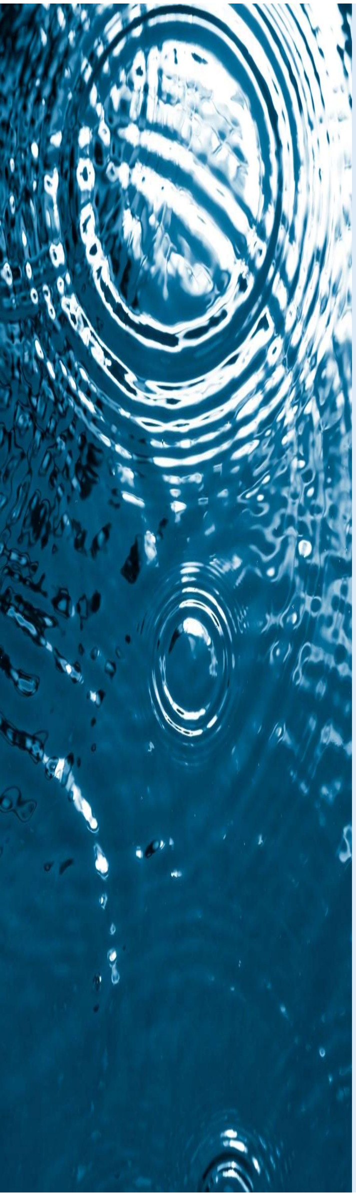


Equity in Arizona's Drinking Water: Groundwater Vulnerability & Contamination Risks

Simone A. Williams, Ph.D.

Research Associate, University of Arizona

EPAZ 2025 Annual Conference

March 3, 2025

Presentation Overview

- Introduction
  - Context
  - Problem Statement
  - Objectives and Hypothesis
- Methodology
- Key Findings
- Policy Implications and Recommendations
- Conclusion

Introduction

Water Security:

- Involves consistent access to sufficient, quality water for human, ecosystem, and economic needs.
- Effective water-related risk management is essential.
- Water security is a global challenge:
  - 30% of world's largest groundwater systems face depletion and degradation.
  - 47% of global population experiences water scarcity annually; expected to rise by 2050.
  - Increasing demand from population growth, agriculture, and industrial activities.

Groundwater (GW) Importance:

- Constitutes 97% of global freshwater.
- Primary source of drinking water for 2.5 billion people globally.
- Vital for agriculture, industry, and rural communities.

Groundwater in Arid Regions

- Essential for meeting water needs due to limited surface water.
- It faces threats from climate change, population growth, urbanization, and mismanagement.
- The need for sustainable management practices is crucial.

Groundwater

A Vital Yet Vulnerable Drinking Water Source in U.S.

Groundwater is a critical source of drinking water, supplying 85% of rural and 50% of urban needs in the U.S.

Arid regions, like Arizona, heavily rely on groundwater due to limited surface water availability.

Contamination from natural sources (e.g., arsenic) and human activities (e.g., nitrate from agriculture) poses significant risks.

Safe groundwater access is a public health priority, particularly for underserved communities with limited water treatment infrastructure.

Problem Statement

AZ Groundwater Governance:

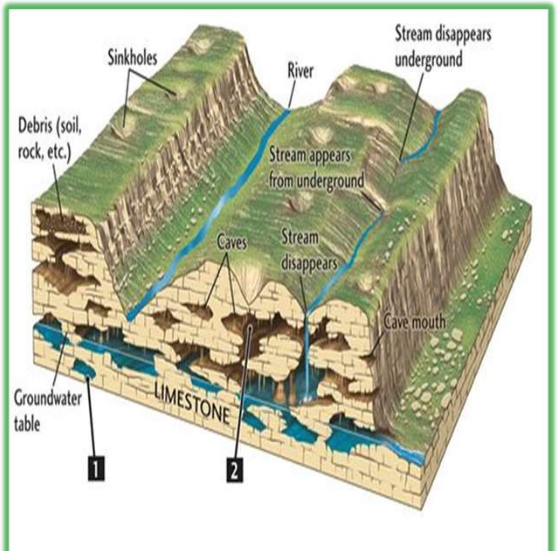
- GMA (1980) established a regulatory framework: 3 levels: AMAs, INAs, and Other Non-Designated Areas (NDAs).
- SDWA governs groundwater-supplied drinking water – risk-based standards (e.g. MCL).

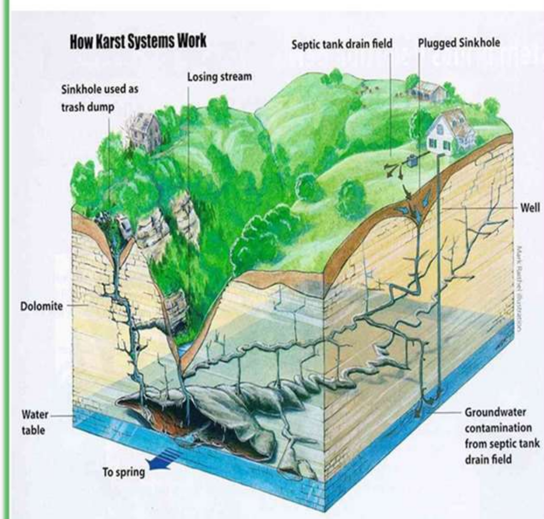
Shortcomings of GMA
- Overlooks interdependence of groundwater and surface water.
- Separate treatment of groundwater and land use policies.
- Unregulated pumping and contamination in rural areas.
- Need for comprehensive management and sustainability focus.

Protection of Karst and Alluvial (Basin and Fill) Systems
- Karst aquifers cover significant land area in Arizona.
- Lack of legal and managerial recognition for karst aquifers.
- Need enhanced research, policy, and management strategies.

Potential Inequities in Groundwater Vulnerability and Contamination Risk (Access/Quality)
- Rural communities outside designated management areas face unique challenges.
- Dependence on shallow wells and scattered populations.
- Tribal communities face similar challenges with unresolved water rights.

