancer, in addition to various health complications. Furthermore, the same authors indicat there is documented evidence in the short and long term of its propensity to induce skin lesions, gastroenteritis, kidney and liver failure, and gangrene (Thakur and Gupta 2025). As indicated by Polukhova (Polukhova *et al.* 2025), chronic exposure to arsenic has been associated with an increased risk of metabolic diseases, including type 2 diabetes, osteoporosis, hypertension, cardiovascular disease and obesity, as well as a range of signs and symptoms, many of which are non-specific. The latter include skin lesions such as palmoplantar hyperkeratosis, hypercarotinised warts or corns, and hyperpigmentation (with interspersed depigmented areas), which has been identified as the most sensitive indicator of chronic arsenic exposure (Polukhova *et al*. 2025). The present study addresses the relevance of chronic arsenic exposure on internal organ involvement in humans. Among the various internal organs affected, the liver has been found to be of significant relevance. As previously mentioned, Pb did not

Ecosist. Recur. Agropec. Núm. Esp. VI: e5240, 2026
https://doi.org/10.19136/era.a13nVI.5240

demonstrate levels that exceeded the designated standard. Consequently, all the wells analysed exhibited levels that were in accordance with the official standard. However, given the existence of records at the limit permitted by the NOM, it is imperative to adhere to a stringent monitoring process to avert the occurrence of values that exceed these limits and the resultant harm to the organism, as previously delineated.

Best forecating model to As, Pb and F levels in groundwater of Meoqui

The most suitable model for all elements analysed in the well water of Meoqui, Chihuahua, was Prophet, which coincides with the results obtained by Hasan *et al.* (2024), Armouti and Awajan (2025) and Grekov *et al.* (2024), although it differs with the results reported by other authors, who mention ARIMA-LSTM (Grekov *et al.* 2024) and XGBoost (Bonkoungou *et al.* 2024) as the most effective predictive models. Although Prophet is generally considered the standard model for measuring groundwater levels and their compounds, the discrepancies among authors regarding the optimal choice for forecasting suggest that further testing is necessary to ensure the models' predictive efficiency. The Prophet model generates forecast graphs that describe the levels of the three contaminants, which are projected to remain below the NOM permissible levels for the subsequent year. This finding suggests that the corrective and preventive well water monitoring activities being conducted by the resource managers are being carried out in an effective manner.

Model limitations

It is evident that certain models yield negative predictions, attributable to elevated variations. The authors elected to maintain these values, though it is imperative that they are interpreted as zero.

CONCLUSIONS

The subject of this study is the inhabitants of the city of Meoqui, in the state of Chihuahua, Mexico. This town, located in the Chihuahuan Desert in the north-central part of the country, has experienced some episodes of concentrations above the officially regulated levels of As and F in the period between 2010 and 2023. These episodes have the potential to present challenges for consumers of drinking water. The levels of As and F have decreased in recent years, which could be related to corrective measures implemented by the water managing authorities. This hypothesis can be extended to Pb levels, which have not exceeded the limit established by the NOM. Projections for the coming months suggest that the levels of As, Pb and F will remain below the maximum threshold established by the Mexican Official Norm for these pollutants. The model that has been found to provide the most accurate predictions of the concentrations of As, Pb and F in the groundwater of Meoqui is Facebook Prophet. This model should be considered in future studies of water analysis in the region.

e-ISSN: 2007-901X

LITERATURE CITED

Agaj T, Budka A, Janicka E, Bytyqi V (2024) Using ARIMA and ETS models for forecasting water level changes for sustainable environmental management. Scientific Reports 14: 22444. https://doi.org/10.1038/s41598-024-73405-9

Armouti B, Awajan A (2025) Water quality forecasting using time series techniques. International Conference on New Trends in Computing Sciences. Aman, Jordan. pp. 373-378. https://doi.org/10.1109/ICTCS65341.2025.10989394

Bencomo-Calderón M, Herrera-Peraza EF, Villalobos-Aragón A (2024) As and Pb Presence within the Meoqui-Delicias Aquifer, Chihuahua, Mexico. Water 16(17): 2538. https://doi.org/10.3390/w16172538

Bonkoungou AA, Zio S, Sabane A, Kafando R, Kabore AK, Bissyande TF (2024) A comparison of AI methods for groundwater level prediction in Burkina Faso. In: Maglogiannis I, Iliadis L, Macintyre J, Avlonitis M, Papaleonidas A (eds) Artificial Intelligence Applications and Innovations. Springer Nature. Switzerland. pp. 3-16.

Burgstahler AW (1966) Detroit fluoride conference. Science 154(3749): 590-590

Dancho M (2026) modeltime: The tidymodels extension for time series modeling. R package. https://github.com/business-science/modeltime. Data consulted: 10 february 2026.