Influence of Land Use and Climate Change
- Significant drivers of water sustainability challenges.





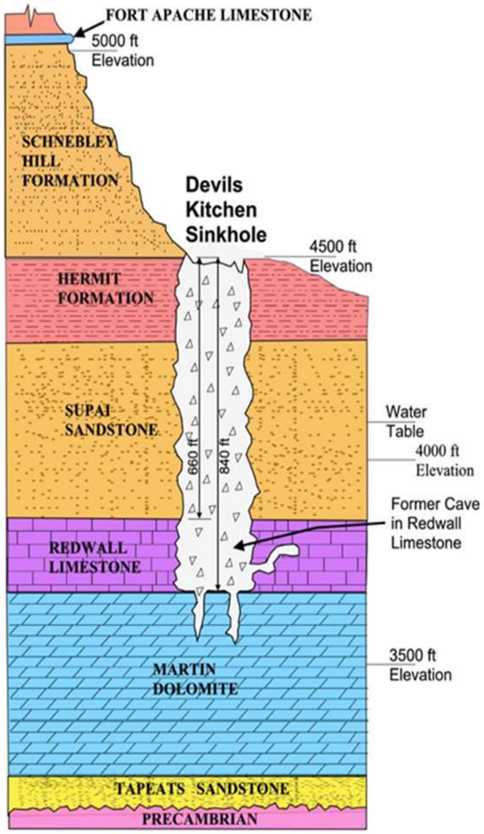
Understanding Groundwater Contamination Disparities in AZ

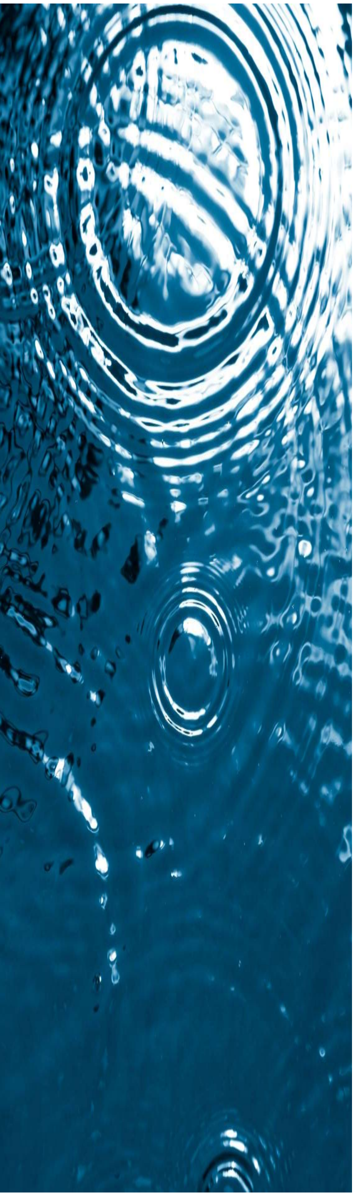
- Groundwater quality is shaped by natural hydrogeology, policy oversight, and socioeconomic factors.

- In the US, marginalized communities, including low-income, minority, and rural populations, face higher contamination risks.

- In AZ, regulatory oversight is inconsistent:
  - Private wells are unregulated,
  - Small water systems struggle with compliance.
  - GMA – uneven regulation (designated/nondesignated)
  - Karst vs. alluvial aquifers

- Understanding disparities in exposure to contaminants helps identify vulnerable populations/systems and informs more equitable policy solutions.





Research Objectives

Drinking Water Quality Disparities:

- Vary by geography, contaminant type, and community.
- Few studies examine contamination levels across aquifers, water system types, and population subgroups at multiple scales.
- Research on environmental equity in groundwater quality is limited in Arizona.

Need for a Multi-Scale Analysis:

- Smaller geographic units reveal significant disparities, but comprehensive studies are lacking.
- Informed public health and regulatory actions require a robust equity-focused approach.

Examine disparities in vulnerability among groundwater-dependent communities.

- **Estimate** nitrate (NO_3) and arsenic (As) concentrations in Arizona’s groundwater-supplied drinking water.
- **Identify** vulnerable communities disproportionately exposed to contamination.
- **Analyze** contamination risk disparities by examining hydrogeologic, policy, and socioeconomic factors.
- **Inform** policy and management strategies for equitable groundwater protection.

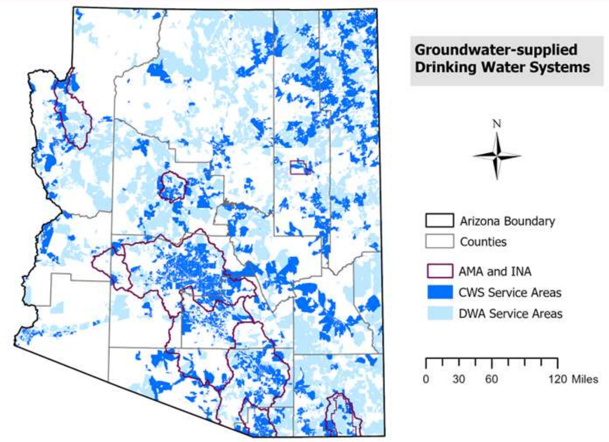
Methodology

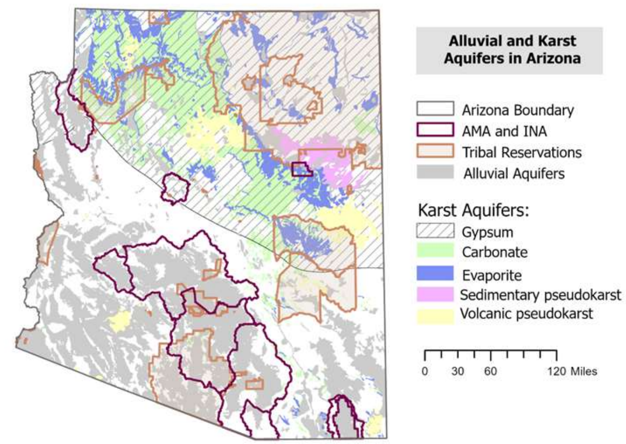
Hypothesis:

- Groundwater sources of drinking water serving vulnerable communities, defined by hydrogeologic, policy, and socioeconomic factors, exhibit statistically significant differences in contamination levels.

Study Area:

- **Arizona**
- **Unit of Analysis** – Water System Service Area





Methodology

Main Variables:

Water Supply Type
- Community Water System (CWS)
- Domestic Well Areas (DWA) – private wells

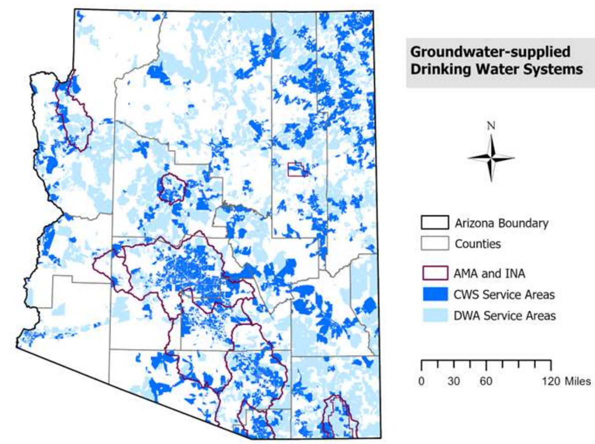
Aquifer Type (Hydrogeology):
- Alluvial
- Karst

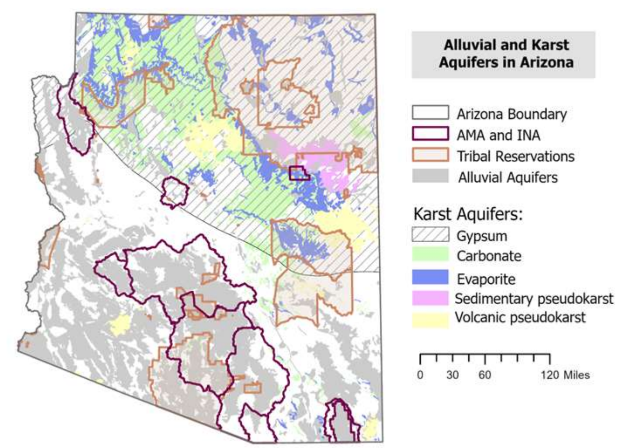
Policy
- **GMA Designated Management**
  - GW Management Areas (AMAs/INA)
  - Non-Designated Areas (NDAs)