Barrera-Prieto Y, Espino-Valdés MS, Herrera-Peraza E (2020) Presencia de arsénico en la sección norte del acuífero Meoqui-Delicias del estado de Chihuahua, México: Arsenic presence in North section of Meoqui-Delicias aquifer of State of Chihuahua, Mexico. Tecnociencia Chihuahua 3(1): 8-18. https://doi.org/10.54167/tch.v3i1.739

Grekov AN, Vyshkvarkova EV, Mavrin AS (2024) Forecasting and anomaly detection in BEWS: Comparative study of Theta, Croston, and Prophet algorithms. Forecasting 6: 343-356. https://doi.org/10.3390/forecast6020019

Gutiérrez RL, Rubio-Arias H, Quintana R, Ortega JA, Gutierrez M (2008) Heavy metals in water of the San Pedro River in Chihuahua, Mexico and its potential health risk. International Journal of Environmental Research and Public Health 5: 91-98. https://doi.org/10.3390/ijerph5020091

Hartmann J, Chacon-Hurtado JC, Verbruggen E, Schijven J, Rorije E, Wuijts S, de Roda Husman AM, van der Hoek JP, Scholten L (2021) Model development for evidence-based prioritisation of policy action on emerging chemical and microbial drinking water risks. Journal of Environmental Management 295: 112902. https://doi.org/10.1016/j.jenvman.2021.112902

Hasan MM, Ng KTW, Ray S, Assuah A, Mahmud TS (2024) Prophet time series modeling of waste disposal rates in four North American cities. Environmental Science and Pollution Research 31: 373-378. https://doi.org/10.1007/s11356-024-33335-5

Herrera-González JL, Rodríguez-Venegas R, Legarreta-González MA, Robles-Trillo PA, De Santiago-Miramontes Á, Loya-González D, Rodríguez-Martínez R (2024) Time series (ARIMA) as a tool to predict the temperature-humidity index in the dairy region of the northern desert of Mexico. PeerJ 12: e18744. https://doi.org/10.7717/peerj.18744

Izah SC, Ogwu MC (2025) Modeling solutions for microbial water contamination in the global south for public health protection. Frontiers in Microbiology 16: 1504829. https://doi.org/10.3389/fmicb.2025.1504829

Jaya NA, Arsyad M, Palloan P (2024) Estimation of groundwater river availability in Leang Lonrong Cave using ARIMA model. Advances in Environmental Studies 2: 1-18. https://doi.org/10.46799/adv.v2i5.240

Jomova K, Alomar SY, Nepovimova E, Kuca K, Valko M (2025) Heavy metals: toxicity and human health effects. Archives of Toxicology 99: 153-209. https://doi.org/10.1007/s00204-024-03903-2

Legarreta-González MA, Meza-Herrera CA, Loya-González D, Chávez-Tiznado CS, Arellano-Rodríguez F, De-Santiago-Miramontes A, Rodríguez-Martínez R, Robles-Trillo P, Véliz-Deras FG (2024a) Time series analysis to estimate the volume of drinking water consumption in the city of Meoqui, Chihuahua, Mexico. Water 16: 2634. https://doi.org/10.3390/w16182634

Legarreta-González MA, Meza-Herrera CA, Rodríguez-Martínez R, Loya-González D, Chávez-Tiznado CS, Contreras-Villarreal V, Véliz-Deras FG (2024b) Selecting a time-series model to predict drinking water extraction in a semi-arid region in Chihuahua, Mexico. Sustainability 16: 9772 https://doi.org/10.3390/su16229722

Pohlert T (2023) trend: Non-parametric trend tests and change-point detection. R package version 1.1.6. https://doi.org/10.32614/CRAN.package.trend. Data consulted: 10 february 2026.

Polukhova S, Mehtiyeva S, Karimova R, Abiyev H, Heybatova M, Aslanova A (2025) Combined damage to the nervous system and liver as a result of arsenic poisoning and changes in biochemical parameters in the blood of experimental animals. Norwegian Journal of Development of the International Science 151: 79-89.

R Core Team (2025) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/. Data consulted: 10 february 2026.

SS (2021) Norma Oficial Mexicana NOM-127-SSA1-2021, Agua para uso y consumo humano. Límites permisibles de la calidad del agua. Secretaría de Salud. Diario Oficial de la Federación. https://www.dof.gob.mx/nota_detalle_popup.php?codigo=5650705. Data consulted: 10 february 2026.

Taylor KW, Eftim SE, Sibrizzi CA, Blain RB, Magnuson K, Hartman PA, Rooney AA, Bucher JR (2025) Fluoride exposure and children's IQ scores: A systematic review and meta-analysis. JAMA Pediatrics 179: 282-292. https://doi.org/10.1001/jamapediatrics.2024.5542

Thakur BB, Devi P (2024) A Comprehensive Review on Water Quality Monitoring Devices: Materials Advances, Current Status, and Future Perspective. Critical Reviews in Analytical Chemistry 54: 193. https://doi.org/10.1080/10408347.2022.2070838

Thakur BK, Gupta V (2025) Welfare estimation of groundwater arsenic contamination in India: Insights for water policy. Journal of Cleaner Production 497: 145107. https://doi.org/10.1016/j.jclepro.2025.145107

UN (2015) Transforming our world: The 2030 agenda for sustainable development. United Nations. https://docs.un.org/en/A/RES/70/1. Data consulted: 10 february 2026.

UN (2023) What is Goal 6 – Clean water and sanitation. United Nations. https://www.un.org/sustainabledevelopment. Data consulted: 10 February 2026.

Wickham H (2016) ggplot2: Elegant graphics for data analysis. Springer, Cham. https://doi.org/10.1007/978-3-319-24277-4