Regulatory Oversight (Primacy)
- State
- Tribal Lands

Service Area Characteristics
- Population
- Housing
- Race/ethnicity

Water Quality
- Arsenic (As) - natural
- Nitrate (NO_3) – human activity





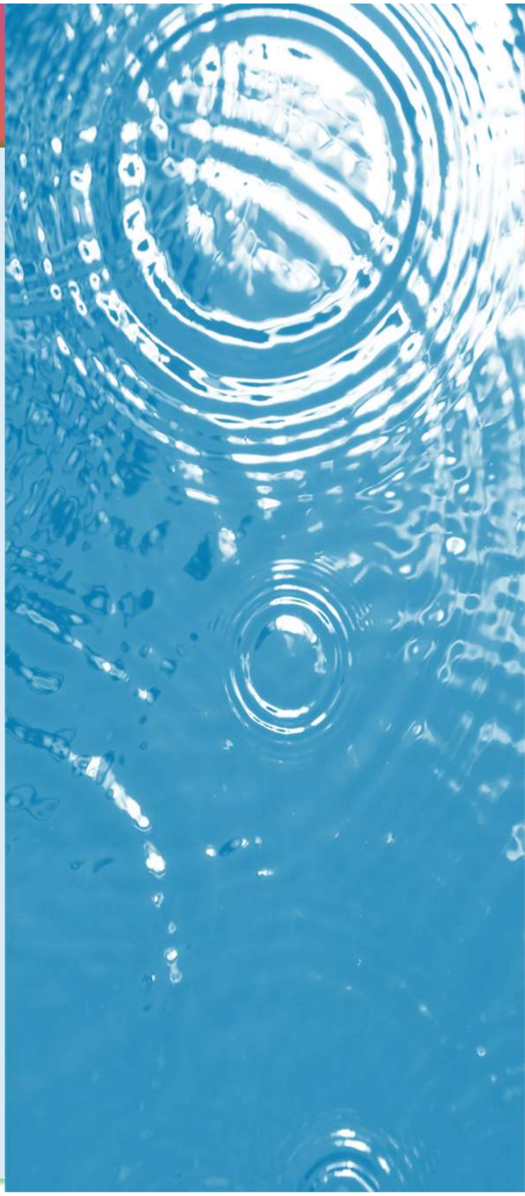
Methodology

Data Processing

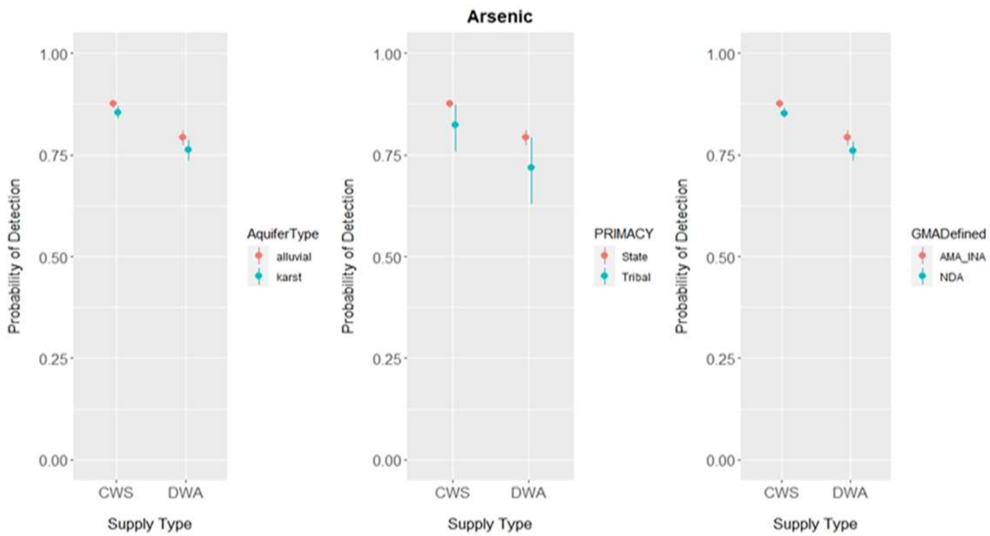
1. **Data:** Secondary Data
2. **Tools:** ArcGIS Pro 3.0.3, R software.
3. **Steps:**
   - Mapping service areas, linking variables, estimating community characteristics, GW access and quality indicators, and subbasin characteristics.
4. **Water Quality Variables:**
   - As and NO_3, nondetects - multiple imputation method.
5. **Contamination Risk Assessment:**
   - Occurrence/Detection
   - MCL exceedance

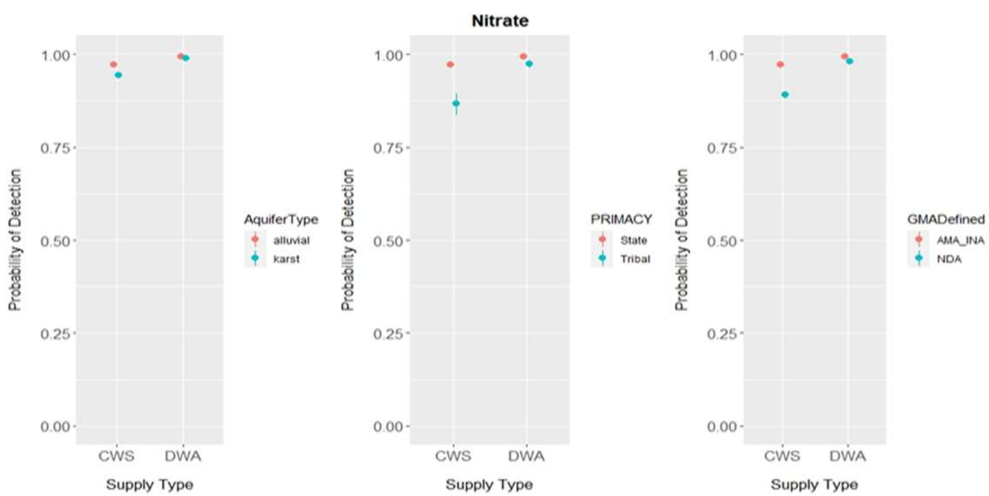
Analysis

- Multi-level
- Stratification – hydrogeology, policy, socioeconomic
- Statistics: ANOVA, multivariate regression models, sensitivity analysis
- Spatial analysis - Cluster analysis



Key Findings: Contaminant Detection Disparities





Arsenic Detection:

- **DWA** less likely to detect arsenic compared to **CWS**.
- **Karst aquifers** have lower detection rates than in **alluvial aquifers.**
- Lower detection in **Tribal** than in **State-regulated** systems.
- Lower detection probability in **NDAs** than in **AMAs/INAs**.

Nitrate Detection:

- Higher nitrate detection in **DWA** than in **CWS**.
- Lower in **karst aquifers** than in **alluvial aquifers**.
- More prevalent in **State-regulated** areas than in **Tribal** jurisdictions.
- Less common in **NDAs** than in **AMAs/INAs**.

Higher probabilities of nitrate vs arsenic detection

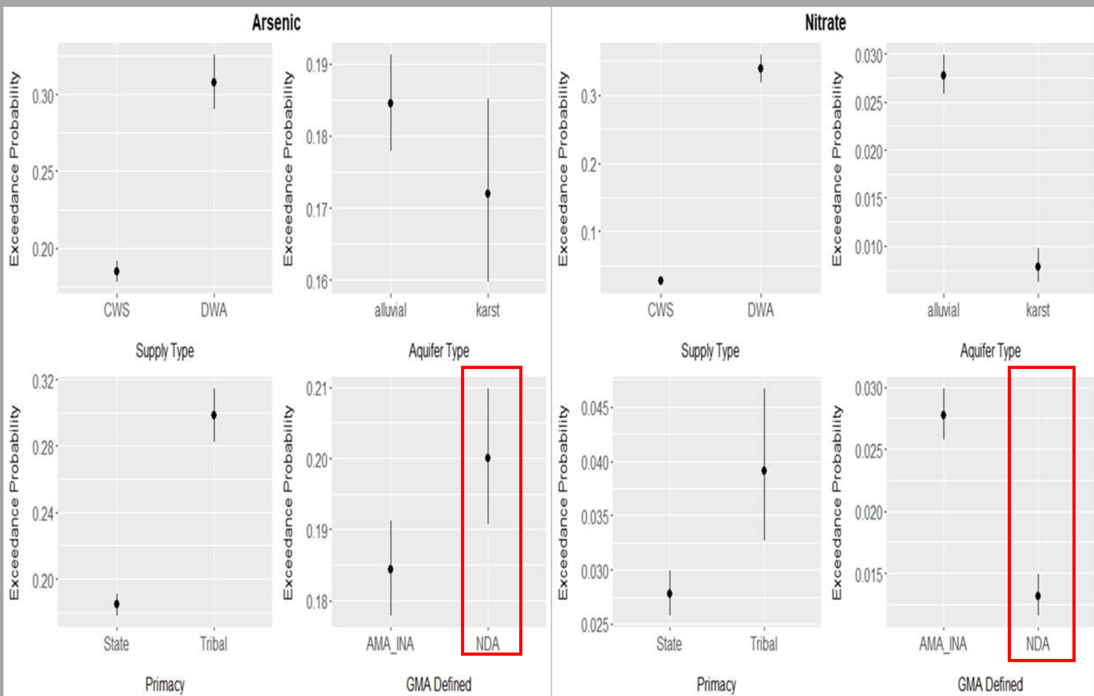
Contaminant Detection Disparities

- All 4 variables are significant predictors of contaminant detection.
  - Aquifer Type
  - Primacy
  - Supply Type
  - GMA Defined Designation

- Differences in the direction and magnitude of influence across predictors and contaminants.

		Arsenic							
		Baseline				Main Effects			
Variables	Contrast	Estimate	Std. Error	Statistic	p-Value	Estimate	Std. Error	Statistic	p-Value
GMA Defined	NDA–AMA_INA	0.017	0.006	2.858	0.004	0.017	0.006	2.858	0.004
Primacy	Tribal–State	0.119	0.008	14.834	<0.001	0.119	0.008	14.834	<0.001
Aquifer Type	karst–alluvial	−0.014	0.007	−2.145	0.032	−0.014	0.007	−2.145	0.032
Supply Type	DWA–CWS	0.130	0.009	14.307	<0.001	0.130	0.009	14.307	<0.001
		Nitrate							
		Baseline				Main Effects			
Variables	Contrast	Estimate	Std. Error	Statistic	p-Value	Estimate	Std. Error	Statistic	p-Value
Supply Type	DWA–CWS	0.166	0.006	29.67	<0.001	0.112	0.005	22.58	<0.001
Aquifer Type	karst–alluvial	−0.032	0.002	−18.58	<0.001	−0.029	0.002	−14.693	<0.001
Primacy	Tribal–State	0.012	0.004	3.083	0.002	−0.022	0.005	−4.935	<0.001
GMA-Defined	NDA–AMA_INA	−0.023	0.002	−12.44	<0.001	−0.025	0.002	−11.691	<0.001

Contaminant MCL Exceedance Disparities



Supply Type: Higher MCL exceedance probabilities in DWA.

Aquifer Type: Lower exceedances in karst aquifers.

Primacy: Tribal primacy is linked to higher As and NO_3 exceedances.

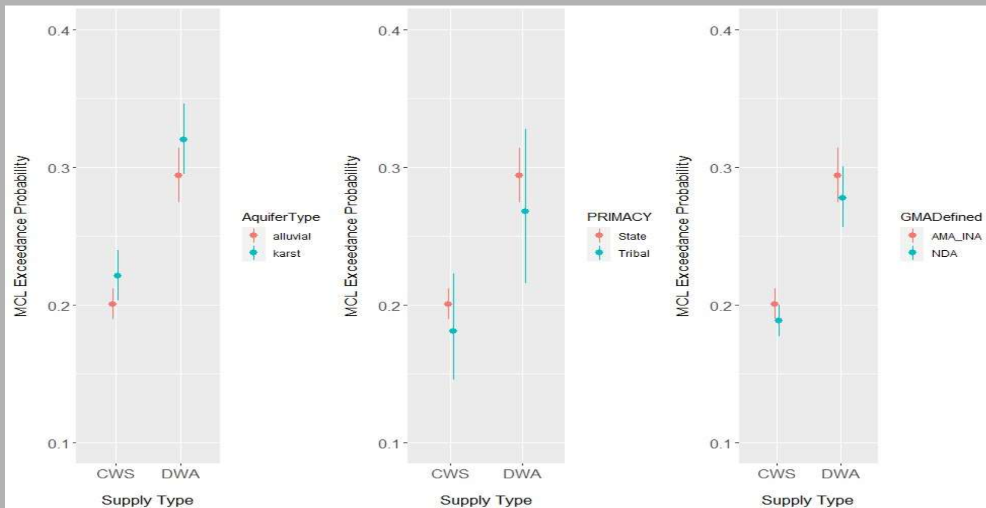
GMA Defined: Higher arsenic and lower nitrate exceedances in NDAs.

Variable	Arsenic			Nitrate		
	Estimate	p-Value	log odds	Estimate	p-Value	log odds
Mean_10	0.007	<0.001	1.01	0.049	<0.001	1.05
GMADefined NDA	0.101	0.004	1.11	−0.733	<0.001	0.48
Primacy Tribal	0.631	<0.001	1.88	0.321	0.001	1.38
Aquifer Type karst	−0.085	0.034	0.92	−1.319	<0.001	0.27
Supply Type DWA	0.676	<0.001	1.97	2.381	<0.001	10.82

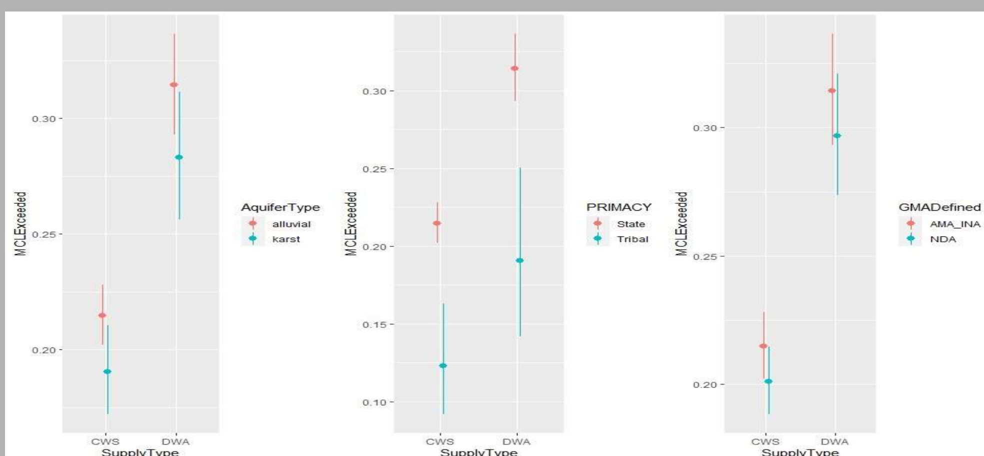
All variables are significant predictors of MCL exceedances.

Mean difference in Arsenic MCL exceedance

Main Effects of Predictors



Interaction Model



Key Factors Influencing MCL Exceedances

Main Effects Model:

- The 4 main variables are significant predictors:

Interaction Effects Model:

- Combined effects show significant, nuanced differences:
  - **Supply Type & Regulatory Primacy:** Amplified effect of DWA under Tribal primacy.
  - **Aquifer Type & GW Mgmt. Area:** Differences in exceedance risks

Equity: Socioeconomic Factors Influencing MCL Exceedances

Predictors	arsenic			nitrate		
	estimate	*p* value	log_odds	estimate	*p* value	log_odds
Water Access						
Mean_20	0.016	0.00	1.02	0.004	0.00	1.00
Demography						
Black_pcnt	0.023	0.01	1.02	−0.005	0.54	0.99
Hisp_Lat_pcnt	−0.001	0.22	1.00	−0.016	0.00	0.98
Indian_Alaska_pcnt	0.008	0.01	1.01	0.016	0.00	1.02
Tot_Female_pcnt	0.020	0.00	1.02	−0.004	0.10	1.00
under_5yrs_pcnt	−0.007	0.01	0.99	−0.004	0.00	1.00
over_65yrs_pcnt	−0.001	0.00	1.00	0.000	0.03	1.00
Housing						
rural_pcnt	−0.001	0.30	1.00	−0.006	0.00	0.99
Family_mchh_pcnt	−0.014	0.00	0.99	0.002	0.32	1.00
Familyhh_pcnt	0.019	0.00	1.02	−0.008	0.00	0.99
For_migrant_workers_pcnt	0.042	0.00	1.04	−0.027	0.03	0.97
For_rent_pcnt	0.045	0.00	1.05	−0.01	0.13	0.99
Socioeconomic						
HU_Owned_clear_pcnt	0.000	1.00	1.00	−0.001	0.72	1.00
HU_Owned_loan_pcnt	−0.002	0.49	1.00	−0.006	0.02	0.99
HU_Renter_occupied_pcnt	−0.008	0.00	0.99	−0.009	0.00	0.99
seasonal_pcnt	−0.001	0.80	1.00	−0.016	0.00	0.98
Institutional Facilities						
Instn_pcnt	−0.001	0.52	1.00	−0.014	0.00	0.99
Non_Instn_pcnt	0.002	0.00	1.00	0.004	0.00	1.00
Instn_Correctional_pcnt	0.002	0.05	1.00	0.005	0.00	1.00
Instn_Juvenile_pcnt	−0.004	0.01	1.00	0.011	0.00	1.01
Instn_Nursing_pcnt	−0.004	0.00	1.00	0.000	0.74	1.00
Non_Instn_Student_pcnt	−0.005	0.00	1.00	0.004	0.05	1.00
Non_Instn_Military_pcnt	−0.003	0.24	1.00	−0.011	0.00	0.99
Interaction Terms						
AquiferTypekarst:Indian_Alaska_pcnt	−0.011	0.01	0.99	−0.039	0.00	0.96
PRIMACYTribal:AquiferTypekarst	0.007	0.98	1.01	2.487	0.00	12.02

1. Demographics Influence Contamination Risk

- Arsenic exceedances are higher in **Black, Native American, female**, and **migrant worker** communities.
- Nitrate exceedances are lower in **Hispanic/Latino areas** but higher in **American Indian** communities.
- **Children under 5** face lower exposure to both contaminants.

2. Housing & Socioeconomic Factors Matter

- Higher arsenic risks in **rental housing** and **migrant worker** communities highlight inequities.
- Nitrate exceedances are lower in **renter-occupied** and **seasonal housing,** meaning **owner-occupied areas** may face greater risk.
- No significant difference in **rural vs. urban** areas.

3. Institutional Settings Show Higher Nitrate Risk

- **Correctional** and **juvenile facilities** have higher nitrate exceedances, indicating institutional water vulnerabilities.
- **Student** housing sees slightly lower arsenic exposure.

4. Policy & Hydrogeology Shape Contamination Risk

- **Karst aquifers** increase vulnerability in **American Indian** communities.
- **Tribal jurisdiction** in karst areas is linked to much higher nitrate exceedances.

Spatial Distribution of Contaminants

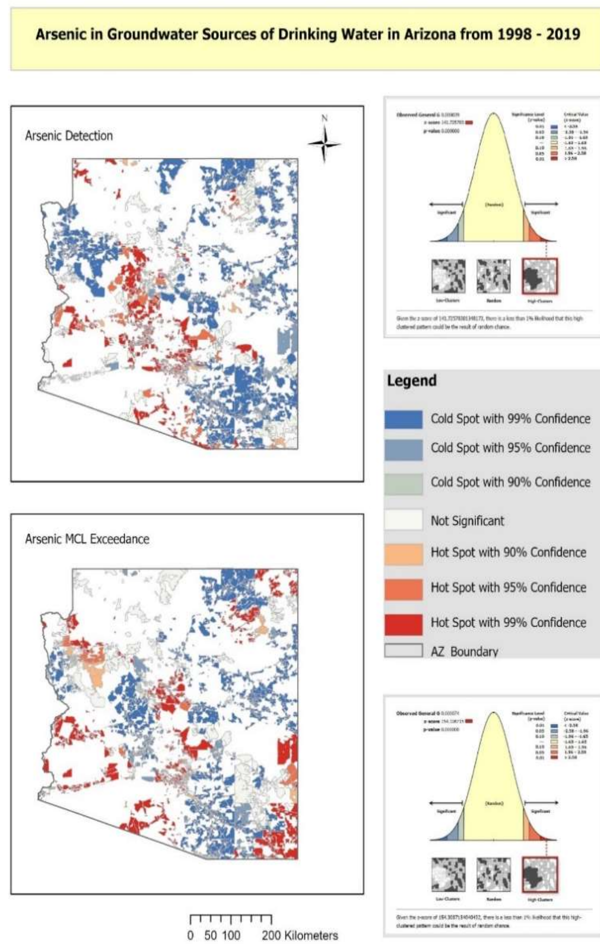
- **Significant As and NO_3 Spatial Clusters**
- **Differences in detection vs exceedance clusters**

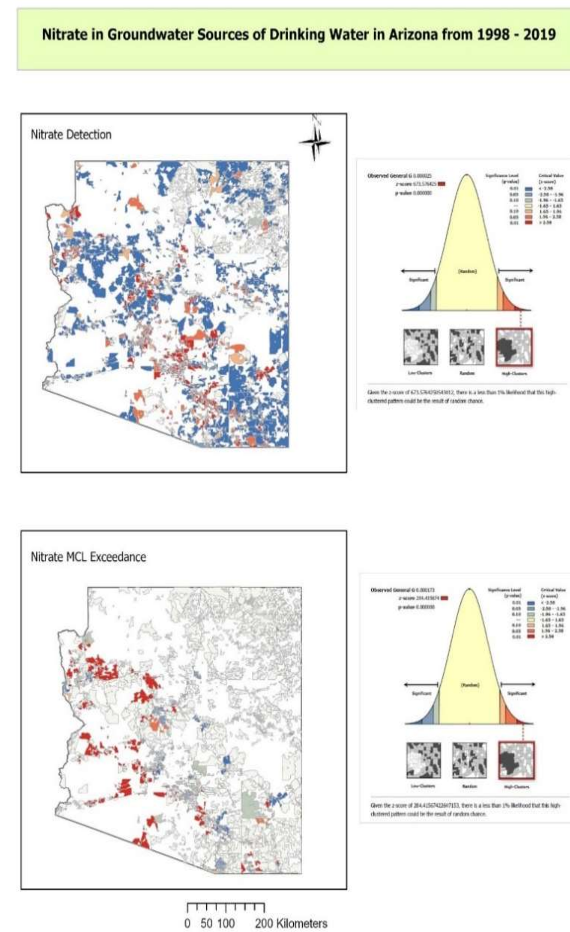
Factors Influencing Spatial Patterns:

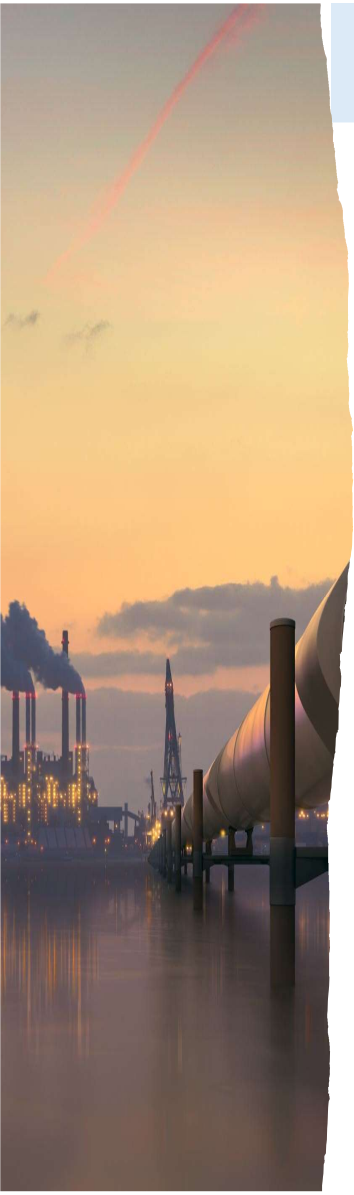
- Variations in threshold values for detection and exceedance.
- Differences in sampling protocols and testing techniques.
- Geological formations and land use practices.
- Temporal variability due to changing environmental conditions, human activities, and regulatory standards.

Implications:

- Emphasizes the varied nature of groundwater contamination.
- Highlight the importance of considering multiple factors in analyzing GW contamination.
- Essential for accurate risk assessment and targeted intervention strategies.







Equity Implications for Management and Policy

Study results support accepting the hypothesis:

"There are significant differences in contaminant occurrence and exceedance".

1. Groundwater Contamination is Unequal

- Arsenic & nitrate exceedances vary by region, water source, and demographics.
- While natural and human-induced contaminants are influenced by the factors examined, the extent, direction, and magnitude of occurrence and regulatory exceedances differ.
- Regulatory gaps leave some communities more vulnerable to drinking water contamination risk.

2. Disparities Require Targeted Action

- Hydrogeological, policy, and socioeconomic factors and their interaction drive contamination risks.
- Gaps in groundwater management disproportionately affect Arizona's communities.

3. Strengthening Groundwater Management and Oversight is Critical

- Existing policies fail to ensure equitable protection across all water systems.
- Enhancing monitoring & enforcement is necessary to close regulatory gaps.

Recommendations for Groundwater Management Action

"PRISM“ Framework

Prioritize	Focus resource allocation on high-risk, underserved, vulnerable communities to ensure equitable access to clean drinking water for all.
Regulate	Strengthen and expand groundwater monitoring and enforce compliance.
Invest	Allocate funding for targeted remediation and infrastructure improvements based on hydrogeological, policy, and socioeconomic data.
Strengthen	Improve collaboration across agencies and stakeholders for sustainable groundwater governance (e.g. data collection and sharing).
Mitigate	Implement science-based strategies to reduce contamination risks and address environmental equity in water policy outcomes.

Conclusion

Groundwater contamination poses serious water security and public health risks to Arizona’s communities.

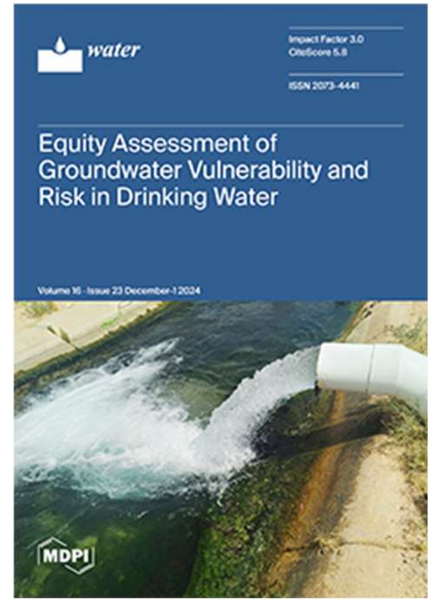
Policy, socioeconomic, and hydrogeological factors contribute to disparities in groundwater vulnerability and contamination risk.

Policy-driven solutions that incorporate these factors are needed to ensure equitable access to clean water.

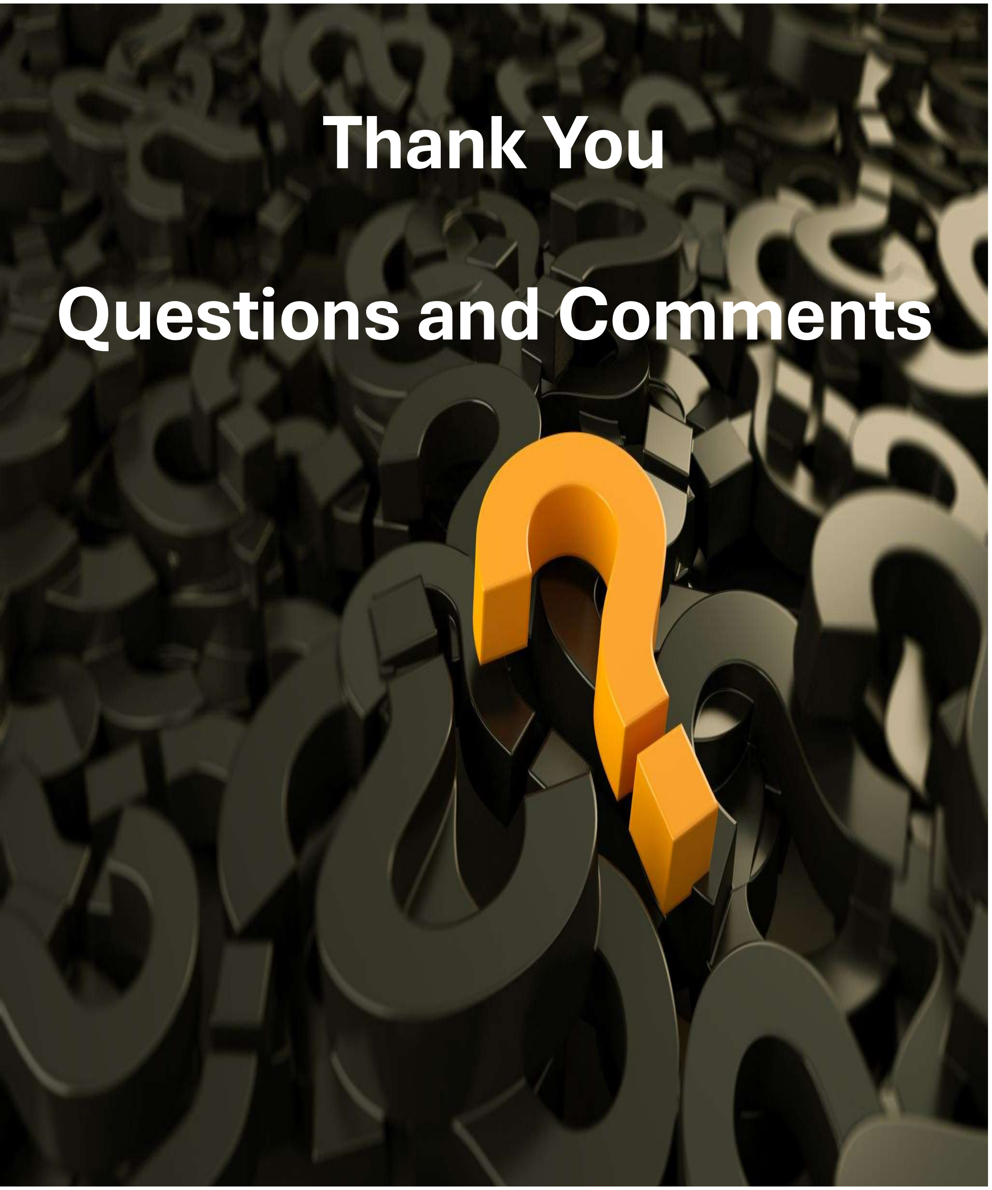
Multistakeholder collaboration is critical to improve understanding of GW vulnerability and contamination risks in AZ/ arid regions.

Acknowledgments

- **Coauthors:** Drs. Sharon B. Megdal , Adriana Zuniga-Teran, David Quanrud, Gary Chritopherson.
- **Research Funding:**
  - Babbitt Center for Land and Water Policy (Lincoln Institute)
  - UA Graduate College Fellowship/ALRS GIDP
  - American Water Resource Association (AWRA) Scholarship
  - Arizona Association of Environmental Professionals (AZAEP) Scholarship
  - 2021 Environment and Society Graduate Fellowship, CLIMAS
- **AZ and Tribal Water Stakeholders**:
  - State, Federal, Tribal, and County government agencies, and watershed councils with whom I consulted and who graciously shared knowledge and information.
- **Research Recognition:**
  - Featured cover article on Water 16(23), December 2024
  - Most Viewed Articles (Hydrogeology), Nov 2024 – Jan 2025
  - Best Dissertation Award 2025 - The Universities Council on Water Resources (UCOWR)



Subject: *[Water] Most Viewed Articles (November 2024–January 2025)*



Scan QR Code

To read published peer-reviewed article:

“Equity Assessment of Groundwater Vulnerability and Risk in Drinking Water Supplies in Arid Regions”

Connect with Me:

Simone A. Williams, Ph.D.

LinkedIn:

Scan QR Code

Via Email:

sawillms@arizona.edu